Comment

# Bad chemistry

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A few months ago I helped move my parents into an assisted living facility. Because they were going from a large house to a two-room apartment - one of the consequences of declining health is that your world suddenly becomes very small - we had the sad task of packing up, and in many instances disposing of, a lifetime of stuff (my father is a pack rat and has never thrown anything away voluntarily). Among the accumulated clutter in the basement I found a cardboard box labeled 'Greg 1965'. It contained, among other things, the complete set of notebooks from all of the classes I took as a junior in high school, back in Washington, DC. One of those classes was honors chemistry, a course designed to provide the same material as an introductory college course. Leafing through that notebook, I realized an extraordinary thing: I could use those notes to teach that same course at any university in the United States today, with no modification whatsoever. The order of topics, the level of treatment, even the examples used, were the same as you would find in nearly every first-year college chemistry textbook. General chemistry courses haven't changed significantly in forty years.

Your first reaction to this might be, "Why should they?" After all, the basics of the subject have been known for more than forty years, and those basics are essential prerequisites for any advanced, more 'modern' material. But I think if that was your first reaction, on reflection you will agree with me that this situation isn't just extraordinary, it's appalling. And it goes along way towards explaining something that's been bothering me for a long time: the flight of increasing numbers of good students away from chemistry.

In the United States, a course in general chemistry followed by a course in organic chemistry is a requirement for admission into medical school, regardless of what subject one concentrates on (we say "majors in") in college. Consequently, huge numbers of college students take introductory chemistry, usually in their first year, unless they have had a high school honors course like the one I took. At Brandeis, the small private university at which I work, there are about 800 new students admitted each year and over 200 of them take first-year chemistry; it is often the largest course on campus. More than half of them do so because they plan eventually to apply to medical school. At Ohio State University, the largest of the public universities in the US, there are about 13,000 new undergraduates per year and up to 3,000 of them might take introductory chemistry. These huge enrollments are both a curse and a blessing to chemistry departments at US universities: they impose a large teaching burden on the faculty, but also justify hiring large numbers of chemistry professors. And with medicine having become an increasingly popular career during the past five decades, the numbers of pre-medical students (we call them "premeds") have been rising steadily, with a few short periods of decrease, for that same period. Yet the number of students who go on to major in chemistry has actually declined since I was in high school, despite this bolus of prospective recruits who are exposed to the subject just as they enter college, usually before they have decided on a major field. Moreover, surveys of students consistently rate introductory chemistry courses among the most disliked, and feared, courses students ever take during their four years at university. Something is very wrong: instead of turning students on to chemistry, our low-level courses are turning them off, in droves.

Where do they go instead? Increasingly, the science-oriented among them gravitate toward biology. It is seen as a 'hotter', more welcoming, and just a more interesting subject. Which would be OK, I guess, except for two things: introductory chemistry and basic organic chemistry is then all of the chemistry many biologists are ever taught (I exclude biochemistry courses here, for reasons I'll discuss in a later column), and this shift away from chemistry is accelerating at precisely the time when, thanks to genomics and an increased focus on human health in the life sciences, biologists need to know much more chemistry.

Last year the US National Academy of Sciences released a report called '*BIO2010*'. It was prepared by the Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century (or COUBETPRSFTTFC for short), which was set up by the National Research Council, the branch of the National Academy that conducts in-depth studies, because undergraduate programs that train biology researchers have remained much the same as they were before the fundamental changes brought on by genomics came on the scene. The report [http://www.nap.edu/catalog/10497.html] is intended to be a blueprint for "bringing undergraduate biology education up to the speed of today's research fast track". It includes recommendations for teaching the next generation of life science investigators, through: eliminating the administrative and financial barriers to cross-departmental collaboration; evaluating the impact of medical college admissions testing on undergraduate biology education; creating early opportunities for independent research; and designing meaningful laboratory experiences into the curriculum.

All of which sounds great, and who would disagree with it? But the report also includes one more recommendation, namely: building a strong interdisciplinary curriculum that includes physical science, information technology, and mathematics. I don't see how that can ever happen as long as college chemistry in general, and introductory chemistry and organic chemistry in particular, remain the way they are now. It isn't just that some of the so-called essential 'basic' material really isn't all that essential to most of the students, or to what other chemistry they will need to learn later. It's also that the examples used to motivate students to learn those topics that really are essential are dull, irrelevant, and archaic. In general chemistry courses today, just like 40 years ago, a week or more is spent teaching gas laws, but blood gases are almost never mentioned. Another week or more is often devoted to nuclear chemistry, but seldom in the context of the use of radioactivity in biology (radiocarbon dating is the favorite example these days). Electrochemistry is given several weeks of instruction, but not in the context of electrophysiology, which is the one place where it really will matter to most of the students in the class. Weeks are spent on molecular orbital theory. I have been a practicing biophysical chemist for thirty years and I can count on the fingers of one hand the number of times I have ever had to pay much attention to molecular orbital theory, which leads me to suspect that there aren't many physicians in the world who have ever found it all that essential in their work either. I could go on - and I could also make similar points about the course content, and emphasis, of introductory organic chemistry - but I think the message is clear: chemistry is not presented in such a way as to make it relevant, or even useful, much less exciting, to the would-be biologists and physicians who constitute the overwhelming majority of those being taught.

