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ABSTRACT

Reports and recommendations prepared by working groups on "The Structure of Chemistry," "Graduate Education in Chemistry and Beyond," "Preparing Chemists to Meet Society's Future Needs," "Chemistry for Citizens," "International Aspects of Chemical Education" and the text of two plenary addresses, "Education for Change" and "New Problems Need New Answers," are included. There are a total of 35 recommendations to chemical educators, researchers, and administrators concerned with details of curriculum, research approach, and methods of support of chemical research and teaching. Not all the recommendations are consistent, as there was no attempt to produce consensus between groups. A list of participants is provided. (AL)

Preliminary Report

INTERNATIONAL CONFERENCE ON EDUCATION IN CHEMISTRY

July 20-24, 1970

Snowmass-at-Aspen, Colorado

Sponsored by:
DIVISION OF CHEMICAL EDUCATION
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Preliminary Report

INTERNATIONAL CONFERENCE ON EDUCATION IN CHEMISTRY
Snowmass-at-Aspen, Colo., July 20-24, 1970

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PREFACE

Social structure has become so large and complex that problems of communication assume proportions which make them both troublesome and important. Education, as one segment of a large sociological structure, is particularly sensitive to communication problems. Its activities must be articulated with the other activities of society if it is to contribute effectively for the good of man.

Is education healthy? Are lines of communication in good working order? Do those responsible for education and educational policy understand the problems of students, of the politicians who shape national goals and priorities, of citizens who pay the bills, of research directors and supervisors who influence the marketplace for scientific manpower, of school teachers at the elementary level where most career decisions are made? Answers to these and related questions tend to be pessimistic or ambiguous. Progress toward providing a base for more favorable answers to these questions requires an assessment of the current situation and specific recommendations for change.

This conference represents a major effort to establish effective communication among chemistry professors; school teachers; academic, industrial, and government research chemists; government policy makers; students; and the public (represented by outstanding science writers). Since many of the problems as they affect the community of chemists transcend political boundaries, this conference involved chemists from around the world.

Five topics of concern were selected from among many by a steering committee. An organizer was appointed to select a limited number of participants and set an agenda for each topic. The five groups met independently, July 20-24, to sort out the issues, to crystallize the problems, and to formulate recommendations. There was informal interaction between groups, but no attempt was made to articulate the individual reports nor to gain concurrence between groups. Thus the reader will discover different viewpoints expressed in the various reports. Within groups, widely divergent views were expressed. This was by design, not accident. Yet the group reports do express a commonality of concern, purpose, and direction.

We urge readers of the report to study it critically. Those who attend the 160th National Meeting of the American Chemical Society in Chicago, Sept. 13-18, will have an opportunity to participate in symposia based on the conference and this report. A final revision of the report, perhaps containing additional recommendations from the symposia in Chicago, will appear in the December or January issue of the Journal of Chemical Education.

If the recommendations of this report are thoughtfully considered by chemists in general, and by those to whom they are addressed in particular, then this conference will enter history as meaningful, and we can anticipate a substantial change in direction for chemical education.

The conviction of purpose of the conferees is clear from the time they devoted to preparing for and participating in the conference and in writing the report. Their dedication to action is demonstrated by their willingness to continue as committees until the recommendations are implemented.

Herbert E. Carter

William B. Cook

Robert W. Parry

Laurence E. Strong

SUMMARY OF RECOMMENDATIONS

This summary gives the sense of the Recommendations developed by the five panels--totaling some 85 participants--who met at the Snowmass conference. The Recommendations and supporting discussion appear in full in the separate panel reports as indicated below.

PANEL ON THE STRUCTURE OF CHEMISTRY

Various new methods for the organization of chemistry, both for teaching and publication, should be investigated.

Chemical education must be continuously reviewed in the light of the development of the science to ensure that students learn what the real challenges now are, rather than what they were some time ago.

Significant experimentation with many new forms of curricula should be actively supported by chemists, universities, and the federal and state government.

Chemists and their representative chemical societies must strive for better projections for the future. Included must be attempts to see developing trends in pure and applied science as well as manpower needs. Although technological forecasting is not a highly developed field, chemists must be aware of possible implications of social and economic trends as they plan for the future.

While the growing involvement of chemistry in technological aspects of the solution of societal problems is to be commended, we must at the same time preserve a progressive program of basic research.

The individual chemist should ask himself whether his work is significant for the development of chemical science or other branches of science and engineering, <u>or</u> endeavors of mankind. The desire to be "relevant" in some way is not the only legitimate motive for research, but is a factor of sufficient significance to warrant evaluation on an individual basis.

<u>A more stable, basic support level for chemical re-</u> search and education is needed in the United States and some other countries to ensure steady progress and to avoid waste of human and physical resources.

<u>International study of the advantages and disadvan-</u> tages of the various systems of support in different countries is needed.

PANEL ON GRADUATE EDUCATION IN CHEMISTRY AND BEYOND

<u>New types of graduate programs, coupled to the</u> changing horizons for the chemical sciences, must be developed and implemented to augment the traditional responsibilities of graduate education.

<u>New awareness of opportunities for leadership by chemical scientists must be created. This can be</u> done by broadening graduate chemical education to include related scientific and nonscientific topics, and in other ways.

<u>New Ph.D.-granting departments should be established</u> only where a unique need and adequate resources can be demonstrated.

<u>A systematic study to determine the nation's require-</u> ments for scientific manpower should be undertaken immediately.

PANEL ON PREPARING CHEMISTS TO MEET SOCIETY'S FUTURE NEEDS

<u>The educational community must make major efforts in</u>

curriculum development and in teacher training for the teaching of science and chemistry in the schools of the world so that education in both primary and secondary schools may reflect the broader view required today.

Chemistry departments in the colleges and universities must broaden their curricula to include efforts to make chemistry students aware of chemists' role in society and to sensitize them to society's needs.

The university graduate schools should aid in the development of more flexible graduate programs in which concern for society's problems plays a more explicit part.

The complex, many-headed system of adult education should give particular attention to the problem of broadening the appreciation of chemists, chemical engineers, and other scientists for the needs of society and for the opportunities for scientists to contribute to their solution both within their field and as a component of multidisciplinary attacks.

The federal support agencies can greatly accelerate the capabilities of chemists in societal areas by providing for new programs and more funds in environmental and multidisciplinary areas, while at the same time not neglecting the basic sciences.

The federal agencies with explicit responsibility for social problem areas, such as the Department of Housing and Urban Development, should recognize the central importance of chemistry to the solution of these problems, and should support applied research in chemistry and should equally encourage multidisciplinary research in which chemists participate.

The federal agencies particularly concerned with foreign policy should give increased recognition to the central needs in developing nations for technology transfer and for education of scientists and engineers. Support programs within the universities to fund university science participation are essential, and substantially more use could be made of the capabilities of the science-based industries.

The many state and federal regulatory agencies have a special responsibility to permit and indeed encourage research on new responses to societal problems while at the same time protecting the health and safety of the groups with which they are concerned.

Schools, industries, and government agencies that employ chemists must develop an explicit commitment to assistance by chemistry to the solution of society's problems.

In view of a certain need for more and more kinds of scientists for the solution of these world society problems, employers of scientists should make particular efforts to employ additional women.

The American Chemical Society and, specifically, the Division of Chemical Education, must assume a responsibility for the further studies, encouragement, and fund-raising which are essential to get these many specific programs solidly under way.

PANEL ON CHEMISTRY FOR CITIZENS

In the elementary schools emphasis should be placed on stimulating curiosity and discovery, the participatory "fun-and-games" aspect of science. The inborn curiosity of elementary students should be nurtured by providing an environment that encourages experimentation and investigation.

For secondary schools, a program for producing materials for the study of chemistry from a humanistic point of view should be developed. A diversity of new learning aids will enable teachers and students to emphasize those aspects of the materials which interest them most and need not impress upon them a specific list of subjects.

In colleges and universities, experimentation should be encouraged toward the development of humanistic, in-depth science courses much less committed to complete coverage of chemistry than has been the case in the past.

Courses should be developed that deal with the philosophical and ethical implications of science, as well as with its practical implications, and these courses should be intended for all students in their last years of college.

The American Chemical Society should make special provisions to increase significantly the contact between college and university teachers of chemistry and all teachers of chemistry in the lower schools.

Television programs should be developed that show in simple terms how science solves and creates problems in our world. These would be "shows" emphasizing drama, if necessary at the expense of full logical development.

Case histories of applied chemistry should be prepared by groups of appropriate experts, in the form of well-documented, almost scholarly position papers. The most important function of such position papers would be to serve as the substantive basis for the creation of national television programs.

PANEL ON INTERNATIONAL ASPECTS OF CHEMICAL EDUCATION

Science educators in all nations should participate actively in a reexamination of national goals for development and of the contribution that science education can make to the attainment of those goals.

Education in science, including chemistry, should be extended in all countries, both for technically-trained chemists and for citizens who receive a general and sometimes limited education.

Chemical education should be continually renewed in each country. In view of the steady change in chemistry and other sciences, facilities should be provided in each country for maintaining and improving the qualification of teachers and the quality of teaching materials.

International exchange of information on the improvement of chemistry teaching should be increased and coordinated.

The accommodation of foreign scholars by host countries should be improved. Too often the mentors of foreign students forget that students from less-developed countries will return to an environment which does not correspond to that of the more-developed country.

THE STRUCTURE OF CHEMISTRY

Introduction

The purpose of this report is to attempt to identify what chemistry is in 1970 and what it may be like in the near future. There are a number of reasons why it is important that this attempt should be made. Students all over the world are asking, "Why?", when they begin any course of study. Sensible answers are not easily given. To say that chemistry is fun, that the professional chemist can earn a decent living, and that chemistry together with other sciences is socially desirable does not satisfy thoughtful students. They need to be told what chemistry is so that they can think reasonably about the field.

During the 20 years from 1950 to 1970, we have seen the accumulation of a vastly greater amount of solid, new chemical information than was produced during the century from 1850 to 1950. But there has been no change in the conceptualization of what chemistry is all about even remotely comparable to what occurred during the earlier century. We are, therefore, in the position of claiming great advances during the recent era, and then saying that nothing has really changed.

If chemistry is to develop along sensible and logical lines, it is necessary to take stock of the situation in the field at regular intervals. The fairly widespread uneasiness about the present and future state of chemistry and of chemical education may be due in large measure to the failure of chemists to undertake a critical review of the discipline over such a long period.

During the discussions which led to this report a number of themes appeared. Since chemistry is best described in terms of the things that people who call themselves chemists do, it became clear that there is a relation between chemistry and the way it is taught. This theme recurred throughout the discussions. If chemistry teaching is structured in a particular way, chemistry itself will tend to reflect this structure.

Description of chemistry as the work done by chemists raises problems because of the diversity of the work areas. Some specification of experimental and intellectual methods improves the accuracy of the description. The differences in the ways that chemists themselves see the field show precision definition to be impossible, but also demonstrate one of the strengths of chemistry.

Attempts to identify the factors that have helped to stimulate and those that have tended to inhibit the development of chemistry were particularly rewarding. One of the major factors involved here is that chemistry is practiced by people and that the personal interactions among chemists and between chemists and people in other areas of science may either help or hinder the progress of our understanding of the world we live in.

Another recurring theme was the dynamic character of chemistry. It may not be possible to predict what chemistry will be a decade from now, but certainly it will be different from what it is now. At present, for example, chemists show increasing interest in complex systems, and it would seem likely that this trend will continue.

Finally, we should report that the panelists found the conference to be a remarkable experience. The group was cosmopolitan, coming from five countries, from many kinds of educational institutions and industrial laboratories, spanning a wide range of age and experience, and having extremely varied professional backgrounds. However, the 19 panel members found a wide common ground for discussion and understanding, if not always agreement. Many panelists experienced renewal of their own enthusiasm for chemistry and delight in the realization that broad, meaningful communication with other chemists is really possible. There is no way in which the full flavor of the meeting can be transmitted through the written word, but we will attempt to convey some of the substantive points of discussion in this report.

Scope of the Field

Discussion of the structure of chemistry requires definition of chemistry and its scope. Chemistry, or better, chemical science, is in large measure defined by what is done by people who call themselves chemists. These are, in general, people who teach or were taught in chemistry departments. Despite the obvious difficulties associated with summarizing these activities in a few words, the panel agreed that a reasonable short definition of the scope of chemistry is:

> Chemistry is the integrated study of the preparation, properties, structure, and reactions of the chemical elements and their compounds, and of the systems which they form.

This definition, interpreted in the broadest sense, could include much of all natural science, a consequence of the large and fruitful areas of overlap which chemistry has with the other sciences--especially physics, and the biological, earth, and materials sciences.

As contrasted to a physicist, a chemist tends to work on molecular rather than atomic systems, and on molecular transformations and the related molecular structures, rather than on phenomena associated with simple substances only. Compared to a biologist, the chemist tends to be interested in the details of the structure and properties of the molecules of the living cell, rather than in the total operation of the cell and collections of cells. Thus, chemistry is uniquely a "molecular science," and the viewpoint of the chemist and his approach to understanding natural phenomena is concerned with molecular models in most instances. Of course, there are well-known exceptions to the above description of chemistry. Indeed, the ability of chemists to extend their activities into other areas of science is evidence of the vigor of the subject.

Chemical science is dynamic in scope. An important aspect of the overlap with other fields is that many chemists find themselves working in areas currently described as interfaces; for example, molecular biology and solid state physics. In fact, some of the most exciting areas of research are at these changing interfaces with other disciplines. However, we know that interfaces are often absorbed and become an integral part of the science. Examples are nuclear chemistry, quantum mechanics, statistical mechanics, and magnetic resonance. As a consequence, those subjects considered central to chemical science both in terms of education and practice change with time. Thus, we feel that it is detrimental to define the scope of chemistry narrowly, since to do so can restrict chemical science from developing in important nontraditional areas. The growth of chemical science will best be stimulated by avoiding restrictive definitions, both in its relations to other sciences and in its own substructure.

An increasingly important part of chemical science at this time is the use of chemistry in analysis and modeling of complex systems. It is possible that in the near future some people will choose to call themselves "systems chemists." The concept derives from systems analysis, an approach now associated primarily with engineering science. The behavior of many complex systems -- a rocket motor, a living cell, a polluted atmosphere -- depends critically on chemical properties and chemical reactions. Combination of the growing competence of both systems analysis and chemical science will make the two tools increasingly compatible for use in broad attack on some of man's most challenging objectives.

