Commentary

Bioorganic First: A New Model for the College Chemistry Curriculum

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by I. David Reingold

Everyone who teaches chemistry at the college level knows that the vast majority of the students in our lower-level classes are not interested in chemistry for its own sake. About 60–80% of them, at most schools, are there because they have to be, because it is required for some other goal they have, be it a health profession, a biology major, studying the environment, an engineering career, or something else. The majority of these nonchemists have their primary interest in the life sciences. And yet, the vast majority of chemistry departments continue to offer a freshman course that is extremely physical and mathematical in its approach, with relatively little obvious application to biology students. This is followed by an organic course that thoroughly surveys all the organic chemistry that a chemistry major might need to know, including a great deal that biology majors do not need and omitting much that they might find fascinating. I present here a new approach to the college chemistry curriculum that caters deliberately to the biologists, resulting in more useful and friendly courses for them.

At the same time, this new sequence introduces the chemistry majors early to the connections between chemistry and biology. This connectivity is beneficial in its own right, but has recently taken on more relevance because the ACS's Committee on Professional Training (CPT) has declared that all approved chemistry departments must cover the equivalent of one semester of biochemistry in their "core" courses, those taken by all chemistry majors. This biochemistry content can be either offered as a separate course or incorporated into the material covered by the other core courses. Our new curriculum allows for the easy introduction of a great deal of biochemistry at very early stages of the students' study of chemistry. I will argue that this is a logical and beneficial approach to the curriculum even in the absence of CPT's requirement, and the new requirement makes it even more attractive.

Why Bioorganic First?

In recent years the typical freshman chemistry course, usually called "General Chemistry", has come under increased scrutiny, almost always to its detriment. It is not hard to see why. There is a long list of problems associated with General Chemistry, some of which I list here.

Familiarity. It is too much like high school chemistry. Students have seen this material before, and although some learned it better than others, and almost no one learned it properly, they *believe* it is the same old stuff.

Survival Strategies. It is stuff they believe they know how to deal with: they were taught algorithms to get the right answer, and no matter how much you tell them that in college we want them to *understand* the material, many will resort to old tricks for getting answers even though they have no clue how or why these tricks work.

Math Preparation. It is too mathematical. Some students are so frightened of even the relatively simple math involved in general chemistry that they focus all their energy on manipulations and lose sight of the concepts underlying them.

Disjointedness. In spite of many noble (and some successful) attempts (*1*) to bring a story line to general chemistry, it remains for most students a mishmash of topics with no obvious connection: gas laws in week 5, electrochemistry in week 23, stoichiometry in week 7, periodic properties, atomic orbitals, …. Although we faculty may see that all these topics are related, to most students they are isolated segments of material to be learned and then forgotten, because they have no apparent bearing on what comes later. Testing strategies often reinforce this notion by testing only the material covered in the most recent period of time. Perhaps the most egregious example of this is hybridization, which is usually taught in general chemistry and then never used or even referred to again until the following year in organic.

Playing Field. Students have too wide a range of preparation. Some students really did learn a lot in high school, some learned how to get decent grades without understanding anything, others learned less than that. In teaching the same list of topics to this crowd, it is virtually impossible to teach at a level that is simultaneously appropriate for all these students.

Symbolism. It asks students to do calculations on systems they are not equipped to understand. Until students really understand molecules, chemical formulas are nothing but letters and numbers on a piece of paper. There is no reason why students should recognize C_4H_{10} as a tangible object. It is no wonder, therefore, that they do such marvelous things to it when trying to solve stoichiometry problems!

Anyone who has taught general chemistry will recognize this list and can probably add to it. But Seyhan Eğe and Brian Coppola at the University of Michigan, among others, stopped moaning and started doing something about it (*2*). They realized that teaching Organic Chemistry *before* General Chemistry would solve most of the problems listed above. For example:

Familiarity. Organic is not at all like high school chemistry. There is no sense of déjà vu.

Survival Strategies. With totally new material, it is much less difficult to convince students that their old strategies will not work.

