

What I Learned From 30 Years in the University About Catalyzing Change

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Based upon my thirty years of experience in universities, I want to discuss three general types of problems that interfere with the health of the science taught by science departments at the university level. I shall call these: (1) the laboratory problem; (2) the problem of first-year courses; (3) the inertia problem. I will illustrate these problems—and some alternatives to avoid them—with examples from my experiences as a student, faculty member, and science department chair. Finally, I will outline how the National Research Council, which I chair, might be able to assist the process of change in our approaches to science education nation-wide.

The Laboratory Problem

All laboratory curricula are not equal. Laboratory experiences based on choices made by the student are far more educational than those which require the student simply to follow instructions. When risk is involved, the lab experience becomes not only exciting and motivating, but also a more accurate representation of our work as scientists.

Let me illustrate with some of my own experiences:

- ◆ As a pre-med student at Harvard, my laboratories were nothing more than cooking classes—how to follow and document recipes. As those laboratories were required, I labored through them. By my junior year, however, I was so

disgusted with my *Physical Chemistry* laboratory that I petitioned out of it. I was told that, without the lab, I would find the class extremely difficult. In fact, omitting the lab in no way distracted from my understanding of the material.

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- ◆ The following summer, I found a chance job in a research laboratory. The exposure there to real research led me to change my entire career plans, and instead of medical school I went on to do graduate study in biochemistry.
- ◆ Later, when I was a faculty member at Princeton, every student was required to undertake some form of independent study. I often supervised as many as eight undergraduates in my lab each year (four juniors and four seniors). According to informal polls, virtually every student in our department viewed this independent study as the highlight of their undergraduate career. Even those students whose performance in my lab was poor considered the experience to be invaluable.

As these examples illustrate, all laboratories are not the same. Depending on the design, work in the laboratory can be the highlight—or the low point—of an education in the sciences. The right type of laboratories offer prime opportunities to attract and develop a new interest in science. These opportunities are being missed in much of today's college course work for undergraduates.

The First Year Science Course Problem

From my experiences I can highlight similar problems with first year courses:

- ◆ A few years ago, I sat in on an introductory biology course taught by a friend of mine at Berkeley. In a lecture hall with about 1,000 students—connected by television to perhaps 1,000 more—my friend attempted to present the detailed biochemical pathway by which sugars are broken down. Though this is, in both of our opinions, way too much detail for introductory students, he had been selected to teach this material in a two-week series of lectures.
- ◆ That introductory science course contrasts with one I was involved with many years earlier as a teaching assistant, taught by Leonard Nash at Harvard University. Rather than attempt to cover all of science, this course examined four or five subjects with

What I propose is a course for all 13th grade level students along the following lines; one that:

1. Introduces mathematical concepts, explaining what it is that math does, that math is the glue that holds science together.
2. Presents the formal ideas of logic.
3. Presents anomalies and conundrums, errors and limits.
4. Introduces the four entities of nature (force, matter, space, and time); and examines how the concepts have changed over time—how force, energy, matter, and time relate.
5. Describes how molecular properties manifest in large systems, e.g. in the brain.
6. Discusses things that are a) readily observable, and b) observable in labs. Explain these first in lay-terms, and then in "less-than-lay-terms."
7. Shows how scientific ideas that occur in one discipline may occur in another, pressing the point that science is a system and that the system is nature.
8. Moves to a final discussion about science/technology/use.

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enough depth so that students could get a real understanding of the subject. Although most of the students had no prior interest in science, they were stimulated by **how** the material was presented.

What happened to Leonard Nash's course when he stopped teaching it? Though widely recognized as successful, it did not spread to other universities nor, after his retirement, did it even last at Harvard.

About ten years ago, I contacted Leonard and asked him for his notes. Upon receiving them, I discovered why it might be difficult to teach that kind of course. First of all, unlike a good textbook, the notes were telegraphic and idiosyncratic. More fundamentally, Leonard's introductory course reflected his own particular set of interests--the history of science and organic chemistry, among others. It would be difficult to find somebody with the same set of interests to take over where Leonard left off. Perhaps we have the introductory courses that we do because any biologist can teach Biology 1, any chemist can teach Chemistry 1, and so forth. The type of course that Leonard Nash taught requires more special knowledge and creativity from the instructor, and perhaps more cooperation between departments.

Rather than excite the students with introductory science courses, as Leonard Nash did, our general approach has been to overwhelm all but those who are predisposed to pursue science with exactly the kind of unnecessary details that my friend was expected to teach at Berkeley. This "fraternity initiation" approach seems highly unproductive in an age in which we want **everybody** to appreciate science.