Theory and Experiment

In chemistry, as in all sciences, we are frequently bedeviled by the confusion which exists between the terms we use; for example, "description" and "explanation" or "hypothesis" and "theory." Furthermore, the term "model" has hidden implications which are not always appreciated. The ways in which people in various disciplines inside chemistry itself interpret or use the above terms are so diverse that difficulties of understanding and communication arise. Indeed, initially at least, there was no common ground among all members of the panel on the use of these terms.

Since the structure and development of chemistry has been strongly influenced, if not largely determined by the patterns of thought intrinsic in the theories of chemistry, it is obvious that a discussion of the role of theory and experiment as part of the structure of chemistry is essential.

In chemistry, whether the goals are the synthesis of a new substance or the investigation of properties or principles, all directed explorations spring from various theoretical pictures. This is, of course, simply the application of the scientific method. The way in which chemistry may differ from other physical sciences lies in the nature of the theories involved.

By and large, the underlying basic theory of chemistry is already well established. Thus, no longer at issue is the molecular basis of the subject. Interactions between constituent particles in molecules are governed by the laws of quantum mechanics, while the properties of large aggregates at a molecular level are described, in principle, by statistical mechanics, and transformations on a macroscale conform to the laws of thermodynamics.

As is well known, however, the great difficulty in applying these laws to real situations may render them of marginal (or limited) value for the practicing chemist. He is forced therefore to adopt thought processes, or mental constructions, which we shall refer to as models, to guide his thinking. These may assume a mathematical form or they may be completely qualitative. Mathematics is a language for expressing relationships in a quantitative manner; as used by physical scientists it is not intrinsically theoretical of itself.

The really characteristic feature of a chemist is his ability to make these models experimentally productive. He hopes that they will have some measure of physical significance but he insists that they serve a useful role as guides.

Of course, we do not wish to undersell the importance of serious, profound, and elegant theory. The study of the correlation between a priori theory and experimental results is an integral part of the structure of chemistry. Inasmuch as this is well known, we have chosen to dwell here in more detail on the less frequently emphasized role of theory and models, and on their strengths, weaknesses, and methods of invention and application.

It matters little whether a particular model has any lasting merit. Thus, a rejected theory (e.g., the phlogiston theory) may have been of considerable value in the development of a subject if at one time it provided a satisfactory correlation of available experimental data and enabled people to propose more experiments.

Another aspect of models which needs to be borne in mind is the value of those which are easily used and quickly lead to an appropriate answer. Thus, if one wishes to guess the shape of $SeOCl_2$, the electron pair repulsion theory immediately enables one to conclude that it is a pyramidal molecule. One must be careful, however, not to push a simple model too far in order to obtain better agreement with experimental results if the degree of refinement becomes inconsistent with the simplicity of the model chosen.

We have probably underemphasized in our teaching the enormous help provided by model building in stimulating new experiments. Yet, we may have been equally remiss in failing to expose the transient nature of many of the fashionable schemes put forward for the interpretation of data.

We also note that chemists have a strong tendency on occasions to play trivial games, dwelling for too long on what are essentially loose ends in fashionable areas. This intellectual rigidity leads to many largely predictable results, the research simply being a pedestrian extrapolation of previous investigations. This syndrome can be circumvented only by seeking areas where there is a need for invention of new models.

We must recognize that the focus of attention on a single model may seriously inhibit chemical advances. It has been said, and not without a grain of truth, that the factor which distinguishes a chemist from a physicist is that the former argues from 100 weak facts, whereas the latter argues from one strong fact. Without pausing to comment critically on the risks involved in placing too much reliance on one so-called "strong fact," we must concede that chemistry may be a less straightforward subject than physics. The ultimate molecular properties are inferred from indirect measurements, so evidence from many different sources is essential. The emphasis on a single model may, in fact, distract an investigator from achieving his goal of building better models for molecular behavior.

Another role of models that may be underemphasized in education is suggested by the frequent allusions to "accidental discoveries." There is no denying that unexpected results of experiments and accidental manipulations have led to many important discoveries in the same or nearby fields. However, the recognition of a novel occurrence is the recognition that a result conforms poorly with the model used, be it intuitive or explicit. Serendipity cannot happen to those unschooled in the interpretation of facts. Anomalies are easily rationalized by the uninitiated as experimental errors or as unremarkable variations from the norm. All of us are aware of the more pretentious models in fashion at a given time, but these are only rarely the most important models useful for interpretation of a given problem. In teaching, we must strive to reach not one but a number of alternative interpretations of known phenomena in the hope of enlarging the horizons and sharpening the perception of our students.

Having emphasized the crucial role of models in shaping science, we would risk sabotaging any value of this discussion if we created the impression that the model is the final goal or the most esteemed outcome of our efforts in chemistry. The model is the sine qua non of an advance in a field, but has no value except in the context of facts that it correlates. A teacher cannot impart any significant flavor of the model without considering some of the facts; and a student must recognize the absurdity of thinking that a chemist will ever develop a facility in formulating models useful in his field unless he acquires a sound and comprehensive knowledge of facts in his field of investigation. Real success in training students can only be achieved if we are able to continuously blend theoretical and descriptive chemistry. That these two mainstreams sometimes seem to flow in opposite directions may well be due to our common tendency to recognize only a small fraction of chemical model building as theory, and to ignore the rest.

Factors that Stimulate and Inhibit Development

Advances in chemistry typically occur on narrow rather than broad fronts. Following seminal experiments or new concepts in a particular area there is often a rapid proliferation of our knowlege concerning it. This intensive study is not indefinitely productive and can detract attention from other areas in which important advances can be made. We feel it is important to identify now and on a continuing basis those factors which may act to stimulate or inhibit important advances in chemistry. We considered three aspects of chemistry: the education of chemists, the practice of chemistry, and the support of chemistry by government and other groups. Several factors appear in each case to influence development.

The most fruitful chemical endeavors are probably best described as adventurous. Virgin areas are explored for which current models and theories are often inadequate, some risks are taken, and a largely uninhibited approach is taken in the development of new models. The conservative approach in which known models or theories are refined and improved, though necessary, is often less important in advancing the field. In education we should encourage a creative and adventurous approach to problems, and we should provide for the practicing chemist an environment in which these attitudes will flourish.

Analysis of what methods and attitudes aid advance in chemistry is made difficult by the tendency of chemists to justify their findings as an illustration or test of a simple model rather than stating candidly the original motivation for the work. We generally agree that simple models do motivate and inspire experimental and deeper experimental work, and that in healthy situations the results of experiments are used to make useful modifications of the model. In these activities a certain rigor is required. Here we encounter a dilemma in both teaching and research. Rigor in testing a model is properly associated with work of high class; and the rigor can take many forms, such as careful experimentation and intellectual analysis or detailed and accurate mathematical formulation of the model coming from the work. Emphasis on this aspect of science can, however, lead to the assumption that rigor and good science are synonymous. Rigor for its own sake is totally sterile; elegant mathematical development of bad theory may make it worse, and some work done in the name of experimental rigor may become meaningless ritual. The exalted ideal of rigor may be a repressive influence, since truly adventurous research may hold little promise of results that can be quickly fitted to conventional rigorous treatment. Scrupulous honesty in teaching is required to show students the excitement and value of beginning new work and bringing it to a level of rigor appropriate to the models being tested.

To attract good people into chemistry the first course should expose the student to the exciting problems studied by chemists today, and the likely nature of future problems. Subsequently, we should encourage the student to be versatile and give him confidence in his ability to solve problems independently rather than attempting to teach him large numbers of specific facts, theories, or techniques. An important aspect of this is to give the student an appreciation of the roles of theory and experiment in the scientific method and an understanding of the role of serendipity in advancing chemistry. To achieve these goals requires a rather loosely structured curriculum to allow the pursuit of individual goals.

For pedagogical purposes some structuring of chemistry seems necessary, even though structure may inhibit development, particularly individual application of chemistry. This structure should serve for learning and understanding rather than create obstacles to growth and application. The classical structure of organic, inorganic, and physical chemistry, which has largely determined how chemistry was taught, increasingly fails to reflect what is actually done in chemistry. Inorganic and organic chemists use and contribute ideas and methods traditionally associated with physical chemistry. This breakdown of the traditional divisions can be seen as a healthy sign, since a chemist should not be inhibited from exploring a problem or idea simply because it is "not in his field."

Competition of ideas does much to generate enthusiasm and provides an important stimulus to research. However, collaboration between chemists, or between chemists and other scientists having different backgrounds and viewpoints, has been particularly effective in solving problems and in generating new chemical ideas. Such collaboration is sometimes inhibited by intolerance. Intolerance can appear in chemistry in conflicts of personality between individuals, in the attitudes of "physical chemists" toward "organic chemists" and vice versa, in the attitudes of industrial and academic chemists toward each other, in the attitudes of chemical educators and research-oriented academic chemists toward each other, or in the attitudes of chemists toward scientists in other fields. We feel that increased communication and broad-based chemical education help to eliminate this problem. Our own experience in the panel discussions indicated that a search for the common goals and characteristic thought patterns in chemical science can be a stimulating educational experience.

The Substructure of Chemistry

We discussed at some length the matter of substructure within the discipline. The traditional substructure of physical, organic, inorganic, and sometimes analytical, chemistry has natural origins in the past activities of chemists, and in large measure continues to determine how chemistry is taught. However, it does not now always accurately reflect or encompass what is actually done in chemistry. "Inorganic" and "organic" chemists increasingly use and contribute to the ideas and methods traditionally associated with "physical" chemistry. Moreover, people trained as chemists make frequent and important contributions in areas which overlap strongly with physics, biology, and earth and materials sciences, and which may involve activity in and application of all of the traditional subfields. This breakdown of old divisions and expansion beyond old boundaries is certainly a sign of the health and vigor of chemistry.

The strong interaction between inorganic, organic, and physical chemistry raises the question of whether another organizational scheme would be preferable. We agree that desirable features of alternate plans of substructure would be that they should aid in the organization of instruction in chemistry, reduce parochialism and increase exchange of ideas among all chemists, and facilitate application of chemistry to complex interdisciplinary problems. An alternate classification should recognize the scope of chemistry in its broadest aspect, and offer easy accommodation to all fields of chemical activity.

With these points in mind, we have reexamined the traditional substructure of chemistry and some alternate modes of reorganization. The suggestion that chemistry be subdivided into the areas of structure, dynamics, and synthesis does offer the opportunity to encourage a broader viewpoint among chemists, but this subdivision may have difficulty in maintaining the unity of such a well-organized subject as chemical thermodynamics, or in accommodating such special areas as solid state chemistry or macromolecular chemistry. We also discussed a very similar tripartite subdivision into: the structure and physical properties of pure substances, chemical transformations, and the application of chemistry to complex systems. Spectroscopy, diffraction methods, and other structural techniques fall into the first area, together with the measurement and elucidation of such things as phase transitions and mechanical, thermal, and electrical properties. The area of chemical transformations encompasses reaction kinetics, thermodynamics, and synthetic techniques and methods applied to both systems. Application of chemistry to complex systems can include such fields of current activity as biochemistry, molecular engineering, materials science, and geochemical phenomena. This classification has the merit of explicit inclusion of chemical systems analysis, which we believe to be poised for rapid growth.

In examining these schemes and modifications of the traditional substructure, we have found some definite similarities between the various modes of organization. We have noted that there are several areas of chemical activity which extensively overlap two or more subdivisions of any particular scheme. Moreover, we anticipate that as chemistry evolves and is applied to more complicated problems, the most effective work will involve integration of any substructure. Any scheme could fail if rigid interpretation of its structure leads to isolating areas of chemistry from one another. These observations make us unwilling to suggest that any one plan of organization is or will be clearly superior to all others. Instead, we urge experimentation with all well-conceived substructurings of chemistry that offer aid to instruction, increase in interaction among all chemists, and extension of the boundaries of chemistry, and which facilitate the application of the subject to complex problems.

The Structure of the Support System for Chemistry

We concerned ourselves primarily with the system of support for activities at the postgraduate and research level, recognizing that support at the undergraduate level is largely controlled by general, national educational policies and that chemists can make only a very limited case for special treatment within these policies.

The great proportion of the funds for the support of departments of chemistry comes from the following sources:

1. The parent institution, which in turn derives its funds from various sources.
2. Local and central government agencies.
3. Commercial organizations, especially the chemical industry.
4. Charitable foundations.

In most, if not all countries, the great proportion of the support comes from government agencies, and this proportion is likely to increase.

The overall magnitude of the support which comes to a department of chemistry is the major influence in determining:

1. The number of faculty, research workers, and students.
2. The standard of equipment of the laboratories.
3. Mainly as a function of 1. and 2., the scale and scope of the research which can be undertaken.
4. The scope and diversity of the educational program at the undergraduate and postgraduate levels.

Support from the sources listed may come either to a university department as such or to individuals or groups of individuals within it. The pattern of individual support can clearly exercise a substantial influence on the balance of the various research activities within a department and may limit the extent to which the department as a whole can maintain a planned balance of such activities. We are divided on the desirable weighting of departmental as distinct from individual support. Members of the panel from outside the U.S. prefer a system under which the bulk of the support is given to the department, so that the department is able to:

1. Provide centrally common research services, including expensive instruments which are essential to the effective prosecution of the great proportion of research in chemistry today.
2. Maintain a steady development of its established research activities which it considers to be

flourishing and fruitful, and to move resources in a controlled way to those activities which it considers to be most promising.

3. Support a research area which, although it might not readily attract outside funds, is thought to be a valuable complement to the other research activities in the department.
4. Generally maintain a balanced program of research such that, as far as possible, each field of activity contributes to the health of the others, to the benefit of all of them.

Under this system, support to individuals or small groups is given for the initiation of new research activities which are of exceptional timeliness and promise, and which are sometimes necessarily highly speculative, and for their development to the stage at which they can, if appropriate, be absorbed into the general balanced program of the department. Panel members from within the U.S. generally prefer a system heavily oriented toward external support of individuals or small groups, believing that outside assessment of research projects is more likely to ensure that any specific research project within a department is more likely to receive the share of the funds which it merits in terms of its scientific potential.

