Exhortations for Good Teaching

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It is a special privilege to be honored at this First Awards Symposium of the American Chemical Society's Division of Chemical Education. This is the first time the Division has held a symposium with a talk by a Nobel Laureate, a talk by the President of the American Chemical Society, and two award addresses—and all presided over by a most distinguished chemistry educator who himself was awarded the 1980 ACS Award in Chemical Education. I am grateful for the participation of Roald Hoffmann, George C. Pimentel, Ronald I. Perkins, and Henry A. Bent in this symposium and I am thankful for the toasting and roasting festivities organized by A. Truman Schwartz. This historic occasion is a tribute to good teaching and a means for sharing our aspirations for chemistry and chemistry education.

It is befitting and perhaps ironic that Union Carbide Corporation is the sponsor of the ACS Award in Chemical Education. Chemists are yet to communicate chemistry effectively to nonspecialists. This is a responsibility that we must meet—and it is a challenge. We, of course, communicate chemistry very well to each other through technical publications, at scientific meetings, and through oral and other means. But, we do a very poor job of communicating our science with all its beauty, charm, rigor, rewards, etc., to nonscientists. What can be more rewarding to teachers than sharing our knowledge of the chemical world we live in with those who potentially can become chemists and especially with the rest of the population who enjoy the benefits of the scientific and technological advances in chemistry. When accidents or tragedies involving chemicals occur we face great pain and sometimes loss of life; we usually hear mostly about the bad effects of chemicals but not enough about the beneficial uses of the same chemicals involved in the accident. Shouldn't we, the practitioners of chemistry, communicate all that to our students and to the public at large?

Our Critical Role in Communicating Chemistry

We as chemistry educators need self-renewal and determination in preparing our students to deal with perplexing issues such as energy conservation, the use of pesticides, nuclear fallout, food additives, and the effects of chemicals on health, particularly the effects of alcohol, tobacco, marijuana, and cocaine. Also, we need to train competent researchers and technologists to maintain our scientific preeminence and to expand our technological advances. New research and technological innovations will bring negative impacts, no matter how positive their overall consequences might be. The negative impacts may result from threats to our moral and ethical beliefs, from decisions to commit resources to substitute machines for teachers, or from bureaucratic incompetence.

We, as chemistry educators, must be adaptable in pursuing our goals, but we should not compromise our purposes or the means of reaching them. We must reassert the primacy of a rational endeavor to save and renew our commitment to teaching chemistry as a *laboratory* science. The pressure to eliminate the laboratory experience for students at the precollege levels and at the introductory college level must be dealt with by convincing our colleagues and our administrators of the educational values of a meaningful laboratory experience. We must be convinced of these values; otherwise, how can we convince others? The trend to eliminate laboratory work is based on economic reasons rather than pedagogic ones. We all know that the cost of chemicals and equipment as well as the availability of qualified instructors are very significant factors. This is why we should be deliberate and courageous. As we attempt to adjust and adapt, we must not compromise the integrity of our academic offerings. Several suggestions have been made to use computer and videodisc delivery systems as *substitutes* for laboratory work. I believe we should carefully examine these suggestions to determine their pedagogical value and not be simply lured by their novelty or by cost-savings which they may

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possibly provide. Fundamentally, my conviction about laboratory work is best stated in the words of the great master Leonardo, "There is no higher or lower knowledge, but one only, flowing out of experimentation."

I am often characterized as being an incurable optimist despite the fact that I see the world we live in to be mostly irrational, cruel, beleaguered economically, unstable politically, and full of anxiety. In this society, we often *seem* to be reckless, lacking purpose, wanting instant gratification, and not very clear about our values. The syndrome of "looking out for number 1" is widespread and condoned. We live in a time when the characteristic values of our Western heritage are no longer adhered to or professed. Our behavior domestically and internationally is not always consistent with the fundamental premises upon which this nation was founded.