Math Preparation. Organic chemistry has minimal math. Further, students will be a year older by the time they get to the math, and should be better able to handle it from a purely mechanical point of view. Many will have had additional math courses during their freshman year. This way, each year represents an increase in mathematical sophistication, a much more natural lead into Physical Chemistry (for those who will take it).

Disjointedness. Organic chemistry does have a story line. Everything builds on what comes before, and all exams are necessarily cumulative.

Playing Field. Organic is equally unfamiliar to most students. Although there are some exceptions, most high schools, if they get to organic at all, cover only nomenclature. Thus the playing field is much more level.

Symbolism. Students can learn about chemistry on a qualitative level before trying to apply equations to it. The equations ought to make more sense when there is a factual and intellectual framework on which to hang them.

In addition to solving the problems listed above, there are several other advantages to teaching organic first:

Organic offers a great context for many of the topics of general chemistry. Topics such as kinetics, equilibrium, or hybridization can be introduced, not because we have reached Chapter 5, but because we need them in order to understand something, and we will then proceed to use them over and over.

The chemistry covered first is the material that is most useful to biologists. With good communication between the two departments, biology courses can begin building on organic chemical concepts in the sophomore rather than the junior year.

Although most organic chemists deplore the reputation the course has, it is undeniably true that many students do not make it through the course. Intentional or not, it functions as a "weed-out" course. If students are going to discover that they cannot make it through two semesters of organic chemistry, it is better that they discover this in their freshman year than later.

The combination of the previous two lists has led some schools to offer organic in the freshman year. But what most of them have done is simply to transplant their sophomore organic course, more or less intact, to the freshman year. However, on reflection it becomes clear that there are problems with traditional sophomore organic chemistry as well, and teaching it to freshman only exacerbates them. The key here is to recognize what appears to be almost universally true: that the vast majority of students taking organic chemistry at most institutions are not interested in chemistry per se. They are taking chemistry because they have to; further, the majority of those who get as far as organic want to be health professionals or life scientists of some type. And what do they find in our organic courses? Many topics that are of little interest or use to them, such as the Diels–Alder reaction and ylid chemistry. On the other hand, many aspects of organic chemistry, such as protein structure, are of intense interest to these students but these tend to be squirreled away in the last couple chapters of the book and we rarely get to discuss them owing to lack of time. Isn't it time we started catering deliberately to the majority of our audience?

Putting all these factors together leads almost inevitably to a single conclusion: College chemistry for almost all students should *start* with organic chemistry, but not the typical organic course. It needs to lead in gently enough for any student with a year of high school chemistry; it should eliminate the vast majority of topics unnecessary for life scientists; and it should integrate biology-related topics as much as possible, and do so as soon as the necessary background is covered. It is a semi-organic course with a biological flavor—call it "Bioorganic Chemistry for Freshmen" (at Juniata this is called "Organic Chemical Concepts").

A course for freshmen that is grounded in biochemistry surely is a giant step toward satisfying the ACS Committee on Professional Training's recently instituted requirement that accredited programs must include coverage of biochemistry in the core of material that all chemistry majors are exposed to. If sufficient biochemistry can be incorporated in the labs and follow-up courses, the CPT should be satisfied with this approach. Of course, CPT has not yet begun approving this aspect of the curriculum, so the preceding claim remains to be tested.

There are already many courses out there that combine General, Organic, and Biochemistry, and there are many books that cover that ground. But all those courses, and all those books, are targeted at a very different audience. They are terminal courses, for students needing one semester or one year of chemistry and then no more. They tend to be rather superficial in their coverage. I am suggesting "Bioorganic Chemistry for Freshmen" as the introduction to a deeper study of chemistry, for both chemists and other natural scientists. As such it must be a rigorous course, suitable background for further study.

Features of the Bioorganic Course

Introductory Material

All organic texts and all organic courses begin by reviewing that subset of "General Chemistry" that is essential background for the study of organic chemistry. If the students have not just emerged from General Chemistry, as is suggested here, this material must be *covered* rather than reviewed. A suggested list is provided in the supplemental material.[W] Depending on the background of the students and the fortitude of the professor, this material could be dealt with in anywhere from three to eight weeks.