Funding by external agencies, especially government agencies, exerts a powerful influence on the balance of research activities not only at the departmental but also at the national level. This influence can be unplanned, and determined largely by current scientific fashion, or undertaken as an act of policy. The latter is especially the case when the agencies purposefully direct their funds toward general areas which they consider to be either of outstanding scientific potential or of exceptional social or economic relevance. It is thus essential that the distribution of funds by these agencies should reflect the advice of thoughtful, well-qualified scientists, who command the intellectual and personal respect of the scientific community. Furthermore, the membership of the committees should change with reasonable frequency in order to prevent undue influence by particular individuals or groups.

Any support system should have the following additional features:

1. It should recognize, and provide planned support for, the following categories of activity within chemistry departments:

   a. The training of chemists at all levels. (Adequate funds should thus be provided for student scholarships and fellowships and for the maintenance and development of teaching programs.)
   b. The development of the science of chemistry.
   c. The contribution of the research to the development of other fields of science and to the solution of problems of social and economic importance.

2. Its funds should not be subject to severe fluctuation over short periods, since the sudden withdrawal of funds has highly undesirable effects on the balance of research activities and can also lead to substantial personal difficulties among chemists and to a general weakening of morale. A basic level of funding should be planned and assured over, say, a five-year period, with supplementation as national needs require and commercial prosperity permits.

3. It should ensure that there is at least a minimum satisfactory level of general equipment and research services within a department.

4. It should be able, in addition to providing adequate support for the development of the work of established scientists, to identify the young scientist of outstanding promise. In both cases it should be able to give the exceptionally able scientist a good degree of freedom to follow his own ideas as they emerge and not tie support entirely to detailed programs specified in advance.

5. It should provide some support, probably rather limited in scale, for the maintenance of research activities within departments in small institutions which are oriented heavily toward undergraduate teaching, in

order to maintain the vitality of that teaching; this should be done even when the research programs might not in themselves command support in competition with projects in the large research departments.

6. The existence of several funding agencies to which the individuals or groups can apply provides a safeguard, since support of projects is not subject to the fashion which may prevail within any one agency at a particular time. (On the other hand, some of us have reservations because duplication of function may be overly costly, especially in times of economic duress in science.)

Support from private organizations, while relatively small in scale, is of great value. These bodies may recognize scientific, educational, or social merit in projects which might not appeal to government-financed agencies. Furthermore, such support provides a buffer against the influence of short-term political decisions on the scale and direction of public funds.

Irrespective of their intent, grant-awarding bodies exert a profound influence on the structure and development of science as a whole, including chemistry. The persuasive ability of agency representatives has an effect on the total amount of money made available by government. Decisions as to whether emphasis will be placed on institutional or individual grants are usually formulated within the granting bodies. Finally, judgments as to priorities within fields are usually made by the agencies and their advisers from the scientific community. Within any field the balance of emphasis in questions such as sophistication versus naive innovation are largely controlled, sometimes unconsciously, by granting bodies.

Some of us are concerned about the practice of allocation of grants on the basis of "scientific merit alone." This criterion is so correct in principle as to be almost unassailable. In practice, we must always ask, "Who determines scientific merit?" The general tendency in both the U.S. and the countries of western Europe to turn for advice to outstanding scientists in a discipline is probably the soundest possible procedure. Yet, we must grant that even this procedure has weaknesses. An outstanding scientist is almost surely subject to bias, as are all people, and is likely to see special merit in work similar to his own. If he did not see such value, he would probably be doing other work. We can only wonder as to the extent to which this subtle influence has been partly responsible for some of the elegant repetition now seen in chemical research. If this is a problem, we offer no easy solution, but believe its existence is worthy of note.

The Condition of Chemistry in 1970

The understanding and application of chemistry as a molecular science has accelerated rapidly over the past 20 years. Fundamental concepts in atomic-molecular theory have been extensively developed with only minor changes contemplated in the future. The basic postulates of electromagnetism and quantum mechanics are applied with increasing accuracy. Chemical bonding and molecular structure are now interpreted on a sound scientific basis. Many chemical applications of molecular behavior are sufficiently advanced so that chemistry and chemists have become a vital factor in the growth of interdisciplinary areas such as chemical physics, molecular biology, polymer science, solid state science, and materials science. These illustrations demonstrate the breadth of application which sophisticated chemistry has achieved, and there is every reason to anticipate that the understanding and extension of chemical concepts will continue to grow in the foreseeable future. The broad application of the molecular aspects of matter, classically identified as chemistry, can probably now be better described as chemical science. This term denotes the extensive intrusion of chemical concepts into areas not traditionally identified as chemistry.

Parallel to the rapid expansion of chemistry noted above, one finds significant areas in which chemical understanding is in its infancy. Among these are the in-depth understanding of reaction dynamics, of biological materials as chemical systems, of chemical synthesis, and of the preparation of substances to meet the demands of engineering and medicine. The creation of even small molecules of doubtful existence and peculiar bond type illustrates the continued vigor of structural and synthetic chemistry.

Chemists should be, and are becoming, increasingly willing to devote their energies to the analysis and study of total complex chemical systems in the areas of biology and engineering science. A growing number of chemically trained scientists in both industrial and academic research laboratories are working in the broad interdisciplinary area which may soon be known as systems chemistry. Chemistry has utilized basic concepts originated by other scientific disciplines and has thus been a key factor in the rapid development of electronic and optical instrumentation as well as computer science.

The importance of chemical science to the advancement of society has always provided an important role for the chemist and has also been acknowledged by society as a whole. Increasing public concern about national priorities such as the environment, urban development, and other internal problems has led to an increasing challenge of the direction and value of science. This attitude is particularly prevalent among young adults and students. The impact of this group of citizens on the direction of national policy will surely increase in the future. Chemical science appears to be capable of meeting this challenge.

Earlier predictions about the demand for chemical scientists in 1970 considerably overestimated the real employment opportunities in the U.S., Australia, and some other countries. Many promising young chemistry graduates at all levels were hard pressed to find jobs consistent with their educational backgrounds and interests. This problem appears to be related to the unexpected changing of national priorities previously mentioned and consequent deviation from the usual linear extrapolation based on a steady rate of growth of the economy. We feel a degree of optimism for better employment opportunities in the near future was expressed, although we are far from unanimous. Generally, we feel that students with attitudes and/or experience in the area of systems chemistry are among the most employable. This is reflected in the fact that the general slump in the job market in the U.S. has not yet been felt as severely in chemical engineering as in most other fields.

Although chemistry has prospered under the classical substructures of organic, inorganic, physical, and analytical chemistry, it is evident that an era of change has already begun. Based on this traditional classification, biochemistry appears to be replacing classical analytical chemistry as a separate discipline. However, a rearrangement of subdivisions must evolve, with new fields playing an important role. Changes have already been made in many undergraduate curricula and in industrial laboratory organizational structures.

During the 20 years preceding 1970, much chemical effort was devoted to second and third generation research studies of concepts which were regarded initially as fundamental breakthroughs. Frequently, these studies have added little in extending our knowledge of chemistry. Although one can never predict with certainty the true value of any research, in many cases little of real value comes out of these second and third generation studies.

Whether this type of research is a product of our educational system or a negative factor strongly affecting it is not clear. However, it is important to note that we teach our students about questions which were the great problems of science in the classroom and dwell endlessly in the research laboratory on what appears to be finding solutions to minor problems that at best add little to a better understanding of the field.

Despite some of the sobering reverses of the past two years and some signs of senility, the general state of chemistry in 1970 permits guarded optimism. A powerful research capability has been built up in universities, technological industries, government laboratories, and research institutes. The level of capability varies widely among countries, but the international research establishment is far more powerful than it was 20 years ago. Although it is not found in every laboratory or classroom, the spirit of outreach and adventure in chemistry are still alive. The proponents within the panel state that we are entering a "golden age of chemical dynamics," and others look for great new things in other currently undeveloped parts of the field. We see signs of decrease in chemical parochialism, and many young chemists are moving out of their traditional molds. We believe that 1970 will become known as a year in which chemists realized the need for self-renewal and, on looking, found that it was already occurring.

Summary

The full scope of chemically-based science and technology is enormous. The thought and experimental methods developed within chemistry have grown to a stage of maturity that allows them to become useful tools for analysis in biology, geology, and many branches of engineering. There is also significant flow into solid state and low temperature physics, where understanding of chemical structure often provides shrewd insight in the choice of materials for phenomenological studies. Both knowledge of the structure and properties of materials and the intellectual approach of the chemist, most succinctly illustrated by use of the molecular concept, contribute to this outreach of chemical science.

During the past 20 years, chemical knowledge has increased even more rapidly in the traditional areas of the science than at its periphery. This rapid growth is both a matter of pride and a source of a principal problem at present. Some areas of the science that provided great challenge 20 years ago have now been so thoroughly exploited that work in those fields now becomes little more than elegant refinement. We must frankly face the fact that a substantial portion of modern chemical research, in both academic and industrial laboratories, produces elegant solutions to smaller and smaller problems. Other related problem areas remain in their infancy; for example, the correlation of structure with macroscopic properties of matter. Furthermore, all too few chemists really appreciate the opportunities for them.

There are factors that stimulate development and others that are inhibitory. The system of chemical education itself is responsible for both stimulation and repression, since ideas about what can be done or not done are partly shaped by the educational experience. Most undergraduate curricula are traditional and lack coordination, leading to an image of the field as far less coherent than is really the case. Certain attitudes that are deemed to be characteristic of the various subdisciplines are accepted almost as a matter of ritual, impeding communication within the science. We can see real merit in reclassification of the broad areas of chemical activity as a means of rethinking the goals of the science itself, and as a means of showing students the stream of chemical progress, rather than the eddies in that stream. Whether or not the classification scheme based upon structure, dynamics, and

synthesis is the best at this time is left an open question. Probably other plans of equal or greater merit can be found and explored to replace our present system.

Chemists in the United States, and in varying degrees in other countries, are increasingly alarmed by the present unstable and unpredictable support of the science. Instability is shown by the decrease in government funding for basic research, by a slump in the job market, by self-doubt within the chemical industries about their own research and development programs, and by disillusionment about science in the society and especially among today's students. We must recognize that the structure of the field will inevitably be influenced by the demands of the society for our products, in the form of both people and knowledge. However, to panic in the face of current problems, or to attribute our problems exclusively to the society around us, would be folly. The potential of chemistry to contribute to increased understanding of man and his world is so great that we must believe in ourselves and our future. Movement into a new era of chemical science must involve self-renewal that will be fascinating, but also painful. We hope that review of the structure of our field in 1970 will help make the next decade one of useful change and continued progress.

Recommendations

Various new methods for the organization of chemistry, both for teaching and publication, should be investigated. Examples include structure, dynamics, and synthesis; and the structure and physical properties of pure substances, chemical transformations, and the application of chemistry to complex systems.

Chemical education must be continuously reviewed in the light of the development of the science to ensure that students learn what the real challenges now are, rather than what they were some time ago.

Significant experimentation with many new forms of curricula should be actively supported by chemists, universities, and the federal and state governments.

Chemists and their representative chemical societies must strive for better projections for the future. Included must be attempts to see developing trends in pure and applied science as well as manpower needs. Although technological forecasting is not a highly developed field, chemists must be aware of possible implications of social and economic trends as they plan for the future.

While the growing involvement of chemistry in technological aspects of the solution of societal problems is to be commended, we must at the same time preserve a progressive program of basic research.

The individual chemist should ask himself whether his work is significant for the development of chemical science or other branches of science and engineering, or endeavors of mankind. The desire to be "relevant" in some way is not the only legitimate motive for research, but is a factor of sufficient significance to warrant evaluation on an individual basis.

A more stable, basic support level for chemical research and education is needed in the United States and some other countries to ensure steady progress and to avoid waste of human and physical resources.

International study of the advantages and disadvantages of the various systems of support in different countries is needed.

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GRADUATE EDUCATION IN CHEMISTRY AND BEYOND

Introduction

Chemistry has long played a central role in the growth and welfare of our society. The ability of chemistry to serve these objectives depends, of course, on the productivity of people who have devoted their careers to this important branch of science. These careers owe their origins to the quality of chemical education. It is therefore essential to examine from time to time the objectives and performance of chemical education at the graduate level, and the effectiveness of careers in the years beyond the university.

Recommendations

New types of graduate programs, coupled to the changing horizons for the chemical sciences, must be developed and implemented to augment the traditional responsibilities of graduate education.

New awareness of opportunities for leadership by chemical scientists must be created. This can be done by broadening graduate chemical education to allow and encourage inclusion of related scientific and nonscientific topics; urging that postdoctoral research experience be different from that of the Ph.D. thesis; increasing the industrial involvement in education at both the graduate and postdoctoral levels; and expanding programs for continuing education for academic, industrial, and government chemists.

New Ph.D.-granting departments should be established only where a unique need and adequate resources can be demonstrated.

A systematic study to determine the nation's requirements for scientific manpower should be undertaken immediately.

The Expectations of Society

Through funding by tax-supported agencies and other organizations and through tuition payments, society makes a major commitment to chemical education. In return, society has the right to expect some important dividends. Among them are the production of trained manpower required for the growth of our economy, training of competent faculty members for all sectors of our educational system, and enrichment of human knowledge through basic research and scholarly endeavors.

The Graduate Program

The heart of graduate education in chemistry is the doctoral program. It has had tremendous success in producing creative, innovative people. It has been central to the acquisition of new knowledge and has deeply probed the structure, properties, and behavior of matter. The American approach to doctoral education stems from the European systems and exhibits great vigor and productivity. The fundamental science thus derived is basic to our understanding of nature and to pioneering efforts and long-term growth of chemical technology and thus is essential to the public welfare.

The need for vigorous graduate programs in fundamental chemistry will surely continue. The Ph.D. students trained in such rigorous programs will be the leaders in pure and applied chemical sciences in the coming decades. Experience has shown that many trained in these programs will hold important jobs in industrial management and government.

How might the present graduate program be strengthened? With the profound growth in chemical knowledge, the Ph.D. degree has moved toward narrower specialization. A concern for the future is to modify this trend by increasing the breadth of permissible Ph.D. programs, both within the broad scope of chemistry and by the study of other disciplines. The rapid growth of science and technology has created even greater demands for adaptability over both the short tern and the long term. Added breadth would lead not only to a greater capability for careers in chemical sciences, but also to greater overall flexibility.