Can all this be the result of our educational system? How can we, as educated men and women, tolerate such societal deterioration? How can we, as educators, tolerate being a part of an educational system that does not appear to have clearly stated purposes? Should we not step forward and state our individual purposes for teaching, and more specifically for teaching chemistry? Should we not tell our students, at least, *why* we teach chemistry? Should we not be aware of how our behavior both in the classroom and outside the classroom influences attitudes? Should we not tell the general public what the purposes of education are and why they should be supported? Should we not educate our students and the public at large about chemicals, their properties, their usefulness, their benefits, and their potential hazards? Should we not be patient, intelligent, deliberate, and vigorous in the pursuit of greater understanding of our chemical world?

The answer to most of these questions is *yes; my* answer is yes. What is yours?

The enormous ramifications of using chemicals to cope with energy, food, and industrial demands must be dealt with on a sound scientific basis *as well as* on ethical and moral grounds. Our tasks as chemists and chemistry educators extend beyond research and transmitting knowledge. We should strive not only to train competent scientists and engineers but also to inform and educate the general public in the best possible ways we know. Problems of population, food, fuel, pollution, etc., can be solved if we prepare our students and the public-at-large to live in a world of wonder, excitement, awe, and chemicals whose properties and effects are understood. Our major concerns must include not only survival but the *quality* of life. As educators we must teach our students and the general public the *difference* between chemistry and chemical technology and emphasize that both can lead either to improving the quality of life or destroying it.

The burden of what I have enumerated so far is enormous, and I will not be surprised if some of us begin to experience moments of self-doubt and feelings of withdrawal as we think about the awesome responsibilities we have. The health and vitality of chemical education and the quality of life in our educational institutions, and eventually in society at large, is in our hands. Let us not surrender our mission of influencing attitudes and changing behavior. If we are not competent and sincere in renewing and pursuing our mission, we will cease to be educators.

The United States now faces a situation that is far more critical and more consequential than what the country faced in the immediate post-Sputnik era. There are at least three reasons for this:

1) We have more people living in this country now than we did 25 years ago. The population of the United States has increased by approximately 50 million people. To put that number in perspective, that is roughly the population of Great Britain alone. What does that mean? There are more students to teach and we need more *qualified* teachers to teach them.
2) Secondly, we need to have a good supply of scientists, engineers, and technologists coming through our educational systems in order for our society to continue to enjoy the benefits of science and the benefits of technology. That is essentially what the National Science Foundation set out to do in the immediate post-Sputnik era. Now, we need to maintain having a good supply of scientists, engineers, and technologists for economic and national security reasons and in order to retain our international preeminence in science and technology.
3) The third reason, perhaps the most important and most consequential of all, is that we now live in a more advanced technological society than we did 25 years ago. And it is the education of the nonscientists, the nonengineers, the nontechnologists in science, in engineering, and in technology that requires our attention.

I submit that our greatest challenge now is to extend learning opportunities so that all individuals can continue to expand their knowledge and understanding of chemistry. Improving chemistry teaching is crucial, but it is not enough. Our adult population also needs to learn new science concepts. We need not only skilled scientists, engineers, and technicians, but managers and decision-makers who understand the nature and implications of their fields. And we need a citizenry that can follow and weigh the progress and implications of science and technology. That is why we *must* be creative and inventive in communicating the very essence of our science and its results to *all* segments of our society and why good teaching is so essential.

Hierarchy of Teaching/Learning Activities

Good teaching requires great awareness of the interactions of teaching and learning. In teaching and in learning chemistry, teachers and students engage in a complex series of intellectual activities. These activities can be arranged in a hierarchy which indicates their increasing complexity:

1) observing phenomena and learning facts
2) understanding models and theories
3) developing reasoning skills
4) examining chemical epistemology

This hierarchy provides a framework for the purposes of course design and of including lecture demonstrations in teaching chemistry.

At the first level, we observe chemical phenomena and learn chemical facts. For example, we can observe that, at room temperature, sodium chloride is a white crystalline solid and that it dissolves in water to form a solution with characteristic properties of its own. One such property, electrical conductivity, can be readily observed when two wire electrodes connected to a light bulb and a source of current are dipped into the solution. There are additional phenomena and facts that can be introduced: the white solid has a very high melting point; the substance is insoluble in ether; its chemical formula is NaCl; etc.

