The Kinetics of Innovation in Chemistry Education: An Investigation of Catalysis and Inhibition

A. Truman Schwartz, Macalester College

When the Chinese were looking for characters to apply to chemistry, they came up with *hua-xue*, literally "the study of change." The appellation is most appropriate because at its core, the discipline is about the transformation of matter. The branch of the science that studies chemical change is known as chemical kinetics. It seeks to determine the factors that influence the rates of reaction and the mechanisms by which reactions occur. This essay is an attempt to apply some of the principles and methods of chemical kinetics to recent reform in the teaching of chemistry.

In October 1999, Conrad Stanitski provided an excellent overview of "Chemistry Education Reform in the 1990s" for the PKAL 10th Anniversary Celebration. There is no need for me either to repeat or to revise his summary. Some of the innovations Conrad described have lost their radical tinge and become well established, and others have not had the revolutionary impact their creators envisioned. There are many innovations, but this essay will concentrate on educational reform. Let me offer some generalizations about what we've learned about the process of reform.

Reform requires increased participant concentration.

The rate of a chemical reaction typically depends on the concentration of the reactants. Similarly, the rate of innovation in chemical education seems to vary with the number of professors participating in the process. But the situation is a bit more complicated than simple linear dependence on concentration, both in chemistry and its teaching. The details of that dependence must be determined experimentally. The order of the reaction is the exponent to which the concentration must be raised in the expression that correctly represents the rate of the reaction. In a first order reaction, the rate is simply proportional to the concentration raised to the first power, in a second order reaction the rate is proportional to the concentration squared, and so on.

Experiment suggests that the rate of innovation in chemistry education is at least second order. Many new ideas originate with individuals, but multi-body interactions are necessary in order for the idea to spread. Facilitating such interactions was at least part of the motivation for the NSF initiative promoting Systemic Changes in the Undergraduate Chemistry Curriculum, launched in 1994. A total of five large grants were awarded to consortia of colleges and universities. The ModularCHEM Consortium (MC^2), headquartered at the University of California-Berkeley, involved 17 colleges and universities, most of them in California <http://mc2.cchem.berkeley.edu>. This project set out to transform both the content and pedagogy of chemistry by creating a series of modules that introduced chemical principles in applied contexts and used student-centered investigations. This modular approach was similar to that taken by the ChemLinks Collaborative, a consortium composed largely of faculty from midwestern liberal arts colleges and based at Beloit College <http://chemlinks.beloit.edu>. Subsequently, NSF brokered cooperation between MC^2 and ChemLinks, and the result was a series of modules for general chemistry, published and marketed as ChemConnections by John Wiley & Sons and later by W. W. Norton.

The New Traditions project, with headquarters at the University of Wisconsin-Madison, is perhaps the broadest of the NSF systemic initiatives <http://newtraditions.chem.wisc.edu>. Its central aim is "to facilitate a paradigm shift from faculty-centered teaching to student-centered learning." The wide range of activities address content, pedagogy, laboratory investigations, computer tools, evaluation, and assessment. The instructional use of technology is a major focus of the Molecular Science Project at the University of California at Los Angeles <http://www.molsci.ucla.edu>. This consortium has produced internet-delivered instructional and course management tools and downloadable software, animations, and tutorials. A new reaction mechanism, a student-centered instructional strategy called Peer Led Team Learning Workshops, is the contribution of a consortium based at the City College of New York

<http://www.sci.ccny.cuny.edu>. Students who have already taken a particular course serve as peer leaders for study groups of 6-8 students.

All of these pedagogical projects brought together faculty from research universities and two and four-year colleges. This synergetic symbiosis (to briefly shift metaphors and disciplines) resulted in enhanced productivity and added depth to the reform. Moreover, participation has spread beyond the original players, thanks in part to workshops and other "adapt and adopt" strategies. NSF was the catalyst for the process, and the sizeable funds eased the projects over the activation energy barrier.

The American Chemical Society as catalyst.
To be sure, NSF is not the only catalyst for change in the teaching of chemistry. The Camile and Henry Dreyfus Foundation supports more modest projects and PKAL has brought together many potential reactants. But over the years, the American Chemical Society has been the most effective catalyst for innovation in chemistry education. ACS initiatives encourage chemists to experiment with educational tools and this drives the perception that chemists are willing to take chances. The secret of their success is in the organization of the membership and the presence of a large, professionally staffed Division of Education and International Activities at their Washington, DC headquarters. The chief membership unit is Division of Chemical Education (DivCHED), with about 5500 members. The Division publishes the monthly *Journal of Chemical Education*, *JCE Software*, and the *CHED Newsletter*. It also heads the ACS Exams Institute, which uses volunteer committees to prepare examinations for a wide range of chemistry courses. Currently, over 40 different tests are available. In addition to offering a rich array of symposia at national and regional ACS meetings, DivCHED members organize and participate in regional conferences for two-year college chemistry teachers and biennial conferences on chemical education.

