Comment

Good chemistry

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Published: 26 February 2004

Genome ***Biology*** 2004, **5:**103

The electronic version of this article is the complete one and can be found online at http://genomebiology.com/2004/5/3/103

Last month (*Genome Biol* 2004, **5:**102) I suggested that the teaching of basic chemistry courses in US colleges and universities was hopelessly out of date, as well as out of touch with the needs of students in the life sciences. Topics and examples in general chemistry haven't changed significantly in over four decades; and organic chemistry doesn't do much better. Both of these subjects are taught to large groups of students who will never become practicing chemists - chiefly, premedical students and life-science majors - and whose experience with chemistry neither endears them to the subject nor gives them much in the way of useful tools for their future professions. Because so many people, including textbook authors and publishers and the chemists who teach these courses, have vested interests in maintaining the status quo, I argued that reform from within the system was unlikely, if not impossible. And I proposed that the entire edifice be imploded and rebuilt from scratch, with the biggest consumers of chemistry students, the medical schools, taking the lead in forcing change from the top down.

I expected these deliberately inflammatory comments to provoke a storm of response, and they did. I received more e-mail about this column than I did even for the column on the dog genome, with its pictures of two cute puppies. But to my surprise, the response was one of unanimous - not just overwhelming, but unanimous - agreement. The consensus among readers seems to be that the system is indeed broken beyond what patchwork renovations can repair.

Given that my remarks appeared in a biology journal, I take this as a sign that chemistry is indeed failing to reach students in the life and medical sciences. (I expect that, had they been published in a chemistry journal, at least someone would have leapt to the defense of the subject; that no one did suggests that the failure is almost total.) Although it's always pleasant to be told one is right, I rather wish I had been wrong. Contrary to what one might have inferred from the commentary, I was trained as a chemist myself; I love the subject and am sick at heart to see what has happened to a once-glorious discipline.

Chemistry bills itself as 'The Central Science', implying that an understanding of chemistry is important for many, if not most other sciences. I agree with that sentiment, but I doubt many of today's students would. The image of chemistry is so poor that DuPont, the giant US-based chemical company, removed "Through Chemistry" from the tail end of its "Better Living" slogan. Basic chemistry courses do so poor a job of conveying the excitement and relevance of chemistry that the best and brightest students are more apt to go into biology, where they end up, ironically, often working on biochemical questions. But why should they stay with chemistry, when the subject matter in their chemistry courses reflects almost nothing of the issues that chemists are actually interested in today?

What is to be done, and, more important, how do we get it done? I originally imagined perhaps the deans and/or admissions officers of the leading medical schools might get together and issue a set of guidelines for reforming the system, but given the enormous inertia in chemistry departments that wouldn't necessarily force the matter. Of the many suggestions I received from readers, perhaps the most thoughtful - and the most practical - came from Hugh Auchincloss, a professor of surgery at Massachusetts General Hospital and Harvard Medical School. He suggested that the way to make the colleges and universities change what they teach is to change the content of the MCAT, the Medical College Admissions Test.

The MCAT is a standardized, multiple-choice examination designed to assess problem-solving, critical thinking, and writing skills, in addition to the examinee's knowledge of science concepts and principles deemed prerequisite to the study of medicine. (Deemed by whom? The answer is the Association of American Medical Colleges.) Scores are reported in each of the following areas: Verbal Reasoning, Physical Sciences, Writing Sample, and Biological Sciences. Almost all US medical schools require applicants to submit

MCAT scores during the application process. Medical college admission committees consider MCAT scores as an important part of their admission decision process - in fact, the unofficial word is that many of the most selective medical schools use these scores to triage the flood of applications they receive.

The idea of using the MCAT as a club to force chemistry departments to change what they teach basic chemistry students is simple and, I think, would be very effective. It's already clear that colleges largely 'teach to the test' as it is. Box 1, for example, shows a small part of the list of chemistry topics that students who take the MCAT are expected to know:

Box 1

1. Absolute temperature, K scale
2. Pressure, simple mercury barometer
3. Molar volume at 0°C and 1 atm = 22.4 mol/L
4. Ideal gas
   a. definition
   b. ideal gas law PV=nRT
      i. Boyle's law
      ii. Charles' law
      iii. Avogadro's number
5. Kinetic molecular theory of gases
6. Deviation of real-gas behavior from ideal gas law
   a. qualitative
   b. quantitative (van der Waals' equation)
7. Partial pressure, mole fraction
8. Dalton's law of partial pressures

Most of these have little, if any, relevance, either to chemistry as it's practiced today or to chemical concepts that biologists and physicians need to understand. The same could be said for more than half of the other topics on the list, both in general and organic chemistry. What is covered on the test reflects the way chemistry is taught, and the way chemistry is taught reflects what is covered on the test, and the wheel goes 'round and we get nowhere.

So, the solution is for the medical college association to change the test, requiring that students learn those chemical concepts that matter for the life sciences, and that they learn to work with such material in the context of the medical and life sciences. 'Traditional' chemistry doesn't have to be shortchanged by this transformation, since students wishing to become practicing chemists could always take a different track - in fact, in many colleges today, there are more rigorous general chemistry courses designed for the handful of true chemistry majors; these could be continued. But for the rest, there would finally be a curriculum that serves their interests and needs.

What might that look like? One possibility would be to replace the current, full-year, physical-chemistry-dominated introductory chemistry course with a two-semester course in which the first semester covers largely structure, bonding and reactivity, with almost all of the examples being drawn from bioorganic chemistry, and in which the second semester would basically be a revival of the old-time physiological chemistry course. In that course, concepts like pH, buffering, solubility of gases and solids, and kinetics would be taught based on examples from medicine, physiology and biochemistry. The second year would then offer first a continuation of organic chemistry, with a focus on the types of reactions important in metabolism and pharmaceutical chemistry, and then a one-semester biochemistry course in which metabolism could primarily be treated in terms of regulation, leaving room for more detailed study of biomolecular structure and function. I would then add a required cell biology course in year three for all life-science and premedical students; at present, premeds need only take a general course in biology.

This isn't the only possible curriculum, of course, and might not even be the best one - that's something that the medical schools should devise, ideally with input from some chemistry departments but, if necessary, without any. The point is to formulate a set of topics - and an MCAT reflecting them - that would leave chemistry departments no choice but to change their teaching.

I think it would even be in the chemistry department's best interests in the long term. If chemistry really is a central science, then it shouldn't allow itself to be marginalized, as physics has, by maintaining an insular, conservative, snobbish attitude toward building bridges to other sciences. Yet such marginalization is already underway, as 'true' chemistry begins to reflect an increasingly esoteric set of concerns - with barely concealed contempt for 'softer' applications in biology - and chemical education continues to present the field as if it hadn't changed in half a century. Chemistry is a wonderful subject, a magnificent intellectual edifice in its own right and a fabulous platform from which to view and tackle the life sciences. But you'd never know that from the way it's taught now.