At the second level, we explain observations and facts in terms of models and theories. For example, we teach that NaCl is an ionic solid compound and that its aqueous solution contains hydrated ions: sodium cations, $Na^{+}{}_{(aq)}$, and chloride anions, $Cl^{-}{}_{(aq)}$. The solid, which consists of Na^+ and Cl^- particles, is said to have ionic bonds, that is, there are electrostatic forces between the oppositely charged particles. The ions are arranged throughout the solid in a regular three-dimensional array called a face-centered cube. Here, the teacher can introduce a discussion of the ionic model, bond energy, and bond distances. Similarly, a discussion of water as a molecular covalent substance can be presented. The ionic and covalent bonding models can be compared and used to explain the observed properties of a variety of compounds.

At the third level, we develop skills that involve both mathematical tools and logic. For example, we use equilibrium calculations in devising the steps of an inorganic qualitative analysis scheme. We combine solubility product, weak acid dissociation, and complex ion formation constants for competing equilibria, which are exploited in analyzing a mixture of ions. The logical sequence of steps is based on understanding the equilibrium aspects of solubility phenomena.

At the fourth level, we are concerned with chemical epistemology. We examine the basis of our chemical knowledge by asking questions such as, "How do we know that the cation of sodium is monovalent rather than divalent?" and "How do we know that the crystal structure of sodium chloride can be determined from X-ray data?" At this level we deal with the limits and validity of our fundamental chemical knowledge.

Across all four levels, the attitudes and motivations of both teacher and student are crucial. The attitude of the teacher is central to the success of interactions with students. Our motivation to teach is reflected in what we do and in what we do not do, both in and out of the classroom. Our modes of communicating with students affect their motivation to learn. All aspects of our behavior influence students' confidence and their trust in what we say. Our own attitudes toward chemicals and toward chemistry itself are reflected in such matters as how we handle chemicals, adhere to safety regulations, approach chemical problems, and explain and illustrate chemical principles. In my opinion, the single most important purpose that lectures serve is to give teachers the opportunity to convey an attitude toward chemistry—to communicate to students an appreciation of chemistry's diversity and usefulness, its cohesiveness and value as a central science, its intellectual excitement and challenge.

Characteristics of Good Teachers

I believe *good* teachers have four important characteristics that distinguish them for all other teachers. Good teachers are:

competent in their disciplines,
committed to their disciplines *and* to the profession of teaching,
comfortable with the methods and techniques they use, and
compassionate with students (and colleagues).

The first characteristic is so obvious that I am often questioned about including it. I *insist* on including it for it is not sufficient for a teacher to be certified as a holder of a degree in chemistry or be tenured at a school or at a college or a university in order to be considered competent. All of us have to *maintain* our competence by engaging in scholarly and professional renewal activities to keep us ahead of our students and at a level of knowledge much more advanced than what is in the textbooks and manuals we use in our courses. Furthermore, if we are competent in chemistry then we must be committed to chemistry. But commitment to chemistry alone is not sufficient; we have to be committed to *teaching* chemistry as well. Many researchers, of course, are committed to their sub-discipline, but they cannot be characterized as good teachers unless they are committed to communicating to those outside their area of *sub-specialty*. They may be good at research, but, if they are, that does not automatically make them good teachers.[2] In my opinion good teachers must be comfortable with the methods they use—be they audiovisual aids, lecture demonstrations, computers, books and manuals, etc. As we adapt to or even adopt a "new" method or technique we often experience discomfort to varying degrees. This discomfort has to disappear; otherwise, we should abandon that particular method in order not to diminish our effectiveness as teachers. We must be careful in not becoming too comfortable and thus quickly risking becoming complacent. In addition, I believe we must be compassionate with our students—we must *care* about them and about what and how they learn. This should not be done by compromising standards; on the contrary, we should set our standards high. Since our purpose as educators is to enable students to develop fuller intellectual capabilities and emotional capacities while they are under our influence, we and others should recognize that their grades are by no means the only measure of our success as teachers or their success as students. As good teachers we must also be compassionate with all our colleagues in the educational enterprise including fellow teachers, administrators, and support staff. This will contribute to creating and maintaining an atmosphere conducive to good teaching.

