We are all educators in the broadest sense. We needn't be in academe; we need not have students, formal classrooms, or formal textbooks. Whenever we communicate what we know—whether about recent research results, new tools or applications—we are trying to educate the listener or reader.

The style and organization of our presentation undoubtedly affects the quality and utility of the educational experience. It is likely, however, that in the formative stages (i.e., before the collating and winnowing of individual concepts and before their ordering into a logical framework and sequence) the raw information is disorganized, anecdotal, only partially interrelated and generally in no shape to release to external scrutiny. Such is the process through which POSTERMINARIES are wont to pass as we attempt to create a beginning, a middle, and an end to the exposition of a tidy self-contained idea. It's therefore ironic that as this POSTERMINARY tries to discuss the exposition process it fails itself to deliver more than a disjointed collection of raw ideas that motivated its appearance.

The other day, at a technical seminar I attended, the speaker immediately followed his first "title and author" slide with his "conclusions" slide. This took me back a bit but was a refreshing change and effectively guaranteed that the ruthless session chairman, who was enforcing the clock with brutal precision, would not rush or truncate the speaker's report of results.

I was thus moved to ponder the rhetorical question, "How do I or does anyone like seminars delivered?" Do we want the "punch line" first or would we rather the suspense build through a logical step-by-step explanation of motivations, methods, assumptions and results before the conclusion is reached. The latter may provide a feeling of vicarious participation and historical perspective, while the first offers the chance to glean the reason for the seminar (and decide whether to stay to the end).

Certainly in preparing the more common historical approach to fit a seminar's time and logical clarity requirements, many salient details are omitted. So, it is unlikely that the attendee will be adequately educated to reproduce the work on the basis of oral presentation alone.

The expository approach to seminar delivery is taught in our universities and, in fact, may emulate science education methods themselves. Somehow the summary of events leading to the primary result is supposed to demonstrate validity of method and, by implication, verity of result. So I was led to consider science education methods in general, leaving the seminar delivery style not thoroughly thought through.

It is hard to discern *what* it was that was taught and learned when we were subjected to expository historical instruction. Was it the history of science? Was it the scientific method? Was it the philosophy of science? Or was it the theories and observations of science itself? As I recall, my physics courses began...

> Long, long ago, in a place far, far away, great men of their day believed that light carried energy–that waves of light could take any wavelength and the shorter the wavelength, the more energy the light carried.
>
> Once upon a time, also long ago, similarly great men believed that the building blocks of matter (atoms) did not consist of a uniform jelly of balanced positive and negative charges, but were minisolar systems with a positive sun and negative planets.
>
> Great vexing puzzles remained. The energy of the light, when trapped in a cavity, suffered an ultraviolet catastrophe—a poetic way of saying that a denominator was misbehaving in a singular non-integrable way out beyond the blue. And those planetary electrons had to radiate light, as accelerating charges were required to do. Losing energy this way should have resulted in their spiraling into the "sun" and in the complete collapse of matter.
>
> To the rescue came Max Planck, who quantized the cavity radiation in the nick of time, and Niels Bohr (on the heels of Sommerfeld), who, also through the magic of quantization, found stationary states where electrons could rest in their orbits without noticeable fatigue...

This was very exciting!

The history of scientific discovery is strewn with the makings of one adventure story after another. For all who are scientifically inclined, knowledge of the litany of observations, puzzles, hypotheses, breakthroughs, more observations, and more puzzles, adds a depth of appreciation for science and the discovery process which would be hard to achieve otherwise.

Should science be taught this way? Is the historical approach—in which a student first is taught the limited (if not wrong) ideas and only later exposed to the revised, more precise, more complex, currently accepted and (possibly) right ideas—the best way to both hold interest and produce the best science graduate? One wonders whether this approach is necessary to create a researcher—viz., to create comfort with the sometimes agonizing process of false starts, blind alleys and disproved hypotheses, punctuated by the minor breakthrough, while searching for the quantum leap. Is this kind of historical perspective a requisite tool of the trade? What about the alternative?

Say a student was confronted at the outset with the fully relativistic Schroedinger-Dirac equation to prepare him/her to pursue physics research. That would be like opening volume one to its last page in order to teach how to write volume two. There is something sleek and beautiful about a fully self-consistent axiomatic theory with no loose ends. It may even be able to explain all current observations. Does seeing it first tell a student that "Everything that there is to do has already been done?" Or, does it motivate the newcomer to produce a similarly gorgeous solution to a new problem? Is the price to remain unfettered by old paradigms the loss of historical perspective and the risk of being fettered by today's paradigms?