Improvements can be made through conscious awareness of the need for adaptability, specifically through the planning of course structures and curricula that expose the student to basic information in other fields. We should examine the interfaces between chemistry and related sciences, so as to improve the interdisciplinary character of chemical training. This is not to say that we should abandon rigor and quality for the sake of diversification; strength will not exist in these new programs in the absence of quality.

Another way to strengthen the present graduate program is to provide a higher level of contact with practical problems. Continued deliberate efforts in that direction should lead to a greater appreciation by students for the relevance of chemistry to the welfare of society. At the same time, it should better prepare them for nonacademic careers, which promise to provide in the future a larger fraction of the employment openings in the chemical sciences.

Postdoctoral Studies

It is essential that informal study be carried on by every serious scholar throughout his career. A formal program of full-time postdoctoral study at a university, however, has become a frequent component of the educational program of the student who seeks an academic career. A common path for the student has been to pursue an advanced program in the field of his doctoral research. Such studies will continue to be important for the exploitation of new discoveries and of advanced scholarship, and for the in-depth training of new students in topics and skills of great sophistication.

However, the postdoctoral experience also carries with it an unusual opportunity for broadening the student in areas of research other than that in which he received his doctorate. As noted earlier, the continuing growth of the chemical sciences makes it increasingly important for chemists to be endowed with diversity and flexibility. Because people tend naturally to specialize and become experts in increasingly narrow fields, deliberate attempts are needed to counteract that tendency. We urge strongly, therefore, that a large fraction of students aspiring to postdoctoral studies be advised to undertake work significantly different from that for which they received the doctorate.

Research advisers should accept the responsibility of advising students to seek new fields of endeavor for their postdoctoral studies. On occasion the shifts might be outside the field of chemistry, but more commonly they would be within the general area of chemistry. They might provide creative attack on important problems that otherwise would be overlooked. Moreover, the funding agencies might recognize these needs and earmark a significant part of their allocations to programs aimed at diversification.

Industrial and governmental laboratories can also contribute to diversification by making available, on a larger scale, postdoctoral programs for students seeking to broaden themselves. For the person who contemplates an academic career, such a program could provide a new dimension in his experience. For the industrial or governmental laboratory, this activity provides the stimulation for new and invigorating ideas.

Education of Practicing Chemists

The extraordinarily rapid growth of science and technology during the past two decades has produced demands for corresponding growth on the part of scientists and engineers. Technological obsolescence in such people seriously hampers their effectiveness and places a costly burden on our national resources. An important source of obsolescence arises from the practicing scientist losing touch with the forefront of his field, through the demands of other activities or through neglect. A related problem arises when the individual finds himself reassigned to a new activity. The critical importance of this general problem has led to the development of major programs of continuing education in many parts of the economic sector, especially in chemistry.

It is clear that the individual has the basic responsibility for his own continuing development. It is not enough for him to be receptive to new knowledge; he must have the necessary drive to seek it out. The employer, however, has the responsibility for providing a work environment that encourages the individual to keep in touch with his profession and for making it possible for him to pursue his education on a current basis. Universities and professional societies must also provide opportunities for this learning process.

For the industrial employer, the question of obsolescence of staff is in part an economic matter. Many industrial employers clearly recognize this and have instituted extensive programs of continuing education during working hours for their people. Participation in such activities, although commonly a voluntary matter, is nevertheless strongly encouraged by the employer. Furthermore, the obvious message is transmitted that the long-range welfare of the individual depends strongly on his ability to remain current with his profession. Nevertheless, there is great need for much more of this sort of activity.

Such educational programs can take many forms. In some instances they consist of informal study groups which get together during working hours to spend a period of time on suitable topics. Of more general effectiveness, however, are programs of continuing education that are developed on a more formal basis. One type is the organized course, either short-term or long-term, that is presented either by members of the company's own technical staff or by university faculty. A second type is a short course in the program of the American Chemical Society; these courses are particularly effective in presenting topical instruction of importance for current work in chemistry. The American Chemical Society occupies a role of leadership in continuing education, but it is clear that the need for these programs is large and that such efforts should be expanded.

An important segment of the professional community consists of teachers in four-year and two-year colleges. These individuals often have very limited opportunity for the stimulation available to those in major universities, and they face a discouraging prospect of obsolescence in their assignments. The question of how to maintain vigorous interest and competence among such teachers is important to the nation's educational resources. Programs of summer study, like those sponsored by the National Science Foundation, provide such a mechanism for maintaining interest. In addition, many liberal arts colleges provide leaves of absence for members of their staff so that these people may seek the refreshment of scholarship. It is clear, however, that the nation should pay greater attention to the needs of its teachers, especially those in two-year colleges, where teaching loads are unusually heavy and academic leaves are virtually nonexistent. Academic institutions must recognize, in their own interest, that the continuing education of their faculty is an integral part of their operating costs. Even in a major university an active research chemist may become increasingly expert in his field but be unaware of opportunities for making contributions resulting from his knowledge of recent advances in related areas. Hence, university chemists are urged to take academic leaves that will expand their breadth. When special competences are available in industrial and governmental laboratories, those opportunities should be considered as seriously as those in universities.

The Role of Industry

Research in the chemical industry has benefited greatly from the fundamental knowledge derived from academic research and from the teaching functions of colleges and universities. At the same time, industries have made significant contributions to education in several areas. It is highly important that communication between industries and universities be broadened and made more effective, for both communities share a concern for the welfare of society through science and technology.

In the advancement of knowledge, industrial research has been a major contributor. The important areas of communications, computation, energy production, pharmaceuticals, plastics, and transportation are examples of fields in which the main thrust for discovery has come from industrial research. A large body of teachable knowledge has emerged from work in these and other industrial activities. Much of this information has not reached the classroom. Although the full communication of such knowledge must be limited by proprietary considerations, still there is great potential value in improvement of the communication between industries and universities.

A very effective method for bettering such communication is the exchange of personnel between industries and universities. Such interactions already occur to some degree, through visits of seminar speakers, with the short-term employment of research scientists from one scientific community in the other, and through the postdoctoral fellowship programs already referred to. These interactions are highly effective in improving understanding and cooperation; they should be greatly expanded, with imagination and mutual good will.

Because of the important role played by universities in training the chemists employed by industries, there should be increased effort on the part of industry, in these times of difficulty for the support of education, to make meaningful contributions to the sustaining of important academic research.

Response to Changing Horizons

Chemical science has come through a period of enormous growth in the past two decades and will see major changes in the decade ahead. Important areas of public concern, such as the broad field of environmental quality, will impose new challenges and responsibilities on all of science, and upon chemistry in particular. Advances in related sciences will develop research activities that overlap those of chemistry. In the face of this future, it is vital for those involved in chemical education to examine the goals and objectives of chemical science and to seek opportunities for leadership. The unique role of fundamental research in chemistry must continue; this will extend the basic knowledge which is vital for progress in many areas of science. However, if chemists fail to respond to new challenges and retreat from opportunities to provide leadership, chemistry will progressively become narrower in relative importance and more remote in relevance.

To respond to these expanding horizons, chemistry departments should continually examine what they teach and how they advise students. While stressing the importance of continued strength in basic chemistry, planners should recognize that flexibility and diversity are vital attributes for those who must deal effectively with problems in a changing world.

Identification of new areas of importance will lead some institutions to develop advanced interdisciplinary programs of instruction and research or to identify new areas of emphasis within chemistry. This evolution may lead in some cases to the need for new kinds of recognition in the form of professional degrees, but the development of new symbols of achievement must be the result and not the purpose of new programs of education. The significance of the Master's degree is not adequately defined at present. The future of this degree will lie in the recognition of needed programs and specialized competences.

Whether a department decides that a new venture is appropriate to its interests and competences will, in the last analysis, depend upon the commitment of individual members of the staff. It is likely that many multidisciplinary activities will be beyond the capabilities of an individual and will demand contributions from groups. Chemists, however, have broad capacities to give leadership to such activities.

Manpower Needs

The employment picture has plainly changed in recent years, and there is considerable ferment over the state of graduate education and professional careers. It is clear that the expansion in employment and research support in the next decade will be substantially less than in the past decade. These changing patterns are not peculiar to chemistry, but are common to all of science and much of the rest of our society.

It is difficult to predict reliably the role of chemistry in the years ahead. Nevertheless, the development of such information is fundamental to wise planning of the nation's resources. From various quarters it has been proposed that a systems analysis of the total problem is needed to develop adequate understanding. Such an analysis would presumably occur under the leadership of a scientific body such as the National Academy of Sciences or the National Science Board. We recommend strongly that the American Chemical Society take an active role in such a study.

In the face of a decline in the rate of expansion in employment and research support there is cause for concern over the proliferation of graduate schools. This growth has resulted from the fact that institutions without graduate programs feel compelled to increase their academic stature by embarking on programs of advanced study. It is clear that the leaders of institutions which contemplate such expansion should give the utmost care and thought to starting new programs. Although there may be special needs for expansion in particular geographic areas, the pressures for general expansion have been greatly relaxed on the national scene. The school with plans for expansion should recognize that an adequate program is extremely expensive, and an inadequate program is a severe disservice to the student. A valuable alternative to the expansion of four-year colleges into universities would be an active, funded program for increasing excellence at the undergraduate level. Particularly important here is the encouragement and motivation of faculty. This development could be greatly helped by a redirection of funding to provide for enlarged programs of undergraduate research and for opportunities for professional leaves of absence.

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PREPARING CHEMISTS TO MEET SOCIETY'S FUTURE NEEDS

Introduction

Most of the recommendations which follow concern themselves with the impact of new social demands on chemists and chemistry and with ways to produce a new breed of chemists. But we must enter a most important caveat. This is that chemistry is, after all, a science. It is a science with both basic and applied components, and its lifeblood is therefore research. Only continued research will ensure that chemical understanding will progress and be able to respond not only to society's problems in the immediate future but to those in the longer-range future that we can as yet only speculate about. Hence our recommendations should be thought of as additions to the current activities in chemistry, not as replacements for them.

Recommendations

The educational community must make major efforts in curriculum development and in teacher training for the teaching of science and chemistry in the schools of the world so that education in both primary and secondary schools may reflect the broader view required today. Every analysis of the teaching of science has concluded that the most important single aspect of effective teaching is the capability and quality of the teacher. In the present instance this implies the need for teachers who not only are trained in a broadened vision of science's capabilities and responsibilities, but are themselves imbued with a philosophy which gives high priority to society's needs.

Chemistry departments in the colleges and universities must broaden their curricula to include efforts to make chemistry students aware of chemists' role in society and to sensitize them to society's needs. This recommendation encompasses many specific programs. It implies more consideration of society's problems in elementary courses of chemistry. It suggests the need for specific courses for chemistry majors in which the uses of chemistry and the needs of society are put in context. Training in multidisciplinary research can be taught by use of special projects or alternatively by use of case studies which illustrate the concrete ways in which science and technology interact with the real world.

The university graduate schools should aid in the development of more flexible graduate programs in which concern for society's problems plays a more explicit part; aid in the development of mixed degree fields which permit experiments with such useful interactive possibilities as, for example, Chemistry and the Environment, and Chemical Ecology; to the extent they influence postdoctoral education, encourage the use of the postdoctoral period as a time in which science professionals can either shift their field into environmentally-oriented areas or broaden their knowledge in these areas. In working toward these various goals, the attitude of the graduate school should not be to weaken the graduate programs within the various science departments. It should be, rather, to provide alternatives and to permit easier transitions among fields.

The complex, many-headed system of adult education should give particular attention to the problem of broadening the appreciation of chemists, chemical engineers, and other scientists for the needs of society and for the opportunities for scientists to contribute to their solution both within their field and as a component of multidisciplinary attacks. As currently practiced, at least three adult education components assume some responsibility for the education of advanced professionals such as chemists and chemical engineers. These are the universities, the chemical and related industries, and the American Chemical Society. The programs of each of these three could be substantially broadened and extended. Universities have on the whole neglected adult education. Here is a critical need to which they should address themselves urgently. Industry can expand its efforts and can in particular give attention to society's problems and the role of industry and of scientists in addressing them. The American Chemical Society has an overall responsibility for ensuring adequate programs for chemists; it has a specific opportunity to modify and extend its Short Course Program to include courses which deal with society's problems and with ways in which chemists can address them.

The support agencies such as the National Science Foundation and the Department of Health, Education, and Welfare can greatly accelerate the capabilities of chemists in these societal areas by providing for new programs and more funds in environmental and multidisciplinary areas, while at the same time not neglecting the basic sciences. NSF, within its limited budget, has shown considerable imagination and initiative in new programs; it will be equally important to expand the successful programs and to develop still others as the occasions arise. HEW has two areas of special responsibility. The first is to improve and broaden the teaching of science in the schools; the second is to give increased emphasis to environmental problems within NIH, and in doing this to give explicit recognition to the need for multidisciplinary approaches.

The agencies with explicit responsibility for social problem areas such as the Department of Housing and Urban Development and the Department of Transportation should recognize the central importance of chemistry to the solution of these problems, and should support applied research in chemistry and should equally encourage multidisciplinary research in which chemists participate.

The agencies particularly concerned with foreign policy, the Department of State and its Agency for International Development, should give increased recognition to the central needs in developing nations for technology transfer and for education of scientists and engineers. Support programs within the universities to fund university science participation are essential, and substantially more use could be made of the capabilities of the science-based industries. As only one example, a broad exchange program to permit visitors from less developed countries to come to the U.S. and spend from six months to a year in industrial laboratories could be highly beneficial.

The many state and federal regulatory agencies, the Food and Drug Administration, the U.S. Department of Agriculture, and the like, have a special responsibility to permit and indeed encourage research on new responses to societal problems while at the same time protecting the health and safety of the groups with which they are concerned. The problem is one of balance and specifically of thoughtful consideration of comparative risks and benefits. Ineffective regulation is clearly bad, but so is the kind of thoughtless regulation that preserves the bath while throwing out the baby.

Schools, industries, and government agencies that employ chemists must develop an explicit commitment to assistance by chemistry in the solution of society's problems. They must demonstrate this commitment by ensuring that their chemistry employees and faculties are encouraged to participate in society-based problem-solving efforts and, when successful, are appropriately rewarded. As one example of the administrative problem to be solved, it will be intolerable for universities on the one hand to encourage their science faculties to participate in these broader programs and yet not simultaneously provide for promotion and salary increases when such participation is successful.