The Learner's Perspective

Good teaching always involves awareness of the learner's perspective. Despite the notion that analogies may not be good instructional devices, I have found it useful occasionally to say that teaching is analogous to the transmission of knowledge and that learning is analogous to the reception of knowledge. The responsibility of the teacher is to transmit and that of the learner is to receive. We all know that learning often takes place without a teacher and even despite a teacher! Nevertheless, this analogy is useful in helping exhort teachers to sharpen their signals and to be aware of what they may be transmitting inadvertently. We should be very aware of the power and quality of transmission, and we should strive to make both as strong and clear as we know how. Most importantly, we should be aware of the direction in which we are transmitting in order to ensure that there are some receivers capable of receiving our signals. My brother-in-law, Frank D. Drake, is a radioastronomer who has pioneered the search for extraterrestrial intelligence, and he has used powerful radiotelescopes to send intelligent messages to outer space. The content and quality of what can be transmitted is of special concern to Frank Drake and his colleagues, but they, unlike teachers, cannot be concerned about the quality of the receivers! They have no say about that, but they are careful about the direction of transmission.

In all our attempts to communicate chemistry and as we design formal courses or plan special presentations, we must be aware of the audiences we are attempting to reach. There should be clarity of purpose of what is to be offered as well as a good understanding of the backgrounds and abilities of those in the audience and their reason(s) for being in that group. Throughout my teaching experience I have found it helpful to assume the perspective of the learner in order to sharpen or revamp whatever I intended to transmit as teacher. In assuming the role of the learner I examined all the material I had put together for a particular unit in the course or for a special presentation. I examined the textbook reading and homework assignments, the CHEM TIPS plan,[3] the "Chemical of the Week" material, the laboratory experiments and the pre-lab videotapes, and the audiotape lessons, and I practiced the appropriate demonstrations, but all along I tried to visualize and imagine how all these were to be "received" by my students. I have always answered all the questions on my examinations *prior* to settling on their length; typically, I would allow 4–5 times the length of time it took me to complete the answers and then add 20 to 30 extra minutes to the time allotted to my students. These experiences were most rewarding in terms of revamping or fine-tuning my course materials and my presentations and in anticipating several "transmission/reception" difficulties.

"Chemistry Can Be Fun"

Good teaching goes beyond the formal classroom. An outreach activity called "Chemistry Can Be Fun" began in early 1982 and was aimed at pre-high school students and their

[2] In this connection, I am bothered when I hear about some faculty bragging that they do not have to teach (in some instances I suppose I should be happy they are not being inflicted on students); and I am saddened when I hear faculty and administrators talk about "research *opportunities* and teaching *loads*"—what a remarkable statement about the value system of some of our institutions of higher education!

[3] Shakhashiri, B. Z. *J. Chem. Educ.* **1975,** *52,* 588.

teachers. Through special presentations full of colorful demonstrations and explanations middle school and elementary school students experienced chemistry in action. Typically, a dozen demonstrations were presented either in the Chemistry Building at the University of Wisconsin-Madison or in schools in the Madison area. Various handouts were distributed along with instructions for some home experiments. In each presentation a great deal of emphasis was placed on the benefits of chemicals and on their safe handling. This approach turned out to be so popular that my colleagues and I have now reached over 20,000 students in the Madison area and several thousand more elsewhere.

Special in-service workshops for teachers were developed and added to the program. All were held in the Chemistry Building. The purpose was to provide teachers with detailed information about the demonstrations presented to the students and to train the teachers to incorporate demonstrations and other experiments into their teaching. Topics normally not included in the school curriculum were discussed at the request of the teachers. We were able to incorporate experiments on topics such as nuclear chemistry and polymer chemistry that could not be done in the school. In most cases the teachers received in-service credit from their school districts.

Eventually, the program was expanded to include a special sequence of Saturday morning sessions for about 40 middle school students. This "hands-on" activity turned out to be so popular that beginning in 1984 it was offered four times in the summer and was called Chemistry Camp. Typically, the students perform experiments carefully designed for their age group and under the supervision of experienced chemistry teachers. The student/teacher ratio was deliberately fixed at 5/1 in order to ensure individualized instruction and for safety reasons. After each session students took with them either an experiment to be done at home or a product of an experiment that was just completed.

A special packet describing the details of these activities along with a one-hour videotape of the special presentation is available at cost from the Institute for Chemical Education.

