REALISTIC ORIENTATION IN CHEMICAL EDUCATION

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ABSTRACT

The general question of the roles of chemical education is briefly discussed.

A principal focus of this meeting is directed at problems that occur as students move from the lower schools to colleges and universities. I will try to help set the stage for our discussions by examining the general question of the roles of chemical education in the societies in which we live and seek to educate our young. I know that the subject is so broad and complex that I cannot possibly do a truly satisfactory analysis. Yet, I believe that we must make the effort occasionally. If we do not make the effort, our discussions about the teaching of chemistry will become sterile exercises in game-playing, like the study of strategy in the game of chess. There are times when I long to teach chess rather than chemistry, because dynamic education in chess can be determined almost completely without looking beyond the game itself.

THE AIM OF EDUCATION

At every stage of the educational process, responsible educators should ask: 'Where does it lead?'; 'What are the goals of our students?'; 'Is our presentation reasonably honest?'; 'How much of our present practice is dictated by tradition rather than common sense?'; and, 'Are we guilty of teaching in aphorisms as a substitute for real logic?' Although we should ask the questions, we cannot expect to find definitive answers. The best answer to any of the questions will surely change from year to year. Moreover, the questions are exceedingly complex. Perhaps this is one reason that scientific educators tend to stay away from them. We are trained almost from birth to regard study of complicated, unanswered problems as unscientific. The notion that we deal with hard evidence and hard answers can be stimulating and comforting, but can also lead to severe perturbation of our natural missions. If we restrict our teaching to topics in which the hard question–hard answer criterion seems to apply, we will focus on a series of remotely related, small problems.

At all levels of education, we defend our choice of subject matter on the grounds that it is 'basic'. Yet, if we look in detail at what is taught, the question forever arises, 'To what is this material basic?' The naïve assumption, that nearly everything taught in a course must be basic because traditionally it has been there, is widespread. We find it in the eighth-grade science courses in

American schools, as well as in courses taken by graduate-degree candidates. In talking with young children about their science courses, I find that they have been subjected to ridiculously rigid brainwashing comparable to the religious education given by the most prescriptive churches. The reactions of children vary. Some accept it and see all they are taught as more truth to be filed away in their mental truth recorders; others see the whole picture as a hopeless and incomprehensible jumble. The latter group may include both those who are most intelligent (by my own judgement) and those who are least intelligent. The least intelligent group may really be those who long ago gave up the hope of making any sense out of organized systems of pedantry. The most intelligent are likely to be those who seek something more sustaining than establishing a truth file—who still struggle to find the magic clue that will make all science fall into place. In fact, I find the search for a scientific nirvana to be a driving desire of many of the most effective young scientists that I meet in my own and other countries. As an aside, I mention the sadness that I feel when a young man from another country tells me, in essence, that his search for nirvana *must* lead to the USA. I recall Herman Hesse's account of the wanderings of Siddhartha and know that chemical science in the USA offers, at best, a small piece of what is sought by one who hunts the ultimate in self realization. The USA has contributed something to science and science education, but there is no nirvana on my horizon.

THE STUDENTS' PROBLEM

Education of students must be discussed internationally because we are one world. However, international conferences should strive for realistic distinction between the problems of a group of chemistry teachers and the problems of their students who enter the picture at a time of great uncertainty.

In the USA changes in the economic climate, in the aspirations of the military services to do research, and in our ideas concerning space exploration have led to an alarming slump in the job market for young chemists. We react as though the sky has fallen on our heads. However, the situation is not nearly as unfavourable as those that have persisted in much of the world for many years. The prospect for employment in jobs that would be considered tolerable by young Americans is nearly non-existent for most of the youth of South America, Africa and Asia. Yet the chemical educators of the USA and Europe have consistently urged their peers in countries having very different national economics to emulate American and European styles of chemical education. We have maintained the view that a chemist well trained in "basic principles" should be prepared to take on almost any problem related to chemistry. Even if there are no such jobs, we maintain that the rigorous intellectual discipline of a classical chemical education will prepare a young man or woman to think any problem through to a clear-cut conclusion.

I see little evidence that these optimistic views contain much truth. Although there are notable exceptions, chemists have not been especially successful when they have moved into other fields. Some chemists have fared well in the financial world, but very few indeed have had much success in government.

If we want to know why the study of chemistry misses the mark as a preparation for successful intellectual activity of any kind, we can gain some clues by listening to the conversations of chemists. I shudder to think how many times I have heard people use phrases such as, 'He thinks like an organic chemist'. We are in a sorry fix, indeed, if one cannot entertain new ideas and thoughts, but instead thinks like the exponent of some narrow, subdisciplinary speciality.