In view of a certain need for more and more kinds of scientists for the solution of these world society problems, employers of scientists should make particular efforts to employ additional women. In addition to specific encouragement of women going into scientific careers, industry should make a special effort to bring back the scientific "drop-outs," i.e., the women who have temporarily foregone their scientific careers for marriage and children. Such women may find this a particularly useful time to shift from pure science to a mixed career involving work on society's problems.

The American Chemical Society and, specifically, the Division of Chemical Education must assume a responsibility for the further studies, encouragement, and fund-raising which is essential to get these many specific programs solidly under way. The appropriate central agency to speak on behalf of the chemists is the ACS. In urging the ACS to assume this increased responsibility, we are aware that adequate attention cannot be given without substantial expense. We are, however, convinced that ACS members would wish the effort to be made and will support the increase in dues which may follow.

Concerns that Require Response

We are sharply aware that we meet at a time when the concerns and priorities of virtually the entire world are undergoing rapid change, and when the role of science and the goals of technology are both under serious question. In the developed nations and specifically in the United States, rising concerns relate especially to the broad problem of the quality of life. There are deep concerns about the problems that stem from the ever-increasing population, about the pollution of the environment, about the decline of urban areas, and about the social and economic inequities that persist among various groups of our citizens. It is widely appreciated that our affluent civilization depends very directly on the scientific and technological advances of the past several decades. But there is also increasing awareness that these advances have all too often been in context of exploiting our environment rather than nurturing it.

These concerns are shared in different degree by all of the developed nations of the world, but at the global level there are two additional concerns of great and perhaps overriding import. One is the world preoccupation with military systems and with defense against them, a preoccupation which has brought the military budgets of the world to the staggering total of $200 billion per year. The second global concern is for the spreading gap in standard of living between the developed and the less developed nations of the world. Of these two, the second is almost surely of longer-range import, since there probably can be no true peace among peoples whose shares in the world's goods differ so widely.

Responses to these many concerns are urgently sought and urgently needed. To be adequate, they will necessarily involve great effort on the part of the scholars, industrialists, and governments of the entire world. And in many cases the solutions will involve not less technology, but more. This is evident for the underdeveloped nations, since technology is their principal hope for a better life. But even for the developed nations, the new directions that will result from the new priorities will probably not involve a movement away from technology but rather the development of more responsive and more responsible technology. The clear implication is that the world will need not fewer scientists and engineers but more. A central requirement, however, is for increased numbers of a new breed of scientist, one who is more sharply aware of the world's problems, more willing to work toward their solution, and more capable of doing this in collaboration with the social scientists and humanists who must also be involved.

In this connection, we point out a need to involve far more women in scientific careers as teachers, research workers, and technicians. Their natural abilities have scarcely been tapped by a field which offers, or ought to offer, a wide variety in choice of specific employment and in intellectual satisfaction.

Role of Chemistry and Chemists

Chemists and the chemical industry are often charged with responsibility for many of the world's urgent problems, and there is some, if limited, justice to this charge. Some of the exploitation of our land can be charged to a search for chemical materials for the world's industry. Some of the world's pollution specifically results from the chemical industry. One can even argue that the rapid population increase, and indeed the pollution and wastes that affluence has brought, are the consequence of the success of chemotherapy in health care and the success in the chemical control of agriculture. In fact, however, these latter effects have been incidental to the search for a better standard of living and have mostly come about as unexamined and unintended side effects. Hence without in any way castigating the chemistry of the past one can still argue that for the future a narrowly technological view will not do.

More fundamentally, what these comments really point to is chemistry's central role in man's search for better control of his environment. Chemistry is the science of molecules, of their synthesis, their modification, and their utilization. And in the most basic sense it is the modification of the atoms and molecules of the world that has produced the new materials, the new drugs, the new fibers that characterize modern civilization. It is equally certain that, as we search for a more responsive technology with greater attention to a balance of nature and more concern for the quality of life, chemistry will be centrally involved. It will most probably be chemical agents that will give to society new and wide choices for birth control. Chemistry will inescapably play a central role in the control of the pollution which now so troubles the nations of the world.

Another way of saying this is to note that technology in general, and chemical technology in particular, fundamentally provide the world with alternatives. Synthetic fibers provide alternatives to the natural fibers whose production has all too often involved exploitation of the natural ecology. Plastics provide alternatives to wood and to metals. If we are to control our pollution, and if we are more broadly to make the transition from exploiting our environment to managing it in a nearly steady state, we will necessarily search for the alternatives that chemical technology can provide.

To the less developed nations of the world, the urgent problem is to satisfy the elementary needs of their peoples for more food, better health, and more amenities. Here, too, chemistry must play a role, just as it has in bringing the developed nations to their current position. One can strongly hope that in performing its crucial role in the developing nations, chemistry can be more sharply aware of the broader implications of development and can be more thoughtful and responsive to the potential side effects of its technology. One can even hope that with a more enlightened technology, the developing nations may avoid some of the serious errors that have plagued the rest of the world.

It is these several points that support our belief that the world of the future will need not less chemistry, but more -- and that the role of the chemical industry will remain as central as it has been in the past. The problem, then, is to maintain the thrust and central use of chemistry and chemical technology, but to do it in ways that respond to changing world priorities.

Preparing Chemists for Future Needs

With at least a partial vision of society's future needs and priorities, and with a partial understanding of the role of chemistry and chemical technology in developing our current society and responding to these new needs, we turn to the particular question of preparing chemists to meet society's future needs (and in the category "chemist" we wish explicitly to include chemical engineers). First we may ask, "Who are the chemists whose preparation concerns us?" There are three groups of particular importance. The first are the budding and potential chemists who are now studying science and introductory chemistry in the schools of the world. The problem of who among these commit themselves to chemistry, and for what reasons, is of central importance to the future. A second group of concern are those students in our colleges, universities, and graduate schools who have made the commitment to chemistry and are now involved in their advanced studies. The third group is the great body of chemists now actively practicing their profession. In this group we include not only industrial chemists and chemical engineers but also the chemical faculty of our schools and colleges, a group which is of central importance in accelerating the educational changes which we believe are needed.

It is important that we also identify the audience to whom our remarks are addressed, and again there are three. The first is the educational system which is concerned with the teaching of potential and actual chemists. The second audience is the groups who will be involved with the utilization and the support of the chemists of the future. These consist of the chemical industry, defined widely, and the government agencies which support chemical research as well as those which develop the many applied multidisciplinary programs that involve chemistry. The third, and conceivably the most important, group to whom these comments are addressed is the chemists themselves and, as their official representative, the American Chemical Society and the other professional chemical societies of the world. Only if the chemists of the world deeply feel the need for change and are deeply convinced of the urgency of society's problems will any recommendations for change be effective.

We can now come quickly to the heart of the new directions which we feel are required by listing the qualities which we think will ideally characterize the chemist of the future. We are well aware that these characteristics will not be shared in equal measure by all chemists, and that there may be excellent reasons why in many cases they will be minimized or even ignored by individual chemists. Even so, some vision of the ideal man is useful as a goal and a challenge. Our ideal chemist, then, would have these characteristics:

1. First and foremost, he would be an able chemist, trained in the intricacies of his science and effective in applying his knowledge.
2. He will be concerned with the application of chemistry. He will be constantly aware that it is as applied science and as technology that chemistry will impact on the world.
3. He will be sensitive to society's changing needs and new priorities, including in particular the urgent problems of the developing nations.
4. Recognizing these needs and priorities, he will feel a personal commitment to help to meet them.
5. He will be trained and effective in the multidisciplinary problem-solving which will increasingly be needed.
6. He will be capable of and willing to explain to his fellow citizens his science and its role in solving the world's problems.

One important reason for spelling out these characteristics is to emphasize the degree to which the typical chemist today (ourselves included) falls short of fulfilling them. Far too often the current-day chemist is too content to practice his profession narrowly, with too little concern and professional interest in societal problems, with low competence in communicating to others about his science, and with negligible ability to participate in effective multidisciplinary research. It is ironic and sad that the academic chemists of our panel are persuaded that these indictments apply in full measure to themselves and quite generally to the academic chemists of our major colleges and universities. We emphasize these unhappy facts only because we wish strongly to make the point that the problem of producing the new chemists will not be an easy one. It will only be done if many important professional groups change their ways to the extent that many strongly entrenched ideas and priorities are greatly modified.

This picture of the "ideal future chemist" and of the problems which face us in obtaining him have major implications to important groups of our community. The most obvious of these implications relates to the needed responses from the educational systems of the world. In its broadest form, the implication is simply that the teaching of chemistry must include thoughtful and inspiring consideration of the uses of chemistry, of the social impacts of chemical technology, and of the need to produce sensitive and broadly responsive chemists. In the training of students in the critical years of from 13 to 16, when most career decisions are made, this represents both a challenge and an opportunity. The challenge is to teach not only science but the implications of science and the opportunities for scientists to respond to world problems. The opportunity is to produce students who will opt for or against a science career with a broader vision of what science means and what it can do. Hopefully science in general, and chemistry in particular, can thereby be seen as an area of opportunity for people with a long-range vision and a social conscience.

The implications of this broadened view of the "ideal chemist" apply with particular sharpness to the colleges and universities, and especially to their chemistry departments. It is here that the specialized and advanced aspects of chemistry are taught, and it is here that students' attitudes of mind as professionals are most directly shaped. A common response to the need for inculcating more social awareness in these chemistry students is to urge that they be permitted to take courses in sociology, psychology, etc. We submit that this, though interesting and useful, is far from enough. It is within their own chemistry departments that most students will develop their strongest motivations, and not least among the operative forces will be the precepts and examples of their professors.

It is within the chemistry department that the appreciation of and training in multidisciplinary research might most successfully be accomplished. These new programs call not only for changed attitudes among the chemistry faculties of the colleges and universities. They demand as well a far deeper knowledge and appreciation of society's problems and of ways to attack them. To instill this knowledge and appreciation in the many faculty members involved will not be easy. Faculty seminars and faculty participation in multidisciplinary research programs are strongly indicated. Formal summer training programs are also surely required, and we urge their prompt development and eventual implementation.

With major effort by our colleges and universities, one can envisage these new programs becoming installed and effective. But what about the current chemists? Who will teach them and give them some appreciation of these broader needs? Here we suggest that the implications refer most directly to two groups. The first is, again, the colleges and universities, whose efforts in adult education have been far too little and too late, and who need to give this kind of teaching a much higher priority than they now do. The second group that must be concerned with this broader view of the chemist are the professional societies of chemists -- in the U.S., the American Chemical Society. If it is important, and we believe it is, that chemists be aware of the opportunities for help through chemistry to the developing nations of the world, the awareness should be reflected in an American Chemical Society program. If it is important that chemists appreciate more broadly the social implications of chemistry and of the opportunities for chemists to help in solving problems of concern to society, the ACS must play a major role. The Short Course Program of the ACS, for example, could be greatly broadened to include multidisciplinary subjects that bear on such problems. We are persudaded that, with the strong approval of its members, the ACS will not only respond to these opportunities but will itself take the initiative.

There are important implications also for the employers of chemists, a group which explicitly includes college and university administrations. If chemists are to change themselves and their priorities in the substantial ways we suggest it must be with the approval of the organizations for which they work. This means more than lip service to "good ideals." It implies explicit recognition of the importance of serious concern for society's problems and explicit reward for good efforts on those problems. To be quite specific, one cannot expect young faculty members to accept these new priorities and to change their own without explicit approval from their department; indeed, without this approval the precept and example of faculty to their students will be singularly unpersuasive. Similarly, one cannot expect an industrial chemist or a fresh Ph.D. to train himself in the chemistry of the developing nations and to commit himself to a two or three-year leave of absence to work in these countries without the most explicit recognition of the importance of the effort by his present or future employer. From this last viewpoint, what we are probably really talking about is necessary changes not only in the minds and hearts of individual chemists but in the entire complex chemical establishment.

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CHEMISTRY FOR CITIZENS

Introduction

The age we live in is marked by two explosively disparate trends. One is a mastery of science which increasingly dominates but fails to control our world. The other is an indifference to science which is starting to turn into a wide-ranging rejection. Our time is distinguished by the ability of man to start to understand broadly his place in the universe. That man has a deep emotional need for such understanding is apparent in every aspect of human history and existence. The need to know what and why is obvious even in a baby, and it never leaves us. To know implies to understand, but because we can never understand fully, this emotional need must often find a substitute in blind or myopic belief. Yet, at a point in history when rational understanding is available as never before, we have the awful irony that it seems to remain limited to a small group of initiates. Meanwhile the outsiders, the great majority of people, are becoming increasingly unwilling to accept science on the basis of faith, and some are toying with the idea of rejecting it entirely.

Science has never been fully accepted by humanity. It has been tolerated because of the material benefits it can provide. But now it is being increasingly questioned whether these practical results of science are indeed benefits. To many young people science is associated with overpopulation, pollution, nuclear warheads, and the creation of an artificial environment which seems foreign to the spirit of man. Thus, since science is being judged solely by the gadgets it produces, tolerant indifference is being replaced by active fear and opposition. Antiscience is growing in the critical group where we had expected to see it least - among the young, bright people. It was their criticism that centuries ago overthrew superstition and faith in religious hierarchies as the dominant factor in man's life. They seem now to see science as just another religion with which the establishment is trying to enslave them. How very different this is from our comfortable assumption that it is self-evident that science can set free the mind of man, so self-evident in fact that the point must soon be automatically recognized by all.

This picture may seem overdrawn, and perhaps at this moment it is. But if present trends continue it certainly will not be overdrawn in another 20 years. We could then be at the threshold of another age of darkness. The fruits of technology will be accepted, though perhaps resentfully, but the understanding that made them possible and that can help us to live with them and with each other and with ourselves - this understanding will be rejected.

We are coming to the realization that at this time the furtherance of science itself is no more important than its communication to humanity as a whole. Yet as we go out to proselytize we recognize the time is late, for the world is on the verge of turning against us.

In the past we have relied, though perhaps not consciously, on awe in the works of science to instill a faith in science in every man. There is a kind of justice in the fact that faith is proving an inadequate means of gaining acceptance of that which at the outset rejects faith. The harder road of education is the only one left.

Millions of college graduates who were required to take a single, general science course to win their degree now form the backbone of public opinion. Many of them, in this one contact with science, came away with a feeling of boredom, if not antagonism. The spark of inquisitiveness, without which science is meaningless, was extinguished.