◆ I recently attended a conference sponsored by the California Science Project and the National Research Council for college teachers of introductory science. An idea emerged for a new kind of "textbook." The book would be produced as perhaps 10 to 20 separate modules; it would serve as a resource for instructors who could choose which four or five modules to teach in an introductory level course. Our outstanding, hands-on elementary science curricula are similarly modular, and I believe that very useful materials of this type could be developed for widespread undergraduate use.

We are not going to get anywhere in science reform unless we begin building upon outstanding examples of *what works*. If we can routinely look beyond our own classrooms, departments, and institutions, we will discover a wide range of alternative approaches and formats to revitalize our own science teaching.

The Inertia Problem

Why are we not doing better in science education in college? The major reason is a problem observed in all human affairs, **inertia**. Again, let me illustrate from my own experience.

◆ All medical schools require a full year of organic chemistry as a prerequisite. A few years ago, I reviewed my son's organic chemistry course. Although the class consisted almost entirely of pre-medical students, the material taught was modern organic chemistry for organic chemists. No one could pretend that the chemistry taught was relevant to medicine.

Introductory Chemistry at Beloit College

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What works for introductory chemistry students at Beloit College is a new course that trades lectures and examinations for more time in the laboratory. Lots of hands-on laboratory experience, students and faculty working together to discover important chemical concepts, and projects that tie chemistry to everyday experience have proved to be effective in catching and holding student interest. Both students who continue in science and those who do not come away from the course with a better understanding of how science progresses and contributes to society.

Structure and Properties of Materials, a one-semester introductory chemistry course for both science majors and non-majors, starts each new topic with an exploratory laboratory investigation. Students work collaboratively to get data for class interpretation, then chemical concepts emerge from class discussion before students apply them to new situations or to questions they have posed themselves. Instead of being a collection of unrelated topics, the course has a theme: properties of everyday materials and a molecular explanation of their behavior. As a result, the textbook has become a resource to help answer questions rather than a blueprint for the course, and lectures have given way to discussion about points that students find interesting or difficult. Instead of mid-terms and final exams, students complete week-long laboratory projects and write formal reports for them, or answer a short "question of the day" that emphasizes explaining the conceptual basis for observations rather than duplicating end-of-chapter problems.

With this approach, which emphasizes science as investigation and provides more hands-on experience, students spend their time designing and carrying out a study of the environmental sources of lead in soil rather than memorizing rules for balancing oxidation-reduction reactions or for calculating the pH of a buffer solution. They understand that science is driven by both the usefulness of what it produces and the desire to understand how and why. Although some traditional topics are skipped because they are extraneous to the questions being asked, the experience gained from completing 30 labs in the first semester shows up in advanced courses as students come better prepared to ask scientific questions and devise ways to answer them. As one student explained it, "We covered more topics in my high school chemistry class, but I understood more in this one."

Following the NSF-funded Project Kaleidoscope National Colloquium on *what works* in undergraduate science education, held at the National Academy of Sciences in February 1991, we decided to experiment with such a lab-intensive, investigative, and collaborative approach to general chemistry. They developed the course during the Fall of 1991, each teaching a section of it, using the collaborative approach they wanted their students to follow. The course continues to evolve as new laboratory projects are developed. It serves also as a site for developing and testing materials for an NSF-funded project to introduce solid-state concepts and examples into general chemistry courses, a project that was published in *Teaching General Chemistry: A Materials Science Companion*.

With three years of experience, we find that while the old format was highly successful for students who became science majors, the new course continues to serve that audience well, but also reaches other groups of students more effectively. The drop-out rate for those who enroll in the course has fallen significantly, student satisfaction with the new format is high, and enrollments in follow-up courses continue to be strong. The only problem has been to supply enough sections to meet the growing student demand; almost half of all Beloit College students have taken the course by the time they graduate.

Nationally, interest in this experimental approach to general chemistry has been high. Although some faculty are skeptical because students will not have covered as much material, many are attracted by the emphasis on open-ended investigation, hands-on learning, and creating a "community of learners" among students and faculty. The course was recently included among the first group selected by Project Kaleidoscope as a *Program That Works* and has been featured in several Project Kaleidoscope workshops. Elements of this approach are also central to curricular reform efforts of the ChemLinks Coalition, a group of 15 liberal arts institutions that received a planning grant to prepare a full application to the NSF program: *Systemic Change in the Undergraduate Chemistry Curriculum*.

As with the introductory courses, the approach to this course needlessly resembled a rite of passage separating the "tough" from the less tough students.