THE CONCEPT OF RELEVANCE

What can we do to establish a more rational connection between our teaching and the real needs of our students? This brings us to the concept of 'relevance', which is now discussed frequently among American scientists. Despite common use of the word, I am not impressed with the quality of thought invested by most people, scientists and non-scientists alike, in their talk of relevance. A common reaction of a chemist is to seek any interpretation of the concept of relevance that will leave his own teaching and research unchanged. I may say that the study of the photochemistry of benzophenone is surely related to the role of sunlight in causing skin cancers, or I may point to the fact that the technological implications of scientific research have rarely been foreseen, or I may think of some other partly true rationalization.

I may defend my teaching practices in similar illogical ways. For example, we have a well-respected theoretical model which says that molecules are built up from nuclei and electrons. The model is good, but do we use it well in our teaching? Surely, we miss the mark as chemists if we end up spending more time in elementary courses discussing electrons than we devote to molecules. We should question seriously the emphasis placed upon the 'rigorous' development of treatments of simple systems by methods that are of no use in treatment of more complex problems. Perhaps the rigorous exercise is worthwhile, and perhaps it is not. I know that bright students are often offended by being led through a tedious mathematical excursion only to find that no use will be made of their efforts. This is a kind of question in immediate relevance that must be faced squarely.

Let me choose another example. Some form of the Eyring–Polanyi theory of rate processes is taught again and again in chemistry courses at all levels. The presentation usually begins in the USA in secondary school courses. Moreover we have a clear understanding that if a high-school course does not contain some reference to transition-state theory, the course is a 'low-level' offering for 'low-level' students. However, I can see very little evidence that students in either high school or university freshman courses derive anything of value from the theory. In many instances, they learn nothing about chemical reactions except the fact that they can be discussed by transition-state theory. I believe that, if we put the theory in, we must show students how it can be useful; in short, we must show the relevance of the theory to other chemical science. In reality, about the only value of the theory is to give the form of the dependence of reaction rates on temperature. It is also of some value in providing a form for analysis of structure–reactivity relationships in closely related series of reactions. We must face the fact that, at least at this time, the theory is really incapable of telling us whether or not a given reaction will occur under any achievable conditions. In short, the value of the theory to practising chemists is real, but limited. Because theory has real value, we probably should present it to students, with careful exposition of its uses and limitations. Only then can we maintain that we have taught something in such a way that it may have some basic value to students.

Building from the example chosen, we come to a most serious problem in our educational system. Most teachers do not themselves know the real value and limitations of the topics that they teach. Although the problem is most acute in the lower schools, it persists throughout the entire academic pyramid. Teachers lack the confidence necessary to state forthrightly the limitations of the concepts that they teach. The secondary school teacher may have only a vague idea of the ways in which transition-state theory is really used and he is likely to have great inhibitions about telling his students that the theory is mainly used for correlation of data and has very little predictive value. The teacher fears the wrath of his students who may ask, 'Why bother with such useless pedantry?' but most of all the teacher fears that he will reveal the fact that he has missed some far-reaching fundamental truth that is obvious to nearly all other chemists. The same kind of fear plagues teachers at higher levels. A physical chemist may formulate the Eyring theory with elegance, including sophisticated hand-waving about the magnitude of the transmission coefficient and the formal inclusion of partition functions for ground and transition states. He may even plunge into such esoteric subjects as dynamic isotope effects in learned detail. However, he is unlikely to tell his students that the theory predicts very little in an *ab initio* sense, because he cannot write down a partition function for transition states involving complex molecules, and because the values of internal energies of activation ($\Delta E^{\ddagger}$) can only be made available in even decent approximation by terribly expensive computation. The man hesitates to state the limitations of the theory, because he knows that his colleagues in organic and inorganic chemistry are making predictions about such reactions using the language of transition-state theory. In a similar way, the organic chemist may teach his students to make predictions of reactivity based upon a sophisticated system of reasoning by analogy. The reasoning is often expressed in terms of transition-state theory even though one can imagine any number of conceptual models which would be equally useful. However, the teacher hides the real genius of his correlative methods behind the language of transition states, because he fears the admission that the theory has done little other than provide vocabulary; he fears that somewhere, hidden in the mathematical machinations of the chemical arithmeticians, there lies a great truth that he has missed entirely.

We can find examples of such nonsensical behaviour throughout all of the teaching of chemistry and chemical engineering. Everyone has created his own small dream world which he refuses to disclose entirely for fear that it will appear irrelevant or childish. In doing so we contrive to hide the relevance that does exist and the creativity that enables a chemical scientist to deal with enormously complex subjects with some real success.