How did we get into this mess? Like a lot of other aspects of our current educational and scientific establishment, this goes back to the heady days post-Sputnik, when the West, in a paroxysm of self-flagellation, decided to reform its education programs to put increased emphasis on the physical sciences and mathematics. The economic slump in the next decade also made professional careers such as medicine increasingly attractive: not only were they lucrative, they were 'safe', offering guaranteed employment. These two circumstances, combined with the flood of students into higher education as the demographic bubble of the Baby Boom generation reached college age, led to large increases in enrollment in basic science courses, including chemistry, over a 20-year period. Someone had to teach these courses, and in the US that someone was usually a physical chemist. Positive feedback loops being what they are, the physical chemists realized that this continuing demand ensured that chemistry departments would keep hiring additional physical chemists. Once they got their clutches on introductory chemistry, they never let go, and as a result, the curriculum has remained mired in a 1950s physical-sciences mentality, and the teachers who should be getting biologists and premeds excited about chemistry - the biochemists - have largely been shut out.

I think it's important to understand this history because it helps explain why modernization of the subject has been so difficult. There is a group of faculty with a vested interest in keeping things the way they are: an entire generation of teachers who have taught general chemistry the same way for years, and consequently have little incentive, and no necessity, to do the work of updating and revising their notes that major changes would demand. And things have been this way for so long that there are other vested interests as well: textbook companies who are making big profits out of books that adhere to the same old curriculum, and, in the US at least, an American Chemical Society that promulgates a 'certified' chemistry curriculum that also hasn't changed much since I was a student.

Given these entrenched conservative forces, I think the prospects for bottom-up changes driven by students or faculty are still poor. It seems to me that the only way to break the inertia of the present system is to put a gun to the heads of the chemists (figuratively, of course) and mandate change from the top down. I don't see university administrations doing that, at least not without someone putting a gun to their heads (figuratively), but fortunately there is someone who can do just that. Because the overwhelming majority of students taking basic chemistry courses are premedical students, medical schools have enormous influence, and potential power, over the undergraduate institutions that serve those students. What is needed, I think, is for the deans and/or the admissions directors of leading medical schools, in the US and elsewhere, to get together and demand that colleges and universities devise a chemistry curriculum that prepares students for the challenges and excitement of medicine in the twenty-first century. Because medical education and graduate biology education have many points of congruence, this would also realize one of the goals of the *BIO2010* report: to give biologists a grasp of chemistry that would assist them in doing interdisciplinary research in the age of genomics.

As an unreformed '60s radical, I like to think of myself as pretty far left of center on most issues. But my experiences in the antiwar movement back then taught me to value evolutionary change, often ahead of revolutionary change, because I've found that revolutions can hurt people and permanently damage human relations. Nevertheless, on this issue I'm as much of an anarchist as one can be. I think the best way to fix the problems of undergraduate chemistry education is for the medical schools to help us blow the whole thing up (figuratively) and start all over again to create something that works. Next month, I'll offer some suggestions for what that might be.

### Follow-up

A few months ago, I wrote about the tribulations of Dr Thomas Butler, the Texas Tech scientist indicted by the US government on 69 criminal counts ranging from illegally importing and smuggling plague bacteria to lying to the FBI about the fate of 30 missing samples of plague bacteria to embezzlement (see The 'Usual Suspects': *Genome Biology* 2003, **4:**118). On December 1, a jury found him not guilty on nearly all of the biohazard-related charges - they apparently believed his claim that he was manipulated by the FBI and has no idea where the missing plague cultures are. However, he was found guilty on 44 counts of theft, fraud and embezzlement (related to payments he received for work on clinical trials sponsored by the drug companies Pharmacia-Upjohn and Chiron) and three counts of unauthorized export and illegal transportation of hazardous materials. He faces up to 240 years in jail and millions of dollars in fines. His attorneys say he will appeal the verdict. Meanwhile, those 30 samples of *Yersinia pestis* are still unaccounted for. (For a superb piece of investigative reporting on the entire affair, see the account by Martin Enserink and David Malakoff in the December 19, 2003 issue of *Science*.)