While medical students must take a full year of organic chemistry, they generally have no requirement to study cell biology. The requirements originated fifty years ago, when organic chemistry was central to the science being applied to medicine. Since then, the underlying fundamentals of medicine have changed dramatically, with cell biology now at the heart of contemporary medicine. One semester of organic chemistry is certainly enough!

- ◆ The persisting irrational medical school requirements are indicative of the inertia problem existing throughout our science departments in academe. Inertia is the by-product of a system that seeks no feedback from its graduates regarding the relevance of their education. Other criteria dominate instead. In our university system, the number of department positions, or faculty teaching equivalents (FTEs), is often determined by the number of students taught by the department. As a result, professors receive more resources for their department if they teach larger classes, meaning that the **number** of students taught can take precedence over **what** is taught. In this case, we sacrifice our students to the desires of our faculties for resources.
- ◆ Twenty-five years ago at Princeton, I participated in an interdepartmental program in biochemical sciences as a member of the chemistry department.

Several young faculty in our group were interested in developmental biology from a molecular point of view and we developed a club in which we discussed this exciting new field amongst ourselves. We then thought that it would be worthwhile to expose our undergraduates to molecular developmental biology, as this was obviously the direction in which the field was progressing. At the time, students were being taught by a senior classical developmental biologist who, though a very good teacher, was unfamiliar with molecular developments. Two of us approached the professor and the three of us became excited about the possibility of co-teaching the course, presenting both the classical and molecular perspectives. Our departments, however, gave us permission to teach such a course only on a "volunteer" basis--that is, only in addition to our normal teaching loads. The biology department had FTEs already assigned to the course and, if they let us teach half of it, down the road their department could lose a faculty position. In the end, the new course was never taught.

This incident reflects the institutional barriers to change that exist in our universities. It is the responsibility of the chief administrators to reverse these and other counter-productive practices. In my case, I wrote a letter to these leaders, but received no response. In fact, by the time I left Princeton, I had accumulated a file filled with similar letters which had had no effect. The apparent indifference to new ideas was one of my major reasons for leaving.

If our universities are to adapt to the rapidly evolving world, they need bold and progressive leadership to fight the forces that typically prevent change.

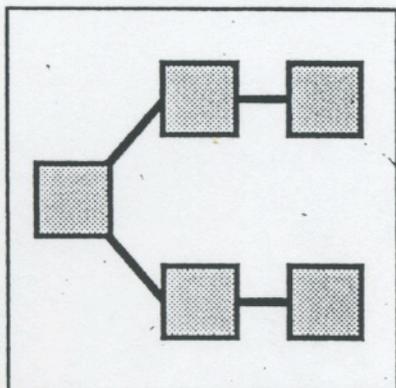
What I Learned in Thirty Years

Drawing from these and comparable experiences, I have developed a series of personal insights concerning the university system. They are:

- ◆ Irrational inertia. Though inherent to large systems, inertia can be overcome with creative effort.
- ◆ Gifted individuals. If you want to accomplish something, gather a few people who really care to do it. In general, I find that larger committees accomplish less because of the conservative nature of the committee process. In my experience, a committee of three people often works best.
- ◆ Delegation of responsibility. One means of overcoming inertia is by providing potential change agents enough "rope." In other words, giving small groups of faculty the flexibility to make changes and revisions within their domain.
- ◆ "Naive" young intellects. Getting junior faculty involved is critical in pushing the system into the future.
- ◆ Meaningful student evaluations. Feedback is essential if we are to confront how we are actually doing.
- ◆ Successful models. This is exactly what Project Kaleidoscope is all about--proving that the reforms successfully established at one place can be reestablished at other sites.

- ◆ Incentive funding. Leaders must creatively use limited funds to induce people to depart from their natural path of conservatism—basically, to use a carrot, rather than a stick, to motivate change.

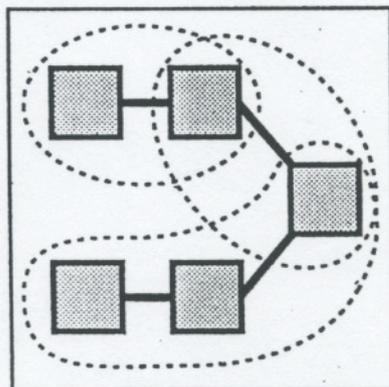
To expand upon this last point, I'd like to illustrate what we did at the University of California-San Francisco. The following diagram charts the standard structure of university departments. As you can see, they are boxed in, indicating limited interaction between them:



The counterproductive nature of this kind of structure is most apparent in medical schools. For more than 60 years, virtually every medical school has had the same standard set of departments: anatomy, physiology, biochemistry, pharmacology, and microbiology. These departments have two primary functions: to teach students and to perform research.