Thinking about these questions forced the recognition that, while buried in the execution of science as my vocation, I give little thought to the educational process per se. But many educators have thought intensely about such issues and often publish their conclusions in journals I never read. Some excerpts in random order...

"It so happens that imaginative, creative thinking, and logical, analytical thinking describe two successive stages of thought that often occur in advances of scientific understanding. The misconceptions concerning the nature of scientific thinking arise primarily out of an emphasis on published scientific papers, which represent the logical, analytical justification stage of a scientific development. Students are not sufficiently exposed to the imaginative, creative processes by which a scientific model is first constructed, or the flashes of insight by which theories are born, or by which solutions to difficult problems are first recognized. A way of presenting science in a more realistic way to students, both creative and logical, imaginative and critical, is from an historical perspective in which occasional episodes in the development of science can be investigated in depth." [W. Brouwer and A. Singh, *Physics Teacher* **21** (4) (1983) p. 230-236.]

"Elementary instruction can fail to exploit the full significance of historical development not only by ignoring it but also by assuming implicitly that logical development always follows the historical path. Or, to put the matter more frankly, many an elementary exposition creates the impression that history has followed the path of development chosen by the expositor, implying, perhaps, that little further is to be gained by explicit historical study." [S. Devons and L. Hartmann, *Physics Today* **23** (2) (1970) p. 44-49.]

"...when gains in intellectual development by students experiencing inquiry teaching are compared with those of students experiencing exposition, the inquiry groups have significantly greater gains." [L.S. Schneider and J.W. Renner, *Journal of Research in Science Teaching* **17** (6) (1980) p. 503-517.]

"Rarely are students of science ever helped to recognize the dualities and ambiguities.... Understanding them, however, would undoubtedly increase student appreciation for the totality of science.... Students come away feeling that everything has been discovered...." [D. H. Ost and D. George, *Science Teacher* **42** (10) (1975) p. 14-16.]

"...the mode of thinking and the nature of evidence is quite different *in* science from that used in studies *of* the scientific approach.... At the very least, there should be a major component of philosophic discussion aimed at clarifying the reasons for accepting [this] particular model. If this is attempted, however, there is likely to be a great deal of confusion among the students. Much of this confusion will occur because of differences in the nature of evidence concerning philosophic questions and scientific questions.... If...it is the scientific skills and knowledge of currently accepted basic concepts that is important, then...introduce historical materials in a very selective way, since [the] real purpose should be to teach modern theories and techniques more effectively, only taking from the past that which seems to have significance in the present. ...If...students should be aware of the history and philosophy of science, present a separate course..." [A.M. Lucas, *Australian Science Teachers Journal* **23** (2) (1977) p. 31-37.]

"One of the main functions of the teacher, and in particular the science teacher, is to act as intermediary between man's [sic] accumulated knowledge and experience on the one hand, and the students who are to be the recipients of a portion of this knowledge and experience on the other. The technique by...which this function is most commonly carried out has been called 'a rhetoric of conclusions.' This implies the passing on to students of a particular state of knowledge—not necessarily the most up-to-date—as if that knowledge were conclusive, did not admit the possibility of the existence of alternatives, and had the nature of unalterable truth. Such a teaching mode is the almost inevitable outcome of textbook-bound instruction simply because textbooks, by their nature, are reports of well-established, smooth running, successful research." [M. Finegold, *Physics Teacher* **12** (7) (1974) p. 401-406.]

"Textbooks...begin by truncating the scientist's sense of his [sic] discipline's history and then proceed to supply a substitute for what they have eliminated....students and professionals come to feel like participants in a long-standing historical tradition. Yet the textbook-derived tradition in which scientists come to sense their participation is one that, in fact, never existed." [T.S. Kuhn, *The Structure of Scientific Revolutions*, 2nd edition, (Univ. of Chicago Press, Chicago, 1970) p. 138.]

"That Newton would not understand what we today refer to as 'Newton's Second Law' points to an interesting example of historical error that can accompany the teaching of science." [C.F. Gauld, *Australian Science Teachers Journal* **21** (1) (1975) p. 57-62.]

"It is then possibly the greatest task of educators to induce students to compromise with not 'knowing' everything, but the main problem seems to be how to do this without diminishing the students' intellectual curiosity." [H.M. Jones, *Journal of Chemical Education* **49** (2) (1972) p. 109.]

There is no tidy moral to this story. There is food for thought ranging from the mundane seminar delivery style to the grand mechanism by which the legacy of knowledge and experience of our scientific progenitors is assimilated in the here and now, how we shall add to it, and how best to deliver *a version* of our truths forward in time. When preparing your next technical talk, it would probably be best to forget what you've read here.

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