

## Teach to Search

### 1996 George C. Pimentel Award, sponsored by Union Carbide Corporation

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George Pimentel was a wonderful man, whose heart and soul were in chemistry. And just as much in research, in which he excelled, as in teaching. From his writing it is clear that he did not separate the two. Nor do I, which is why I am happy and proud to be associated with an award given in George Pimentel's name, and especially one in chemical education.

I will speak of two themes:

- The inseparability of teaching and research. And for that matter, of chemistry and the world.
- The necessity of chemists to teach broadly, to speak to the general public. And the tensions that arise in the process.

But before I launch into these subjects, let me say some words about how I feel about teaching and receiving this award. Whatever success I have had I owe to teaching. The logic or rhetoric of teaching underlies my research within chemistry and my writing outside of chemistry. As I began to think about this, I felt suddenly a little less guilty about receiving an award in chemical education.

Let me tell you why I felt—feel—guilty. What am I—viewed by the community of chemistry as a researcher whose work has received ample recognition—doing getting an award that should be given to those who have toiled so hard, dedicating their lives to chemical education? When there aren't too many of these awards around....

A second source of guilt for me is that I suspect that a significant component in the thinking of the Pimentel award committee was my role in making the Annenberg/CPB television course in chemistry, *The World of Chemistry*. I was a member of the team, indeed, and my soul and sweat went into the project. But the part I played—more than just being a pretty face, true—was in fact much smaller than the parts of several other people, who really deserve recognition.

I will tell you about those people in time. I do feel guilty about receiving this award, but my guilt is assuaged just a little by pride in the fact that I have not only taught thousands, but I have also taught others to teach. I have taught, subtly, the research community in chemistry that teaching strategies are productive in research. And I have contributed, I think, to the growing respect for teaching in the community of chemistry at large.

#### I

First let me address the issue of teaching and research. A damaging misconception about modern univer-

sities is that research dominates and diminishes teaching, and that the tension of balancing (unsymmetrically) the twain is unhealthy. Defenders of the universities argue that the two functions are complementary and that research or scholarship enhances the quality of teaching. I go further: I say research and teaching are, quite literally, inseparable. And they are symbiotic.

One root of the error, I believe, lies in thinking of learning in terms of place rather than audience. Places (classrooms, labs, library carrels) are, indeed, circumscribed, but the audiences of learning (undergraduates, graduate students, faculty, our minds) always shift, overlap, and enrich each other, like the colored glass bits of a kaleidoscope.

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, while in the other session one of the people in the group reports on work in progress. We also ask why marzipan pigs are popular in Denmark, explain all those football and baseball metaphors in colloquial English to our foreign group members, and try to guess who is likely to be the author of those scurrilous referee's comments on our last paper. In these group meetings half the time I'm giving a monologue; the rest of the time the hardly shy remainder of this research family speaks. Is that research, is that teaching?

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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.

Teaching and research are inseparable. The struggle to do both well enriches our personal intellectual lives, and enhances our contributions to society.

I am certain that I have become a better researcher and a better theoretical chemist because I've had to teach undergraduates. When I began at Cornell, I thought I knew all about thermodynamics, 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 followed only 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 rhetoric of pedagogy permeated my research. I think those in the community of chemistry who know my work will recognize what I mean.

I think there is nothing unique to me in all this. I believe that rather than treating 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. Or when I sit down to write a paper, before me the draft or progress report by one of my students.

In fact, understanding 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.

Deep in  
it's a docile crowd  
most of the time, lazing  
around, waiting for the train  
of concentration to haul a few words  
onto paper. It listens, then it stirs, the one  
that speaks in many voices, to say:  
these are just words, falling limp  
into the untensed space they need sculpt, or:  
make me understand.  
They hate my compromises.  
Here and there they offer up a phrase.  
In their babble I hear the voices  
of my teachers rise from a page or café. Sometimes  
one speaks with an accent—I think  
it's my father, it's him, the world  
I have to please.  
For them I leave no word unturned.  
For it I sing, tone-deaf that I am,  
the song that frees itself within.

In the next stage the audience expands to my research group. In the process of talking to them 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 this way and not that 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. 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.

To me, the writing of a research paper 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. F. L. Holmes has argued convincingly the same point, that scientific writing and scientific discovery are not disparate activities. In an analysis of draft manuscripts of a Lavoisier memoir on respiration he "...could watch important ideas emerging, growing, changing form or decaying during the evolution of a scientific paper."