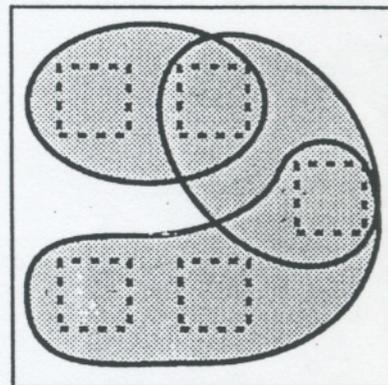
The box-like nature of the department structure interferes with the implementation of these functions. Furthermore, dramatic changes in the field have occurred since the structure was established. In response, nearly every medical school has re-named their departments, for example, from *Anatomy* to *Structural Biology*, or *Microbiology* to *Cell Biology*. Renaming departments, however, does little to resolve the fundamental problem of the boxes themselves,

At UCSF, we tried something different. We were gradually making departments irrelevant, except for the purely administrative functions of paying salaries and administering grants (which will eventually be changed as well). These revisions are schematically illustrated in the following diagram, in which the departmental boxes are overlaid by three faculty groupings, or interdisciplinary programs:



Though there is nothing unusual about interdisciplinary programs, we approached ours in a slightly different way. Take the *Cell Biology* program, for example. Because people teaching cell biology are usually found in several different departments, several courses are often taught on the subject, reflecting the different perspectives. At UCSF, we brought our leading faculty from various departments together to teach a single, intensive, interdisciplinary course on cell biology. In addition, we offered the course from 7:00-9:00 p.m. so that faculty, post-doctorate fellows and other interested persons could attend. This proved to be the genesis of a community of scholars-learners. In the end, it built the *Cell Biology* program at UCSF into what I believe to be the strongest such program in the country.

The next and most difficult step was to change how we accomplished our most cherished function—teaching graduate students. In replacing our departmental programs with interdepartmental ones based upon intellectual areas, we had to convince people to abandon existing programs, which had been successful, to form new communities with people across disciplines. Because it was considered the strongest of the departments and had been attracting the best students, my department had a particularly difficult time in making this transition. In order to entice them, our Dean provided us with a bribe: we would be given new funds only upon implementing the changes. I was in support of the proposed changes anyway, but as Department Chair I needed the promise of increased resources to convince my department. With a "carrot," we were able to implement major changes in a positive way.



Looking at the current chart, the boxes still exist, insofar as the departments continue to pay salaries and administer grants, but they have open boundaries. The **real** fuel is the intellectual involvement of students and colleagues in the interdepartmental groupings. The net result of these structural revisions is a world-renowned program attracting some of the country's very best students.

National Research Council

Since July 1993, I have been Chair of the National Research Council (NRC), a large organization in Washington D.C., that is operated by the National Academies of Sciences and Engineering, involving also the Institute of Medicine. We have 1100 staff members and approximately 7000 volunteers working on one of about 650 committees, each of which addresses some aspect of science or science policy. Of particular relevance to this forum are our substantial efforts aimed at science and mathematics educational reform.

Inertia is the by-product of a system that seeks no feedback from its graduates regarding the relevance of their education.

How can the NRC be a national resource to help create the kinds of change that we want in science and math education? Some possible roles for the NRC in catalyzing change at the college level include:

1. Design strategies to change the way students are educated to become science teachers.
- ◆ Establish a model program that retrains scientists and engineers to become effective K-12 teachers. We're hoping to develop this kind of program in Los Angeles, drawing from their large population of under-utilized scientists and engineers. These individuals will be a force towards creative change in establishing connections between universities and school systems.

- ◆ Prepare a booklet, to be mailed to every embryonic teacher, entitled *On Being A Science Teacher*. This booklet could inform students of the type of education they should expect and also connect them to the considerable national resources that are available.

2. Design strategies to improve the way we teach science to college students--regardless of their major.

- ◆ Catalyze the production of new types of textbooks that would enable people to teach multi-disciplinary science with more effectiveness and ease.
- ◆ Catalyze the development of new types of laboratory experiences that prove to students that doing science is, in fact, very different from following recipes.

At this point, these possibilities are dreams rather than actual programs.

But something dramatic is badly needed. Whatever the mechanism, it is clear that in order to implement reforms in university-level science education--in laboratories, introductory classes, and stagnant departmental systems--we must energize a set of the most respected science faculty and support them with administrative tools.

This is our real challenge.

If our universities are to adapt to the rapidly evolving world, they need bold and progressive leadership to fight the forces that typically prevent change.