In these various activities, ACS members have the support of their colleagues in Washington. Conversely, most of the initiatives emanating from the 16th Street headquarters are implemented by the membership. The high level productivity is a function of the high degree of cooperation. Together, members and staff have spearheaded a large number of innovative projects and products that have significantly transformed the teaching of chemistry. Children of elementary and middle school age are served by Kids & Chemistry, WonderScience, and FACETS (Foundations and Challenges to Encourage Technology-based Science). *Chemistry in the Community* (W. H. Freeman), a high school text, demonstrates the impact of chemistry on such contemporary social issues as water quality, petroleum, and food production. Indeed, the approach proved so successful that it is also used in *Chemistry in Context* (McGraw-Hill), now in its fourth edition and the best selling college chemistry text for nonscience majors. Both of these books are geared toward students, with significant emphasis on active, cooperative learning. These same pedagogical strategies are evident in *Chemistry*, the new college general chemistry book that is currently being tested and will soon be published by W. H. Freeman. Although the text is intended for all science majors, many of the illustrative examples are drawn from the biological sciences. The involvement of ACS extends to graduate education and beyond. A project in its final pre-publication stages is *And Gladly Teach: A Resource Book for Chemists Considering Academic Careers*.

The result of ACS-sponsored innovations suggests that, as in chemical reactions, mixing new combinations of reagents sometimes yield interesting, unanticipated results. Note that most of the books mentioned in the previous paragraph are not only the products of cooperating staff and ACS members, they are also joint ventures of professional organizations and commercial publishers. Typically, ACS obtains seed money from foundations or dues allocation and once the preliminary development and testing work has been done, interested publishers are asked to submit proposals. Negotiations follow, agreements are reached, and a contract is signed. The aim is for the venture to become self-supporting and return revenue to the Society to use for other educational projects.

Overcoming reform inhibitors.

PKAL has prided itself on reporting and celebrating "What Works." You have been reading some brief success stories and getting some indication of the way in which concentration, catalysts, and new mechanisms instigate productive reactions. But just as inhibitors can slow chemical reactions, various factors can impede or divert intended curricular transformations. Occasionally conditions are assumed to be inhibitory for reform. A case in point is the ACS Committee on Professional Training (CPT). Since its creation in 1936, CPT has exerted a profound influence on the quality of chemical education. This appointed body is responsible for examining and approving instructional programs offered by chemistry departments in American colleges and universities. Currently 623 programs bear this highly sought imprimatur. Ironically, both faculty and administrators sometimes regard CPT as a defender of the status quo and an enemy of innovation. Thankfully, in recent years under the leadership of PKAL stalwarts such as Jerry Mohrig, CPT has encouraged departments to experiment with the ways in which they meet the standards. Enough *genuine* inhibitors to change exist; it is not necessary to create excuses for inactivity.

Tradition and nostalgia for "the way I learned it" are difficult to combat. The "if it ain't broke, don't fix it" mentality is also pervasive. Chemical education in this country "ain't broke"—at least not badly, and it is difficult to reform something that appears to be functioning adequately. After all, we do a good job preparing faculty members for Harvard and MIT. The yield may be low but the purity is high for such faculty. Admittedly, MIT and Harvard professors might not be our most important products, but we are extremely proud of them.

Even those chemists who are willing to venture into educational reform face the inevitable activation energy barrier. Time and money are required to get over it. Senior faculty members, and I'm one of them, may suffer from an excess of instructional inertia. Change is uncomfortable and may seem to repudiate the methods you've used successfully, for decades. At the other end of the age spectrum, the tenure and promotion process at many institutions provides young faculty with a healthy sense of self-preservation that prohibits participation in reform. This is especially true because negative student evaluations in the personnel file may be difficult to overcome. Anyone with any teaching experience knows that students are even more nostalgic and resistant to change than teachers are. In the trials of the ChemConnections modules at Berkeley, the greatest resistance to the materials and approach came from the students and their teaching assistants. The former did not appreciate being experimented on— "lab rats" in more than one sense.

Kinetic Conclusions

If one wants to bring about change in chemistry education, it is important to recognize what catalyzes the process and what inhibits it. First of all, changes in chemistry education are slow reactions— just examine the pages of the *Journal of Chemical Education* for evidence. There's a certain déjà vu expressed throughout. The process is more evolutionary than revolutionary—maybe even cyclic. Moreover, the reactions are almost always endoploutic. Finally, it is important to keep in mind that there is no single mechanism that is guaranteed to bring about change. Unfortunately, this is a lesson that some reformers have not learned. There is no ideal way to teach chemistry or any other discipline, but we can work individually and collectively to continually improve what we do. We must strive to make education more engaging and effective. We simply need to recognize that change is as important in the teaching of chemistry as it is in chemical research.