Not that education alone is to blame for the current trend against science. The prime cause is the extent to which science and scientists are interwoven with undesirable features of modern life, from industrial pollution to the absurdities of the arms race. Nevertheless, had their early exposure to science been a rewarding and enlightening experience, today's citizens would more readily discriminate between science - the quest for new understanding - and the manner in which it is used and misused.

We must persuade the nonscientist that science can be regarded as one of the humanities in that it enables him to see himself and his place in the universe in a way that nothing else can. We must show him that science can tell us what may be rationally known, and that it can then provide a clear basis for many decisions in the running of his and the world's affairs. This is more important and more difficult than attempting to instill "facts" and abstractions which seem to have no relevance to life.

The Need for New Attitudes

We need not look far to find reasons for the growing rejection of chemistry and science by the public, the students, and the policy makers. Those of us who are professional chemists have done little to check this alienation; indeed, until recently we seem scarcely to have been aware of it. If the layman sees science as a powerful but sterile discipline which dries up the human spirit, it is because we have not conveyed the essentially human character of the process of discovery. If he sees science as a mindless, computerized juggernaut which once served him, but seems now to threaten his destruction, it is because we have not shown him that he must, and can, share decisions on its control and uses.

What is the basis of our past failures? The ultimate reason seems to be that we have turned inward, toward ourselves. So completely have we been taken up by the development and furtherance of science, and chemistry in particular, that we have largely ignored the obvious truth that effective communication is of equal importance. In the United States after World War II, the growing availability of federal funding gradually transformed research into the only really fashionable way of being a scientist. The status of teaching was correspondingly denigrated, and teaching nonscientists was accorded a low social status within the profession of chemistry. Performance as a teacher has been virtually ignored in university promotion. For science graduates, and especially for new Ph.D.'s, instructing in secondary and primary schools was considered not quite respectable. Hindsight now tells us that the result was predictable. You cannot expect many of the best people to make a career of communicating science if you treat them as outcasts.

We are well aware of the importance of research experience in keeping teaching and teachers intellectually alive. But surely there must be a better balance between the status accorded teaching and research.

The same self-centeredness that caused university chemistry departments to consider academic research the highest goal has led to the easy assumption that what is good for the future scientist is best for the layman also. As recently as 1965, the Westheimer subsection on chemical education (in "Chemistry: Opportunities and Needs"), while discussing the importance of teaching nonchemists, did not consider it necessary to suggest that the essentially different nature of their motivation makes appropriate a different approach to the subject. Thus the nonscientist in college has usually been subjected to the same, or essentially the same, courses which were designed for the professional chemist. In these courses, chemistry is taught for the sake of chemistry itself. That may be appropriate for those already committed to the field. But this approach makes it difficult for the others to see how science relates to their lives and their universe, and they are frequently left baffled, bored, and resentful.

While the long-range solution to this problem lies in a new approach to classroom science, it is clear that rapid remedial action is required to educate and inform that part of the general public that was missed in its student years. To a considerable degree, teachers and researchers both have been guilty of establishing themselves as an elite, separated from the concerns of ordinary citizens. They have not been mindful enough of their duty to transmit to the public in an intelligible fashion the results of their labors.

What the layman usually misses completely in science as it is presented to him is its essential humanism. We have pretended too often that science is a purely logical, and even infallible, structure that exists apart from man. In dwelling on the superbly rational nature of proof and deduction, we failed to convey the emotional excitement and the intuitive nature of discovery itself. Instead, the feeling of chemistry as an "inhumanity" is reinforced by a frequently unnecessary technical language which does more to conceal the essentials than to reveal them. G. N. Lewis wrote in 1922 in his introduction to "Thermodynamics": "A tradition has arisen whereby the friendly usages of colloquial speech give rise to a certain severity and formality. While this may promote precise thinking, it more often results in intimidation of the neophyte." Unfortunately, Lewis's words have not been as influential as the rest of his classic.

Verbalizations and blackboard demonstrations alone more often smother than awaken the enthusiasm of the average student. Too often this approach is not balanced by work with the actual materials of the chemist and by references to ordinary human experience. Yet it is this that makes the subject "real" to the student and so stimulates his interest.

A superb teacher can generally overcome the burden of any particular educational philosophy and make even a professional course interesting to most of his class. But we don't often have such inspired instructors. As a result, most students feel overwhelmed by an enormous mass of foreign, but not fascinating material. The abstractions which are supposed to unify it remain abstract, unreal, and irrelevant. Chemistry appears as a separate world of its own which does little to broaden the student's view of his universe. He fails to grasp the intellectual excitement of the scientific method and scientific intuition, and it never occurs to him that these approaches could be used in his everyday thinking. What is left for him is a collection of "facts" which are supposed to be held together by "theories" which must be memorized since they cannot be understood. Attempts to escape from this educational straitjacket have been frustrated in some cases by the setting of rigorously standardized tests for the evaluation of chemistry teaching.

People are strongly motivated toward understanding the universe and their own place in it. We have usually not taken advantage of this interest and have presented science as a world apart – separate and unreal. Only by emphasizing the intimate connection of science with man's life can we broaden his view of that life and his universe. We must abandon the ridiculous idea that the applications of science are somehow impure. People are fascinated to learn how science can account for what they see in everyday life. They are enthralled by the idea that they can understand the chemistry which controls their environment. And only through this kind of understanding, not only of pure science, but of its application in everyday life, in industry, and by the military, can we expect people to make intelligently the decisions which determine the fate of us all.

The Students

At all levels of instruction, it is crucial that the highest priority be given to the presentation of science as a humane discipline, thoroughly interwoven into life as we know it. Science as an extremely creative exercise of the disciplined imagination would be an important part of this presentation. While this is important at all levels of instruction, it is especially critical in elementary school, since it is there that attitudes toward learning in general and science in particular are usually formed. Teachers should be encouraged to adopt an instructional style which will allow more direct participation by the student and thereby kindle, rather than extinguish, his enthusiasm for learning. In order to reach the largest possible audience, it is imperative that a wider and more varied range of course materials be developed. This is a particularly acute need in the secondary schools. We recognize that such a variety of personal instruction can be only as good as the teacher; therefore, school administrators at all levels must give the highest priority to attracting and holding competent and imaginative teachers for this challenging assignment. Contributions in designing and teaching innovative courses in Citizen's Chemistry should be a major factor in determining promotions and compensation levels. Our recommendations:

> In the elementary schools emphasis should be placed on stimulating curiosity and discovery, the participatory "fun-and-games" aspect of science. The development of technical vocabulary should be replaced by concept development from a base of extensive experience and experimentation. The inborn curiosity of elementary students should be nurtured by providing an environment that encourages experimentation and investigation. These goals can be fostered by allowing the student to develop those aspects of the subject matter of greatest interest to him. High financial priority should be placed both on equipping schools for such courses and on training teachers of elementary science.

Science courses included in the training of elementary-school teachers should emphasize both the methods and the materials appropriate to the "discovery" or "inquiry" approach these teachers will use in the classroom.

Other media, especially television, should be investigated as a means of teaching science to young people. In particular, the American Chemical Society should establish a group to investigate intensively the use of other media in terms of their utility, cost, and ultimate return. We wish to emphasize that the use of external means of instruction such as these is intended to supplement, not replace, the primary method: in-class experience and discovery.

For secondary schools, a program for producing materials for the study of chemistry from a humanistic point of view should be developed. This flexible approach would utilize newly developed, varied materials such as readers, laboratory exercises and equipment, programmed instruction books, films, texts, and teacher's guides. A diversity of new learning aids will enable teachers and students to emphasize those aspects of the materials which interest them most and need not impress upon them a specific list of subjects. These materials would stress the humanistic development of chemistry as a creative product of the disciplined imagination and beyond this emphasize the interrelationships between chemistry and the other natural sciences. An example is the consideration of molecular biology with its biochemical structures leading to a chain of reasoning through the origin of life to evolutionary development. Full advantage should be taken of the relationship between pure and applied chemistry. An example would be the story of DDT: the basic organic chemical research which led to its synthesis, a consideration of its use in controlling agricultural and disease-bearing pests, and finally an evaluation of the conflicts resulting from its wider ecological effects. The ethical and social dimensions of science and technology would be further developed in these materials through topics such as the potential manipulative power of the genetic code. The results of this curriculum development would function as a teacher training program of the first magnitude. The resultant evolution in teacher attitudes and the availability of new materials should increase the number of involved students and their appreciation of science.

In colleges and universities, experimentation should be encouraged toward the development of humanistic, in-depth science courses much less committed to complete coverage of chemistry than has been the case in the past. The importance assigned to this form of educational research should be comparable to that accorded to other scientific research areas. There should be appropriate recognition in terms of salary and promotions for the leaders in the field. These experimental courses should be evaluated carefully to determine their residual value to nonscientists, both during and after graduation from college.

Courses should be developed that deal with the philosophical and ethical implications of science, as well as with its practical implications, and these courses should be intended for all students in their last years of college. Students about to enter professional occupations in areas other than science will need to be aware of the numerous and complicated interrelationships between science and society. Similarly, advanced science students often seek an understanding of how their profession fits into and affects society. Courses designed to benefit these two groups of advanced students are necessarily interdisciplinary. No single faculty member may be able to teach such a course, but cooperation among faculty members and students from a variety of fields can generate the vigorous exchange of ideas which could be the basis of such a course. Advanced interdisciplinary courses could take up a number of subjects of general interest in a variety of specific contexts. These subjects might include the effects of science and technology on society; the relationships among science, government, and industry; and the patterns of development of basic and applied science.

The American Chemical Society should make special provisions to increase significantly the contact between college and university teachers of chemistry and all teachers of chemistry in the lower schools. To this end, changes should be made in the membership requirements for the Division of Chemical Education to enable all teachers of chemistry to become full and active members of this Division of the ACS, and appropriate programs of participation should be developed. The American Chemical Society should establish a study group, composed of teaching chemists and competent specialists in educational theory, to develop up-to-date guidelines for teacher training and related areas.

The Public

The general public pays for science and enjoys and suffers its fruits. Yet most people have virtually no knowledge of the nature of science and no appreciation of how it moves to affect the quality of everyday life. They tend to regard it as a kind of separate religion whose workings cannot possibly be fathomed by ordinary men. At the same time, this religion is removed from humanity, cannot be reached by prayer, and is thus remote and depersonalized.

Scientists have usually concerned themselves only indirectly with communication to the public at large. While this task is very necessary, it is also most difficult. Indeed it seems unrealistic to believe that the true meaning of science can be conveyed to the millions of people who have left school and whose reading is largely confined to the local paper. Yet these persons can be reached through television. And they would probably watch programs dealing with the impact of applied science on their daily lives and their future. Topics in applied science dealing with pollution, medicine, warfare, and space travel are obviously of broad interest. While this type of TV program could not convey the nature and development of fundamental concepts, it could provide some understanding of the relation between pure science and technology. Such programs might bring the man-in-the-street to realize that the application of science and its effect on his life are matters which are not completely beyond his understanding and control. Our recommendation:

> Television programs should be developed that show in simple terms how science solves and creates problems in our world. These would be "shows" emphasizing drama, if necessary at the expense of full logical development. They should leave the viewer with the feeling that science can be both used and abused, but that it can and must be controlled by man, and that there is no substitute for it in dealing with our problems.

Such shows could be developed on the basis of the "position papers" we describe below. There is probably more opportunity than is generally realized for finding a broad outlet for these programs. For example, cable television systems are now required to have a much larger percentage of local (rather than network) programming in their schedules than in the past. Such local systems might be particularly anxious to have well-produced material of the type we have described.

We are not hopeful that the unprepared public as a whole can ever achieve the sophistication to make deliberate broad-based decisions on the direction of science — although the grass-roots pressure they exert will have a pervasive and powerful influence. But within the public is a large body of college-educated nonscientists. That group includes those individuals whose opinion and decisions carry especial weight in shaping the future of science and the world. These people of influence are to be found in the legislative and executive branches of national, state, and local government, in the managerial levels of business and industry, in the communications media, in educational institutions, and in certain branches of the military. Their attitudes toward science and scientists are too important to be left to the haphazard influences of ignorance, misunderstanding, lack of personal acquaintanceship with scientists, and an excusable inability to speak the languages of science.

There was an opportunity to give these people an understanding of the excitement and beauty of science while they were in college and, for the most part, were attending at least one course in science. The opportunity having been allowed to slip by, we see little hope of developing a true appreciation of science now, when these people are fully occupied by their own active roles in society.

We believe, however, that most of these opinion- and decision-makers are necessarily much more involved with the applications of science than with science itself. Their primary concerns include a higher material standard of living, a greater degree of agricultural efficiency, a superior practice of medicine and public health, a more vigorous economy, a stronger military machine — and now the inevitable deleterious side-effects of our present technology. We believe that better insight into the workings of applied science can help concerned people understand what they can expect from scientists and how they themselves can begin to assume their share of responsibility for the more controlled application of science.

Communication with this more educated group can be established through the written word. They are reached at a more sophisticated level through newspapers, Sunday supplements, magazines, and books. Scientists must accept more responsibility for seeing that their work is popularized at this level. Science reporting deserves more support from the chemical profession in particular.

The decision makers as well as those who help form opinions through writing, television, and films frequently lack comprehensive, yet understandable summaries on which to base their thinking. Our recommendation:

> <u>Case histories of applied chemistry should be prepared by groups of appropriate experts, in the form of well-</u> documented, almost scholarly position papers. These studies should describe the genesis of the goal, the programmed research, the dependence on basic science, the forward and backward steps in the achievement of the goal, and the degree to which the originally recognized need was filled. Insistently throughout these case histories, the often extraordinarily complex array of factors involved should be brought to light. The resultant application should then be described in the language of systems, so that its introduction into the world can be treated as a perturbation on this highly complicated,

incompletely describable system.

We believe that these position papers can develop in the responsible, concerned nonscientist the habits of thinking in terms of several variables, of asking more subtle, less simplistic questions, and of expecting less superficial answers. We also believe that such case histories of applied chemistry have a good chance of demonstrating the nature of the relationship between the achievements of basic science and the accomplishments of applied science and will lead without special emphasis to an acceptance of the necessary dependence of new practical developments on the continuing vitality of pure science. Exposure to case histories in applied chemistry (or, more generally, in science) cannot fail to replace the oversimplified expectation that a practical system be all good and not at all bad, with the more realistic expectation that some price may have to be paid for a measure of benefit. Decisions to pursue or abandon goals in applied science normally depend on an assessment of this balance. The public must be given an honest, dispassionately-offered opportunity to participate in the assessment.