In the spring of 1984 Chemistry Can Be Fun activities began to be held in shopping malls. Special announcements were placed in newspapers announcing this activity and large crowds always showed up. I am pleased that this is a continuing activity and I would like to see it done throughout the country. Information about this is also available from the Institute for Chemical Education.

Institute for Chemical Education (ICE)

Good teaching and good teachers need supportive networks. Of all my work in chemistry education I am proudest of the establishment of the Institute for Chemical Education since its potential benefits are so great. In the early 1970's I and others felt the need for a national center to deal in a *concerted* manner with national research and development activities in chemical education. This idea was formally presented in 1977 by Jerry Bell to the Manufacturing Chemists Association and again in 1982 by Truman Schwartz to the Chemical Manufacturing Association. In the summer of 1982 at the ACS 7th Biennial Conference on Chemical Education I announced that the Institute for Chemical Education was about to become a reality. After several strong endorsements from academic and industrial leaders, from ACS leaders, and from the University of Wisconsin-Madison, the Institute for Chemical Education was established in early 1983.

I am pleased with the progress ICE has made since its founding. The summer workshops for precollege teachers have, for the most part, served good purposes and I trust will continue to do so. However, ICE was never intended to be only a collection of summer workshops. Its goals, as outlined in its founding documents and the proposals submitted to secure funding, are to serve educators in the chemical sciences at all educational levels by:

1) strengthening the links between the chemical sciences and other disciplines and technologies,
2) applying computer-related techniques and knowledge from cognitive science to chemistry and chemical education,
3) fostering continuing education and professional growth in the chemical sciences,
4) sponsoring the development and dissemination of creative ideas and practical methods of communicating chemical knowledge and information, and
5) providing a national center for identifying and addressing critical issues in chemical education.

Much of the creative work of ICE is to be conducted by resident Fellows: college and university professors, secondary school teachers, and industrial chemists. About six to eight Fellows usually will be in residence for periods ranging from 3 to 12 months; their projects can be in any area of chemical education and most projects are to result in an instructional product or technique. The results of these scholarly activities are to be disseminated via publications, workshops, and the like.

ICE has done well during W. T. Lippincott's two-year directorship. I am confident the new director Jerry Bell and his associates Glen Dirreen and Ron Perkins will build on the strengths of what has been accomplished since 1983. I look forward with high expectations to my future involvement with ICE and its programs.

The Pimentel and Yankwich Reports

During the past 18 months two very important reports dealing with chemistry and chemistry education were issued. In October of 1984, "Tomorrow, The Report of the Task Force for the Study of Chemistry Education in the United States" was published by the American Chemical Society after about two years of work under the chairmanship of Peter E. Yankwich. In October of 1985, "Opportunities in Chemistry" was published by the National Research Council after almost three years of work by the Committee to Survey Opportunities in the Chemical Sciences under the chairmanship of George C. Pimentel. Both the Pimentel Report and the Yankwich Report have far-reaching recommendations that must be implemented as soon as possible. It is crucial that appropriate funding be secured for both research and education in chemistry. I trust that ACS, industry, and academe are unequivocal on this point. Congress and the executive branch of the government must hear that *both* research and education in chemistry require support. In my judgment, those who advocate support for research only are short-sighted and misleading; in the long run, research will be hurt if adequate support is not given to education.

Acknowledgment

I thank Union Carbide Corporation for their sponsorship of the ACS Award in Chemical Education and for their genuine support to chemistry education at all levels.

I am grateful to so many people who have made my work in chemical education a joy. The over 15,000 students who have enrolled in my classes have had an enormous effect on my teaching. The thousands who have used my books, watched my videotapes, listened and used the Audio-Tape Lessons, and learned from my chemical demonstration projects have made all my efforts worthwhile.

Numerous colleagues at the University of Wisconsin-Madison and throughout the country have contributed to each of my projects in so many different ways and have supported me and continue to support my work. I thank them one and all. Very special thanks go to Jerry Bell, Glen Dirreen, Rod Schreiner, Patti Puccio, and Kay Kilcoyne.

I am grateful for the excellent academic environment at the University of Wisconsin-Madison, which has enabled me to flourish and to enjoy being a teacher.