An invited technical seminar introduces another audience. Sure, I want to impress my colleagues; claim precedence, power; please real or surrogate parents. Many things go on subliminally in the course of any talk. Yet most of all I want to impart real, 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. Depending on their background, different parts of the audience may attach different meanings to the plain English words at my disposal. 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, over-



lapping 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 audiences of young people 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 new-found 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 non-verbal 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.

To return to my main point, I wish to argue that the desire to teach others, enhanced by being *obliged* to teach others, leads to greater creativity in research. The rhetorical imperative operates to make a scientist or scholar examine widely the potential responses (objections?) of his or her audience. Having to teach enlarges one's encounters with real audiences and therefore sharpens the imagined audience one engages in the inner dialogue in the course of research.

I do not mean to imply that you need to be a researcher to teach well, nor that you absolutely must teach to do research well. A reviewer of this paper appropriately reminded me that the "vast majority of high school and college teachers who contribute mightily to innovation in our field...are not researchers." I recall the tremendous success of the graduates of City College in New York (which 60 years ago had little research activity) and the many small colleges that are the baccalaureate source of our best researchers. And there are many talented researchers working in industry and government who have little occasion to teach. I respect the mul-

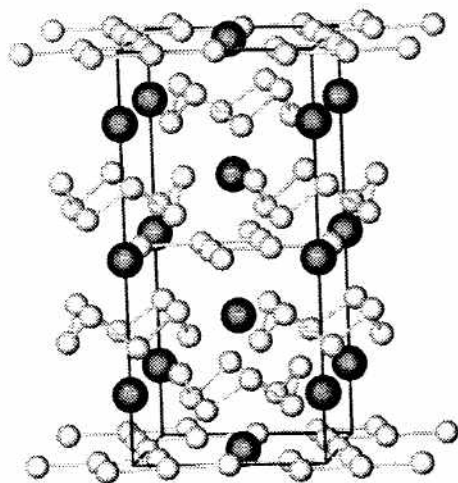


Figure 1. The structure of  $\text{Cs}_3\text{Te}_{22}$ . Small circles are Te atoms, the large gray circles are Cs atoms.

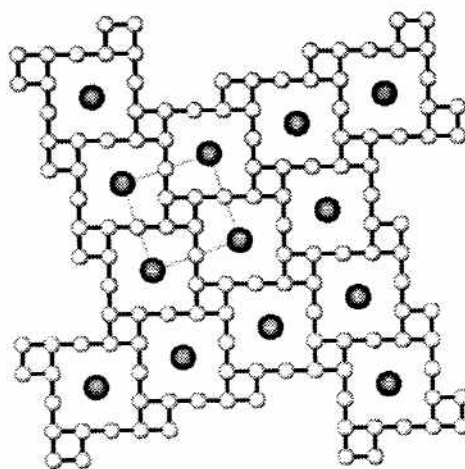


Figure 2. A top view of the  $\text{CsTe}_6^{2-}$  net. One unit cell is highlighted by a square.

tiplicity of professional styles.

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. Teaching is clearly also a rhetorical act. But it is more than mere persuasion because of its empathetic, reflexive aspect being cooperative. How could a 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.

## II

I want to try to illustrate to you what I mean by the rhetoric of teaching influencing my research style. To do that I've picked a recent paper entitled "A 2,3-Connected Tellurium Net and the  $\text{Cs}_3\text{Te}_{22}$  Phase", written by Qiang Liu, Norman Goldberg, and myself, to be published soon in *Chemistry, a European Journal*. Our work grew out of a paper we saw by Sheldrick and Wachhold in a February 1995 issue of *Angewandte Chemie* (W. S. Sheldrick, W. S.; Wachhold, M. *Angew. Chem. Int. Ed. Engl.* **1995**, *34*, 450), who reported a new  $\text{Cs}_3\text{Te}_{22}$  compound. Now the chemistry of tellurium is very rich. For instance, in the Cs-Te system some nine binary cesium telluride phases ( $\text{CsTe}_4$ ,  $\text{CsTe}_5$ ,  $\text{Cs}_2\text{Te}$ ,  $\text{Cs}_2\text{Te}_2$ ,  $\text{Cs}_2\text{Te}_3$ ,  $\text{Cs}_2\text{Te}_5$ ,  $\text{Cs}_3\text{Te}_2$ ,  $\text{Cs}_5\text{Te}_3$  and  $\text{Cs}_5\text{Te}_4$ ) had been reported earlier, and two more have been made since.

The beautiful structure of the Sheldrick and Wachhold compound (Figure 1) displays a number of unusual features. Discrete crown  $\text{Te}_8$  rings can be easily identified in Figure 1. Though such eight-membered crown-shaped molecules are well known for sulfur and selenium, they had not been previously observed for tellurium. Also apparent are infinite two-dimensional