Organic Coverage

In order to make room for both the introductory material and the biochemistry that will be incorporated into the course, many aspects of a traditional organic course have to be dropped entirely and others have to be curtailed. It is this aspect of the proposed curriculum that is hardest for an organic chemist to swallow: *everything* in an organic course is important, especially to chemists, and we have to make sure they have seen (fill in the blank). The key to overcoming this psychological barrier is to recognize that all chemists *will* see all that stuff, eventually, but it is not necessary that they do so *now*. Further, it is not necessary that the nonchemists see it at all. Wouldn't it be easier to teach all the esoteric aspects of organic to the chemists when they are in a class by themselves? Imagine what you could do with a class of junior chemistry majors who had seen a large fraction of organic chemistry as freshmen, and you get to review and expand on it in a required second round! Surmounting this barrier allows one to think dispassionately about what students really need (*3*), not what *you* think is important but they will never see again. A list of omitted and included material appears in the supplemental material.[W]

Incorporating Biochemistry

The time saved by skipping the suggested organic chemistry topics[W] is more than that consumed by covering all the recommended introductory material.[W] Thus, there is some time left over to incorporate issues of direct interest to the majority of the audience: namely, biological applications of the material. Since this is what the students came to hear, it makes no sense to wait until the very end to make these connections. Of course, many of them have to wait until the end, since students will not have enough background to understand the connections until they have covered the requisite organic material, but to the extent that some applications can be introduced early, they should be. Again, a list appears in the supplemental material.[W] Many of these topics are touched on in most organic courses. The difference here is that (i) all this takes place during the freshman year and (ii) these are not just throwaway topics, but integral parts of the course.

Following Up

When a department embarks on a Bioorganic First curriculum, it is not a simple matter of an individual deciding to change his or her course. It must be a decision made by the entire department, because there are wide-ranging consequences. Students who take organic in their freshman year need sophomore (and some junior) classes that are not the same as any current course. The details of our curriculum are described in the supplemental material.[W] In a nutshell, the sophomore year covers the material traditionally taught in General Chemistry, but in a way that acknowledges that most of the consumers are still biologists, that they are sophomores with a sophomore level of math, and that they have just finished an organic course. Junior year includes a required intermediate organic course that fills in the gaps left in the freshman course, but now with only chemists and other interested students in the class.

Summary of Coverages

The net result of all this is that nonchemists (mostly biologists) get less organic chemistry than in a traditional curriculum, but they get it sooner and more tailored to their needs. The organic they do get contains less irrelevant—and more relevant—material than a traditional organic course. They have studied “general chemistry” at a more sophisticated, more applied level. Chemists, on the other hand, have had *more* organic chemistry than in the old curriculum, and they have approached the more mathematical aspects of chemistry in a more gradual way, so that when they get to Physical Chemistry they are just coming off a sophomore-level treatment of physical concepts. Further, they have experienced biochemistry in both the lecture and the lab in several courses, so that there are no longer chemistry graduates who can claim ignorance of the interface between chemistry and biology.

Conclusion

In summary, I have described a new curriculum that should be applicable at almost any institution, one that is more useful and relevant to the majority of our audience while also at least maintaining and possibly improving the education of chemistry majors. The new curriculum promises to be an easy way to satisfy the new biochemistry requirement of the CPT.

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[W]Supplemental Material

An expanded version of this article is available in this issue of *JCE Online*. It suggests topics that should be included in the introductory material, traditional organic chemistry topics that should and should not be included, and additional topics that should be integrated into the course. It expands on Juniata’s experience with this approach and offers further advice for those wishing to attempt a similar approach.

Literature Cited

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3. See, for example, Hawkes, S. J. *J. Chem. Educ*. **2000**, *77,* 321–326; **1992**, *69,* 178–181; **1989**, *66,* 831–832.

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