Subjects for such position papers, to name only a few, might include the story of DDT into the present dilemma; the extraordinary history of thalidomide, including the present crucial reassessment of the interplay of the Food and Drug Administration and the U.S. pharmaceutical industry; the dependence of cleaning dirty bodies, clothes, and dishes on soaps, detergents, and phosphates and the interaction of these systems with the world ecosystem; or the transformation of weed killers into weapons of war.

In our judgment, the most important fuction of these position papers is to serve as the substantive basis for the creation of national television programs. The public's confidence in the scientific establishment can only be raised if these complicated subjects are presented with candor and objectivity. The public must come to understand that its participation in judging the value of the applications of science is absolutely indispensable in setting the goals of applied science. If the analytical basis for making these value judgments is not provided by the community of scientists, to whom can the public be expected to turn?

We assume that these position papers can also be used effectively in other ways: as the basis of individual briefings of decision-making nonscientists; as a contribution to libraries and as background material for students and the reading public; and as the source of translations into more popular forms by concerned editors and members of the press. The overwhelming importance of bringing these stories, and through them a more sober understanding of applied science, to the general public and to students of all ages is clear.

Whether these position papers can be sponsored by a complex organization like the American Chemical Society is moot. Responsibility for their preparation, their distribution to appropriate policy makers, and their translation into television programs for the general public might be assumed by the Committee on Chemistry and Public Affairs of the American Chemical Society. If in that committee's view the assumption of this responsibility is unwise, other organizations, such as the National Academy of Sciences or the American Association for the Advancement of Science, might be approached. It is also possible that this urgent need might better be served by a privately supported group of knowledgeable, concerned citizens and scientists.

Continuing Action

We are not under the illusion that all of the recommendations we have made are new. Nor do we believe that they will be adopted simply on the basis of whatever underlying merit they may have. Similar proposals have in the past remained just that – proposals. We therefore believe it to be essential that there be created a group charged with implementation and further development. Such a panel would have the responsibility of taking any action it deemed appropriate toward the realization of our recommendations. To this end, the panel would have the power to appoint further action-oriented groups and to seek the necessary funds. We wish that the Division of Chemical Education of the American Chemical Society will take the responsibility for soon constituting an effective panel to implement and further develop our recommendations. Until such a group is operational, we of this committee assume that our responsibilities are not ended.

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INTERNATIONAL ASPECTS OF CHEMICAL EDUCATION

Introduction

Problems such as overpopulation, despoilation of the air and water, and the depletion of natural resources transcend national boundaries. The increasing gap between the more developed and the less developed nations has serious implications for everyone. These are international problems. Because we are confident that education in science can contribute to solutions to these problems, we call on teachers of science and, in particular, teachers of chemistry to make a fresh assessment of their responsibilities. To ourselves and to our colleagues everywhere we make the following recommendations.

Recommendations

Science educators in all nations should participate actively in a reexamination of national goals for development and of the contribution that science education can make to the attainment of those goals. Chemistry has increasing relevance to the solution of problems of nutrition, health, and technological development; it holds the ultimate solution to the problem of maintaining the quality of the environment. Chemists and teachers of chemistry should make a useful contribution to the achievement of national goals.

Education in science, including chemistry, should be extended in all countries. We are concerned with two groups: the technically trained chemist; and the citizen who receives a general and sometimes limited education. While the primary contribution of the first group is usually in the field of chemistry, well-trained chemists are potentially able to contribute to society in fields not obviously related to chemistry: administration, law, politics, commerce, and communications. Steps must be taken to ensure the productive accommodation of trained chemists in a variety of socially useful jobs. The second group is the public at large. We take the view that topics from chemistry should be included in general education, and that chemists should make an appropriate contribution to the improvement of general education.

Chemical education should be continually renewed in each country. Because chemistry and other sciences are continually changing, chemistry teachers need help in maintaining their professional status. In each country, facilities for improving the qualification of teachers and the quality of teaching materials should be provided.

International exchange of information on the improvement of chemistry teaching should be increased and coordinated. Some chemists appear to be unaware of many of the useful developments in the teaching of chemistry. We see alarming gaps in the general knowledge of such developments and recommend that these gaps be filled.

The accommodation of foreign scholars by host countries should be improved. The inequality of educational opportunities in various countries leads to an extensive international traffic of scholars. Too often the mentors of foreign students forget that students from the less-developed countries will return to an environment which does not correspond to that of the more-developed country. As a result of inadequate academic counsel many students undertake lines of study which cannot be continued later and conclude their foreign study with a sense of alienation from their own culture and a lack of understanding of their own local problems. Steps to improve this situation are recommended.

The Social Potential of Chemistry

We note that science, including chemistry, is supported by society with the belief that it will contribute to the achievement of national goals: nutrition, health, economic development, and the like. In a world of people with rising hopes and expectations, there is increasing confidence that such goals are attainable, particularly through the operation of a science-based technology.

We also note that, in spite of often remarkable scientific and technological advances, much of society feels that the support of science has not led to a sufficient contribution to the achievement of national goals. People are increasingly frustrated with national efforts which result in small yields, obnoxious by-products, and a residue of unsolved problems.

A principal problem facing man is his relation with his surroundings. Changes in the surroundings, and the dependence of these changes on the human population level, are components of a problem that can be better explored and, when necessary, controlled if the chemical factors involved are understood. A main job of chemists and chemical educators should be to familiarize themselves with the facts in these areas. Without a prompt increase in chemical education related to population and ecology it is unlikely that the solutions attempted will be the best ones possible.

An important problem facing chemists is the current inadequacy of chemical education. Our review of the various national programs in chemical education makes clear that problems with which the U.S. is all too familiar are common to many countries. In society as a whole these problems include the narrow vision that chemists themselves hold of the role and scope of chemical science; lack of public understanding of science and technology; and the alarming number of unemployed among holders of degrees in science - persons whose training should have qualified them to serve society usefully. In science education in particular, the common problems include obsolete syllabi and teaching materials; stereotyped examinations; inadequate training of teachers; inadequate teaching facilities; limited understanding by educators of the scope of chemical education and the professions to which it may lead; and failure to acquaint the general public with the role of science in society.

We hope that the recommendations we make in this report will be of some use in realizing the fuller potential of education in chemistry. The full yield depends on a general revitalization and recasting of science education. We urge the chemists not to wait for others to take the lead, but instead to point the way by examining the recommendations made here and taking appropriate action where possible.

Chemical Education and National Goals

National policies are set with a view to attaining various objectives. In the more developed nations of the world these goals now include relief from pollution of air and water, maintenance of a stable pattern of economic growth, improvement of health and public sanitation, and the like. In the less developed nations the problem is often that of accelerating development to close the gap between themselves and countries whose rapid economic growth started some time ago. The less developed countries face the problems of increasing the productivity of agriculture, of tapping new sources of water, of improving arrangements for food storage and distribution, of starting many new small-scale industries, and of developing basic technologies. Indeed, in all countries education in science must be made more relevant and useful to society.

The unfinished task of making improvements should be taken up by both the scientist and the science educator with the understanding that education operates through a system that has its own infrastructure, processes, constraints, and goals. Efforts should be directed at improving educational systems as well as at developing better science curricula. Care should be taken to prepare scientists and technicians with the kinds of training and in the numbers needed for national development.

Extension of Chemical Education

The traditional role of education in chemistry has been the training of chemists. While this will continue to be one of the prime functions of chemical education, we call attention to new functions of such training.

We believe that education in chemistry should be regarded as appropriate preparation for a variety of different kinds of work. The student of chemistry is taught to recognize the significance of fact and to apply both creative and poetic imagination to a set of facts. This should not disqualify the student of chemistry from any type of work.

We also believe that some aspects of chemistry should be taught to those who will receive only a minimum education. Chemical educators should help to ensure the incorporation of appropriate scientific topics in elementary curricula. They should, perhaps through collaborative international efforts, prepare handbooks and guides for students and teachers. Governments should promulgate science education more effectively, including science education for citizens of all ages who, in many cases, may be unable to complete their formal education.

We recommend that novel, imaginative, and effective steps be taken to serve the needs of those who have not responded well to chemistry as it is now taught in the schools. The use of academically unconventional formats for communication as means of instruction should be explored. These could include flip books, "popular" books in science (e.g., Gamow, Asimov, Eiseley), and "comic" books, for which translation problems are minimal and information retention is high.

Renewal of Chemical Education

College and university chemists should assist the renewal of chemical education by participating actively in the training of science teachers. Professional chemists can contribute to the quality of science education by encouraging scientifically able students to go into primary and secondary science education, and colleges and universities can help these students select programs of concentration in the sciences which are appropriate to these goals.

We strongly approve the resolution of the XXIV IUPAC Conference, Minute 19, 29 August 1967: "That, in order to provide adequately for the needs of the teaching of chemistry, it is necessary. . . to provide in-service training of chemistry teachers as a matter of urgency for all teachers in all countries." We call explicitly on those who are involved in chemical education in <u>every</u> country (whether developed or developing) to take the necessary steps as soon as possible to put this resolution into practice in such a way as to involve every teacher of chemistry, without exception.

We see a need to encourage and enlarge the bilateral exchange of such in-service educational programs as the ACS Short Courses and similar courses offered in other countries. We see a need for a multinational consultative service for curricula development projects. In view of the importance of examinations in education improvement schemes, consultative services for examination construction also would be useful. The ACS Division of Chemical Education, and comparable bodies in other countries, should establish mechanisms for identifying qualified consultants.

International Exchange of Information

Greater information exchange is required between and among groups that serve the international needs of chemical education. We believe that the IUPAC Committee on the Teaching of Chemistry is well qualified to provide this service and should do so. The committee could coordinate the services of UNESCO, the national chemical societies, government agencies, and other organizations. It could fill specific requests for information and help, recognize and assign priorities to major problems, and recommend specific action for solving problems. The IUPAC committee could maintain liaison with other disciplines, both scientific and nonscientific, and serve governmental and nongovernmental agencies around the world.

We suggest that the UNESCO publication, "New Trends in Chemistry Teaching," be issued more frequently and distributed more widely. Steps should be taken to establish the low-cost reprinting of selected articles from _Chemistry_, _The Journal of Chemical Education_, _Education in Chemistry_, and similar journals as parts of indigenous journals. These efforts should in no way replace "New Trends." A mechanism should be established to effect the international exchange of small apparatus and teaching aids. Individuals and local chemical organizations should be encouraged to send _recently_ published books and journals on a regular basis to foreign libraries which need them. (In many cases mechanisms for this now exist, even to paying for shipping costs, but the arrangements are not always well organized.)

Accommodation of Foreign Students

Students who are candidates for further study in a foreign country should have access to information about that country and about academic policies and procedures. We recognize that the scientific community has a responsibility to ensure that academic counsel to prospective students is competent and useful. We recommend that professional bodies accept that responsibility and provide needed information in the form of suitable publications.

We recommend a program of postdoctoral internships. Too often students from less developed countries go abroad to study the latest advances in science and in doing so fail to learn to use science to solve the problems which must be faced upon return. We deem it highly desirable that opportunities be created for foreign students to work as interns in an industrial-technical environment. Such internships should form intrinsic parts of graduate programs.

We also recommend a program of nondegree studies in applied science. We call to the attention of granting agencies and institutions catering to students from the late-developing countries the fact that there is need for instructional programs that lead to useful skills and not merely degrees. Some students with a background in chemistry should take instruction in the many peripheral fields in which chemistry is used to solve technical problems.

We emphasize, finally, that improvement of education in chemistry and the accomplishment of the actions we recommend can be strengthened markedly through international collaboration.

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International Aspects of Chemical Education

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Plenary Address
EDUCATION FOR CHANGE

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Let me preface my remarks this evening with a quotation from an article by Raymond Chandler. This was passed on to me by Prof. Colin Eaborn, and insofar as we need a text for a meeting at Snowmass-at-Aspen, I thought that perhaps this paragraph, which is slightly humorous, if slightly cynical, but definitely sobering, might be appropriate. This is what Raymond Chandler had to say:

> "There must be a hell of a lot of us too, all lonely, all empty, all poor, all gritted with small mean worries that have no dignity, all trying like men caught in a bog to get some firm ground under our feet and knowing all the time it doesn't make a bit of difference whether we do so or not. We ought to have a convention somewhere, someplace like Aspen, Colorado, someplace where the air is very clear and sharp and stimulating, and we can bounce our little derived intelligences against one another's hard, little minds. Maybe for just a little while we would feel as if we really had talent. All the world's would-be writers: the guys and the girls that had education, and will, and desire, and hope and nothing else. They know all there is to know about how it is done except they can't do it. They have studied hard and imitated the hell out of everybody that ever rang the bell. What a fine, warm bunch of nothing we would be, he thought. We would hone each other razor sharp. The air would crackle with the snapping of our dreams, but the trouble is, it wouldn't last. When the convention is over, we would have to go back home and sit in front of this damn piece of metal that puts the words down on the paper."

During the next few days we will be discussing several aspects of education in chemistry. I would like to direct your thoughts for a while toward education in a broader sense; but I believe that what we will be considering tonight is as relevant for education in chemistry as it is for primary, secondary, and tertiary education in general. When choosing the title, "Education for Change," I had in mind the fact that we are training students today for a society in which change is occurring more rapidly than at any previous stage in human history. Three questions are uppermost in my mind. First, is it possible to educate students for change? Secondly, is it desirable for us to try to educate for change? And, thirdly, if the answer to the above two questions is yes, then how do we educate for change? I apologize in advance for posing far more questions that possible answers thereto, but perhaps some solutions will appear later in the week.

I appreciate that as a chemist I am rather presumptuous in daring to discuss a subject which is usually regarded as the province of the professional educationalist. However, this leads me to enunciate my first heretical view and a defense thereof. Winston Churchill once said that modern warfare was so serious for the future of mankind that the strategy of its prosecution should never be left to professional soldiers; similarly, I believe that education is so vital in modern society that we cannot afford to leave the direction of it to professional experts on education. The day-to-day details and tactics are very much their concern, but not the overall objectives nor the financial priority in comparison with other demands on the public purse.

