

RESEARCH STRATEGY: TEACH

Roald Hoffmann

A damaging misconception about modern universities is that research dominates and diminishes teaching and that the tension of balancing (unsymmetrically) the twain is unhealthy. I'm contrary. I say not only are the two inseparable, but teaching makes for better research.

As I reflect on the possibility of a separation of research and teaching, I look at my research group. We meet twice a week—four graduate students, four postdoctoral associates and I. One time we talk about the incredible, fertile literature of chemistry, whereas in the other session one of the people in the group reports on her work in progress. We also ask why marzipan pigs are popular in Denmark, explain to our foreign group members all those football and baseball metaphors in colloquial English, and try to guess who is likely to be the author of those scurrilous referee's comments on our last paper. Is that research? Is that teaching?

I travel to the University of British Columbia to lecture about my work, about making and breaking bonds in the solid state. Ninety percent of the audience consists of graduate students, with a sprinkling of undergraduates. I talk to them. Is that research? Is that teaching? I think the answer in both cases is yes. It's research, and it's teaching.

I am certain that I have become a better investigator, a better theoretical chemist, because I teach undergraduates. When I began at Cornell, for instance, I thought I knew all about thermodynamics. What I knew were all those beautiful partial differential equations that relate the derivative of A with respect to B to C . But thermodynamics is a subject of great richness, with practical, common-sense roots (steam engines, the boring of cannon) and a mathematical structure of breathtaking sophistication. I had only followed the latter, and hadn't really understood the full empirical beauty of "thermo" until ... I had to explain the subject to students without the crutch of the mathematical apparatus. The more I taught beginning classes, the more important it became to me to explain. The tools of pedagogy

permeated my research. I think those in the community of chemistry who know my work will recognize what I mean.

Audience

I believe that rather than treat research and teaching as disparate activities, it is more productive to cast the discussion in terms of audiences for creative work in science or the humanities.

In the beginning is research or discovery, a gleam of the truth, or of a connection, within an individual's mind. Actually I've experienced such moments, and so have others, most often not in isolation, but in discourse with another person. Pieces of understanding may have already formed in the inner dialogue between parts of me, me and an imagined ideal audience of one, or of a multitude, in the lonely dialogue with the voices of skepticism and self-doubt that are all me, all of me.

In the next stage the audience expands to my research group. In the process of talking to them the depth of my understanding of the discovery deepens, takes a stronger hold on reality.

Then I write a technical paper. Now my audience is out of my control. Writing is the message that abandons, as Jacques Derrida has called it. I can't grab that removed reader in Poznan or Puna and tell him, "No, you must read it that way, and not this way." It has to be all there, in the words with which I struggle. It has to be there—the substance of what I found, and the argument to convince him or her, the absent reader. And I write for that audience from a position of substantive ignorance about them—I don't know their preparation, their level of sophistication, their willingness to work to reach enlightenment! It begins to sound an awful lot like teaching.

The writing of a research paper to me is in no way an activity divorced from the process of discovery itself. I have inklings of ideas, half-baked stories, a hint that an observation is relevant. But almost never do I get to a satisfactory explanation until I have to, which is when I write a paper. Then things come together, or maybe I make them come together.

A technical seminar at another university introduces another audience. Sure, I want to impress my colleagues, claim precedence, power,

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please real or constructed parents. Many things go on subliminally in the course of any talk. Yet most of all I want to impart significant new knowledge. But the audience includes people of disparate backgrounds. The organic chemists may not know much about my present loves, which are surface and solid-state chemistry. There are many graduate students here. I want to teach all, convince all. Remarkably, incredibly, we can do it, speak to many audiences at the same time. That's what teaching is all about.

To me, the steps from a research seminar to teaching a graduate course, then an undergraduate one, are small moves in interacting with the continuous, overlapping spectrum of audiences. In the theater of the mind the audience is always shifting, never constant. There are different strategies, call them tricks, the stuff of experience, that one applies with these audiences of young people and that one might not try in a research-group meeting. But the similarities of pedagogical strategy across the spectrum of teaching/research far exceed the differences.

The spiritual rewards for opening a person's mind, sharing newfound knowledge, are also quite similar. I've taught introductory chemistry many times, to thousands of students. There is the same unmitigated pleasure that hits me when I detect, on an examination or by the nonverbal signs students give in lectures, that someone has understood the magnificent and simple logic of the mole, so that he or she can tell me how much sulfur there is in a pound of sulfuric acid.

As my friend R. Freis has pointed out, following St. Thomas Aquinas, teaching is truly a cooperative art. It works together with the nature of the student as learner, knower, apprentice, in order to bring that nature to its perfection. The ability to deal with knowledge pre-exists in the learner; the teacher awakens it. Teaching is clearly also a rhetorical act. But it is more than mere persuasion, because of the empathetic, reflexive aspect of it being cooperative. How could the mind that faces up to the problem of teaching a novice something new and difficult possibly avoid using the same strategies in explaining to itself something still more new, more difficult? Which is what people call research.

Community

Much has been written about the ways in which state-of-the-art research enhances teaching. The evidence for a direct link is not clear to me; obviously the meld of teacher and student matters. How else could one explain the tremendous success of the graduates of City College in New York (which 60 years ago had little research activity) or the many small colleges that are the baccalaureate source of our best researchers. Nevertheless, I do think that there are certain ways in which education flourishes in the intellectual climate of a major research university.

First of all, it takes little to make a student aware that his instructor is not just reading a set of old lecture notes but is a living, thinking creature in an active intellectual community. A small



Historisches Museum, Bamberg, Germany

Figure 1. Chemists, working in a cold laboratory and without safety glasses, carefully record their data in this 18th century painting by J. F. Treu entitled *Instruction in Chemistry*.