The defensive style of teaching is cruel and ineffective: cruel, because both students and teachers feel they are caught in a fraudulent game, and ineffective, because the most meaningful thrusts of modern science are lost. Why does the silly game go on? I believe that we teach one another that there is no other way. We present courses in science, especially at elementary levels, as cold, coherent systems of thought and action. There is seldom an opportunity for the teacher to evaluate explicitly on the basis of his own understanding or intuition. How unthinkable it would be to hear a professor say, 'The part of thermodynamics that appears widely useful *to me,* is very simple. Because of custom and the need for practice in manipulation of equations, we will also study some applications of thermodynamics which are far from representative of the most important chemical applications'. Consider the effect on the young teacher holding only the first university degree as he goes out to teach students in elementary or secondary schools. His instincts will probably push him toward intellectual dogmatism and those defensive feelings will be strongly fortified by the fact that he has never heard any hint of another educational style in university science courses. The whole act constitutes a dreadful, vicious circle. Students in the lower schools are taught by authoritarians who manage to convey the idea that science is nearly finished, because there seems to be no prospect of changing the conceptual basis of science. Students, who perform successfully under such tutelage, then pass on to colleges and universities expecting to receive more of the same fare. I have felt frustration with the intolerance of students for discussion of my own confusion and lack of understanding of chemical problems. A good many students seem to feel that there is no profit in worry and debate about such unresolved issues, because they are convinced that *I really do know the answers* and only lead them through the questioning process as a kind of intellectual exercise. Moreover, there may be some truth in the views of my students. The puzzles that I discuss do tend to be peripheral matters related to some of the things which I understand best. It is little wonder that students feel that the debate is esoteric game-playing, as long as I always stay away from areas in which I am totally confused or sceptical. The net effect is a pressure from many students to continue just the kind of prescriptive and dogmatic education that they need least. There is no point in seeking culprits. Poor teaching occurs because our educational systems are complicated social systems. We must identify needs and develop strategy for working toward them, because there is no simple adjustment that will result in a 'solution'.

NEED FOR NEW STRATEGY

I have touched on a number of problem areas in chemical education—rigid paternalism in teaching, failure to evaluate theory realistically, failure to show why 'basic' concepts merit that description, and scorn for the important and complex chemical problems faced by members of the human race. The challenge of finding new strategy belongs to all of us. I have suggestions to offer the members of this conference, but neither my suggestions nor those of any other individual can be taken as a definitive policy. Otherwise, we will merely create a new orthodoxy with its own inhibitory influences.

My first suggestion is that we try to produce new kinds of instructional materials. Especially important will be essays written in a style which is apparently incompatible with textbooks of chemistry. We need thoughtful expressions of personal opinion concerning the ways in which common elements in chemical educational programmes do, or don't, fit in with the overall educational process. Any such examination is certain to lead to differences in opinion which do not fit well in textbooks. We have to get away from the position that everything that we teach is of indispensable value. I feel no shame at all in the realization that I have taught students both trivial things and, I believe, important ones. Teaching and learning will improve if we accept as normal the fact that the process does not suffer from the inclusion of topics of limited importance. Furthermore, we should be able to tolerate the fact that what one man regards as trivial may play a truly basic role in another's conceptual framework. We know very well that such differences exist now; but, we would all gain from careful exposition of these positions—both positive and negative.

I do not believe that written essays are the only ways to develop such extra-educational materials. At the present time, videotape with high quality sound track has become relatively inexpensive, so extensive use of such equipment to record and disseminate discussions becomes feasible. This medium has the special advantage of being able to show real interaction involving two or more people.

Finally, I believe that we should work with other groups of people, from both the academic and non-academic areas, to produce high quality materials showing the relationship of chemical science to the other affairs of men. Our students demand information about the relationships among the things that they study, in schools and in life. As chemists, we sometimes try to respond by discussing chemistry in a technological economy, and so on. The results are often rather poor, largely because well-meaning chemists know too little about the non-chemical phases of the subject. I, personally, would like to work with a team composed of an economic theorist and a wise businessman in an attempt to do a real analysis of the current state of trends in chemically based technology in my own and other countries. I am interested in both economics and technology. However, my understanding of those fields is so inferior to my understanding of chemistry that I am certain that a consortium could produce something far more useful than anything that I could do by myself.

In closing, I wish to add the thought that the presence of many people from a number of countries at this conference is in itself significant. Only a few years ago, international conferences in chemical education were uncommon and not especially imaginative. Beginning with the Frascati Conference of two years ago, we have seen a series of truly inspiring meetings. Clearly, chemists have discovered education in chemical science as a creative and challenging field. Changes such as many of us desire are almost certain to come, although the forms of change may be quite different form those which we now imagine.