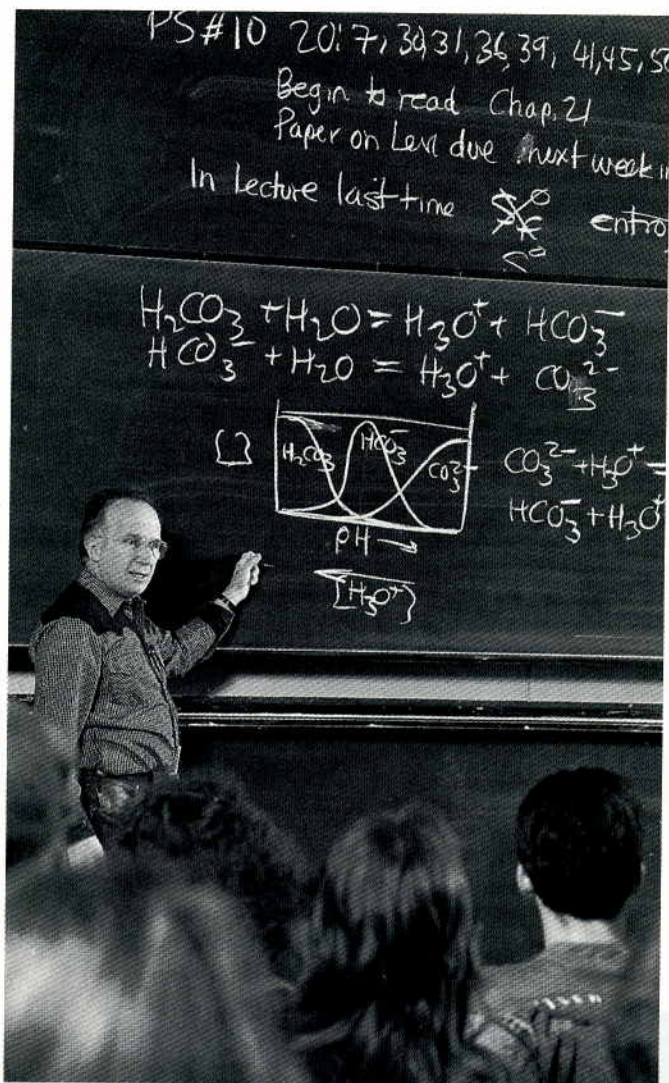


Figure 2. Introductory chemistry class learns from the author about ionic equilibria in carbon dioxide solutions. (Photograph by Chris Hildreth, Cornell University Photography.)

comment suffices, along the lines of: "I just heard in a seminar that this equation we've been talking about, although in general quite reliable, is not universal. A group at Konstanz...." Or, "Incidentally, next week we have a seminar speaker from Harvard, Dick Holm, who is an expert on electron transport by metal clusters in biological systems. Those of you who are interested...."

Second, undergraduates take in not only the subject matter of their courses; they are also extraordinarily sensitive to the person of the professor outside the classroom. Do you realize what an effect it has on an undergraduate to go into the library to study on Saturday afternoon, everyone else at the football game, and see there his organic chemistry professor sit for two hours looking through, and taking notes on, the new journals that have come in that week? Or in the course of a summer job to sit in on research-group meetings, hear the family-like banter, feel what it is like to learn that you've been scooped, sense the single-minded concentration on the new?

The usual advantages of the active research scientist as teacher, often cited, are authoritativeness, proximity to the sources, and a sensitivity to what is and is not important in the current state of the science. I think the intangibles, a selection of which was given above, are equally important.

Positive Tension

Given all this, we must face up to the stress and tension that do characterize the life of active university research scientists. Part of that stress comes from the balancing act we must perform between our teaching and research functions, perceived as distinct. I have argued above that we should not see them as such, for every activity is mixed-mode. Nevertheless, being human, we do characterize them as such. And they compete for slots in the 24-hour day.

My argument, not likely to be popular, is that a measure of tension is one of the wellsprings of creativity. First consider stress in the individual. We are unique products of genetics, basic psychological drives, childhood traumas, the coping with the irrationality and pain (and pleasure) of life. This we have learned from Aeschylus and Freud. What creative individuals bring to this world is often derived from the tension within them, the dissatisfied, ever-reaching psyche.

In a complex dance of desires and constraints American academics balance their various responsibilities and come out with marvelous new molecules, or mechanistic detail of a chemical reaction probed on a femtosecond time scale. That dance is not a courtly pavane; probably it's been choreographed by Twyla Tharp. Its driving force is tension, the creative tension of desire and doing.

This is not a rationalization for the inhumane level of stress that sometimes characterizes the workplace of the academic or the taxi dispatcher. We see some of our best students choosing industrial careers over academic ones because they expect lower stress levels in industry. This, incidentally, is just about as realistic as the romantic notion that teaching in a small liberal-arts college is devoid of tension.

I believe that human beings are inherently creative. But more than that—they rise to the occasion. They produce their best work, work that perhaps they themselves felt incapable of achieving, when their psyche, other individuals (friends, competitors), society pushes them on, by incentives and obligations to do that work.

It seems an imperfect system, this concentration of research, scholarly and teaching functions at one place, the research university. It is also an idea that inherently generates stress for the individuals who make it go, with minimal financial encouragement. But what a place! The exciting, tense, productive research setting in which professors do their balancing act, the university, is correctly seen by most students as what it is, the world of mind and hands learning, teaching. Both. I wouldn't want to be anywhere else.