Let me begin by indicating what I mean by the terms I shall use. Much of what I have to say on this subject is, I am sure, common ground to us all. But the word "education", like "democracy", means so many things to different people today that it is right that I should say in advance what I mean by "education." Somebody once said that democracy didn't just happen; it is a state of mind and needs constant nourishment to ensure that it retains its objectives. Similarly, we need to remind ourselves from time to time just what we believe education is and what it is we are trying to achieve through it.

I define education as a process in which a person receives a training for a full life in a rapidly changing modern society, carried out in such a manner as will ensure the maximum development of the individual personality.

This says a lot in a single sentence, and several points call for further comment and elaboration. Let us take these in turn.

1. Education. This is a word which should never by used by itself; we should always talk about education for, or education in, or education through something, since no educational process can

take place without some subject being involved as the vehicle or the objective. I believe that many of our colleges or departments of education have gone off the rails in recent years because they have too often regarded "education" as an end in itself. Education is like pressure; it can neither be real nor be transmitted except through some medium. For far too long we have been mesmerized by certain professional educators who consider it more important for a teacher to be able to "teach" well rather than to possess a sound knowledge of the subject he is allegedly teaching. On this point, I am thoroughly old-fashioned and believe that the first thing a teacher of chemistry (or indeed any other subject) needs to possess is a sound knowledge of chemistry. But I do not underestimate the importance of the need for him to know how to teach.

2. Training. This word means, in this context, guidance, and for education in any subject this implies an effective pupil-to-teacher relationship. The teacher's job is to indicate what to learn and how to learn; but contrary to the view of some of our more avant-garde protesting students, the teacher cannot learn for the student. While I accept that many of our teachers are inefficient, students should recognize at an early stage in their careers this difference between teaching and learning. No matter how good the teacher may be, the student himself must still do most of the hard work in the learning of a subject.

But above all, we must emphasize that the centrally important person in the educational process is the teacher. This is true whether one is concerned with the five-year-old infant or the Ph.D. student, although the role of the teacher will vary.

3. Full Life. No person is trained to live a full life in a modern society unless several aspects of the development of the whole being have been catered to. These include: (a) recognition of oneself as an individual with the development of some kind of ethical standards. This may take place via training in religion of one kind or other; whether these beliefs are rejected later or not, they form at least a basis against which future behavior can be measured; (b) man is a social being and needs to be made familiar with the nature of, and the reason for, the development of the society in which he is living. Normally this involves a wide range of subjects such as history, geography, etc; (c) man needs to be able to communicate both by the spoken word and the

written word, in his own language and, ideally, in some other language as well. In many countries this ability has declined in recent years, at a time when the world is becoming smaller, when the need for effective communication is even more important; (d) man must be numerate. It is essential that he receive an understanding of the process of quantitative thinking appropriate to his intellectual ability. Nevertheless, as pointed out by A. N. Whitehead (1), the eminent mathematician and philosopher, in his lecture, "The Aims of Education", not only is a knowledge of mathematics essential for all members of society; he emphasizes that we should concentrate on those aspects of mathematics which are useful. He said, "Through and through the world is infected with quantity. To talk sense is to talk in quantity. It is no use saying that a nation is large--how large? It is no use saying that radium is scarce--how scarce? You cannot avoid quantity....quadratic equations. Why should children be taught their solutions? Unless quadratic equations fit into a connected curriculum, of course there is no reason for teaching anything about them. Furthermore, extensive as should be the place of mathematics in a complete culture, I am a little doubtful whether for many types of boys, algebraic solutions of quadratic equations do not lie on the specialist side of mathematics;"(e) man usually needs to earn his daily bread. His vocational needs must be catered to; (f) in a rapidly changing world in which there is going to be more and more leisure time, for most people, training for leisure is essential.

4. Rapidly Changing Modern Society. Two features of general importance for education in 1970 are, first, that people need to be educated to live in a modern world and, secondly, that they should be trained to recognize that it is changing rapidly and to be prepared to accept that change as the norm. I do not propose to discuss whether education can change man; I suggest, however, that a good educational system will enable a person to accept change more readily than he is at present inclined to do because he is innately conservative.

5. Individual Personality. It is assumed as an axiom that the development of the individual personality is of prime importance, and the way in which subjects are taught must be such as to ensure that the individual is encouraged to express his ideas and feelings freely.

Let us now consider two aspects of change, the nature and extent of it and its effect upon the individual. One of the constantly quoted current cliches is the statement that we live in a rapidly changing world. But the fact that the statement has become a cliche does not make it any the less true. Unfortunately, many groups in society, including politicians and educators, who constantly refer to change are often reluctant to recognize it or to take it into account in their planning for the future. We need to emphasize in our courses that change is taking place at a rate unparalleled in human history. The idea of a steady improvement or change in the development of mankind is now acceptable, and one can recognize at least three periods when an explosively rapid development took place, resulting in a marked acceleration in the rate of change in society. These periods brought with them painful social problems of the kinds with which we are all too familiar today.

The first big change occurred when man began to switch from a life as a migratory hunter to one in which he became a farmer with a more or less fixed abode. It had gradually dawned upon him that farming the soil brought a higher standard of living and, even more important, a more secure future. This resulted in a major change in his way of life, and he had to develop new skills to cope with that change. Of course, not all peoples adapted in this way and, indeed, even today the Australian aborigine is still largely a migratory hunter. Methods of farming, however, did not change rapidly thereafter, and an Israeli peasant of 1000 B.C. would not have found in Europe in 1600 A.D. very much difference in life on the farm.

According to Hargreaves (2), the rate of material change and discovery between 1 A.D. and today can be plotted reasonably accurately on graph paper. In each case, there was no significant change in the rate of change until the middle of the 18th century. Wind, water, and muscle continued to be the main sources of power; the speed of communications by land and water scarcely increased, and the first doubling of knowledge did not take place until about 1750 A.D.

During the next 200 years the graph ascends sharply. The discovery of steam power was followed by electrical and, later, nuclear energy. Communications were speeded up by using more rapid land transport and eventually were divorced from physical transport by using the telephone, resulting in an even more rapid rate of development.

The major change which occurred about 1750 was the so-called industrial revolution; perhaps this is better described as the energy revolution. It transformed western countries from a largely subsistence and family-based economy in a peasant or semi-feudal society living on the land with little contact with other than one's immediate neighbor into a mainly urban society in which machines with previously undreamed-of sources of energy became the central feature of society.

This had several inevitable consequences. Towns grew rapidly because people had to be located near the machines and their sources of energy. There was a big change in family life, owing to the day-time employment of men and women in factories, with painful social consequences, especially for children. But the industrial or energy revolution did make universal literacy essential, and much of the development of education in the 19th century can be traced back to the demands made by that revolution, which needed a work force which was both literate and numerate. Naturally the emphasis was initially on the purely utilitarian subjects: reading, writing, and arithmetic.

We are now passing through the third major change. Sometimes this is called the second technological revolution, and it is based upon the application of scientific discoveries. Peter Drucker (3) suggests that a better description would be the "knowledge revolution."

The third revolution involves the harnessing of knowledge in a manner undreamed of even 100 years ago. Drucker defines the knowledge industries as those which produce and distribute ideas and information rather than goods and services. He points out that in 1955 the knowledge industries accounted for 25% of the U.S. Gross National Product. Half a century before, in 1900, they had accounted for only 8% of the GNP. By 1965 they accounted for 33%, and they are expected to account for more than 50% by 1980. Drucker points out that the U.S. has changed from being essentially a goods economy in 1939 to a knowledge economy today. We need to remind ourselves of the facts pertaining to this change. It is claimed that half of the world's knowledge has been discovered since 1940, and at present it is doubling every 10 years. (Some say every five years if one takes into account solely discipline and written records.) Thus, in the first 500 years following Gutenberg, that is to say from 1450 to 1950, some 30 million printed books were published in the world. During the past 25 years an equal number of books has appeared; incidentally, a much higher percentage of the community is capable of reading them. Drucker points out also that, and I quote, "Thirty years ago, on the eve of World War II, semi-skilled machine operators, the men on the assembly line, were the center of the American work force. Today the center is the knowledge worker, the man or woman who applies in productive work ideas, concepts and information, rather than manual skill or brawn. Our largest single occupation is teaching, that is the systematic supply of knowledge and systematic training in applying it. In 1900 the largest single group, indeed the majority, of the American people, was rural and living on the farm. By 1940 the largest single group, by far, were industrial workers, especially semiskilled (in fact, essentially unskilled) machine operators. By 1960 the largest single group were what the census called 'professional, managerial, and technical people,' that is knowledge workers. By 1975 or, at the latest by 1980, this group will embrace the majority of Americans at work in the civilian labor force."

Drucker stresses that although knowledge does not eliminate the need for skills, it is fast becoming the foundation for skill. It substitutes systematic learning for a long period of experience. Indeed, it is suggested that knowledge, this systematic organization of information and concepts, is therefore rapidly making the old five-year "apprenticeship" scheme obsolete.

But there are many obvious and painful consequences of a changeover to a knowledge economy. It leads to obsolescence of most manual and semiskilled workers; but paradoxically, it does not lead to a "disappearance of work" for the knowledge worker. The typical knowledge worker in the U.S., western Europe, or Japan is in fact now working harder than a few years ago; and there is a demand for more and more workers of this new kind. The manual worker, the typical employee of yesterday, may have more leisure and may go home early in the evening, but the knowledge worker, the accountant, the medical technologist, etc., and the teacher, etc., take work home with them when they leave the office or school.

What then is going to happen to the uneducated or uneducable in the future? The outlook at present appears to be grim. C. P. Snow once suggested that by 2000 A.D. only 10% of the people in advanced western countries and Japan will have to work! Pessimists suggest that the economy of most so-called advanced countries would be better off if the unskilled were provided with an adequate pension and a fishing rod and encouraged to keep out of the way. This possible solution has several previous parallels in human history. Toward the end of the Roman Empire, slaves at home or abroad were, in effect, the machines, and they also provided the energy; much of the knowledge work was done by a small number of people, many of whom were imported from other parts of the Empire. Bread and circuses were provided to occupy the time of the masses - and the Empire collapsed. It collapsed because it was defeated by an invader who required fewer material comforts, who accepted austerity as a matter of course, but who had a real sense of motivation and purpose. The implications for us at the present time do not need any underlining.

We come now to change and the individual. Man is a mixed-up creature at the best of times and is positively ambivalent toward change. On the one hand, he is basically conservative and is anxious to preserve things as they are to ensure that he feels secure. On the other hand, he accepts with alacrity changes which benefit himself materially, provided it does not require too much mental effort to make use of them. He says he wants change around him provided it does not cause him to change too much.

One frequently tends to dismiss conservatism in mankind as a characteristic of the older generation, but it can be seen in the youngest child. A youngster wants above all physical security, a regular pattern of behavior, whether it be the food he eats, the places he visits, or the kind of amusement he is provided with. How often have parents taken children to a new and exciting restaurant to find that the offer of a menu with new types of food is greeted with a firm and unchanging request for "hamburger and french fries", or in the United Kingdom, "sausages and chips"?

Man will accept change, but he needs to be educated to do so. We can't slow down the world, but at least we can try to ensure that fewer people want to get off. Only the right kind of education will achieve this.

To sum up so far: rapid change, at an ever increasing pace, is a characteristic feature of our society. We need to recognize this; to fail to plan for it is to invite economic disaster and social disorder.

And finally we ask the question, what can we do to ensure that our educational system trains the people it produces to accept change as the norm? I suggest five possible steps which we can take.

First, we must recognize and get across to the student the idea that he will almost certainly change his career more than once during his lifetime; if he does not change his career, then the way in which he does his job will certainly change. His early education at school and junior college needs to be as broad as possible to ensure that there will not be large areas of knowledge with which he is totally unfamiliar and of which he is going to be thoroughly scared if he has to study them in years to come.

Secondly, the content of subjects taught should be carefully examined to make sure that they are seen to be relevant by the student. They must be taught against the background of a modern world with constant emphasis on the way in which the subject has changed and is changing. The teacher needs to emphasize at all times the possibility that new developments are likely. As an example, there must be many teachers of chemistry who wish they had said five years ago, "Perbromates have not yet been prepared.", instead of, "Perbromates cannot be prepared."

Thirdly, we must consider the role of the teacher. Given ideal classrooms, first class apparatus, and plenty of teaching aids, the main factor in teaching will always be the teacher. He needs to be good at his subject, adequate in his knowledge of teaching methods, with the appropriate personality for the job. These qualifications fit him for many jobs which are far better paid than teaching. But the public in general and the politicians in particular need to recognize that only the best people should be attracted into teaching at all levels. The teacher also needs adequate time for keeping up to date, and the idea that, once trained, he is able to teach his subject for the rest of his life without training courses must be finally rejected.

Fourthly, the teacher needs this retraining in his subject with courses of adequate duration at reasonable intervals. The IUPAC Committee on the Teaching of Chemistry suggests a minimum of three months' retraining every five years. This will cost money — far more than the 6.3% of the GNP which the U.S. and the United Kingdom now spend on education. In the United Kingdom, we spend more on either alcohol or tobacco than on education. Unless we get our priorities right and increase this sum to something like 10%, we cannot hope to attract and retain the first-class teachers we need for the decades ahead.

Fifthly, we pass on to retraining in general. Often we hear fear expressed that retraining for new jobs is not really feasible if the person has reached a certain age. Studies by industrial firms and various universities do not support this widely held myth. Drucker mentions several examples of men between the ages of 45 and 50 being retrained very successfully for new careers. The relative ease with which so many military officers at 48 to 50 effect the transition to a new career is a case in point. Indeed, it may well be that their frequent in-service training courses have made them especially receptive to retraining for new jobs after leaving the services. Dr. Hargreaves, an authority on education and the use of computers, gives some very interesting results of the retraining of people for new careers in technology. He says, and I quote,

> "If we move on now to the time that people are entering on their careers, we see that people, particularly in specialized and management areas, can expect to be retrained in basic skills two and three times in the course of their careers. The old idea that you can be deemed to know all about your subject at the age of 21, after which the formal training process ceases, is reminiscent of the sign on the Georgian backwoods road which read 'Choose your rut carefully; you will be in it for a long time.' There is clearly a need for a fresh look by government, the unions and

industry so that people who need retraining can have this before, rather than after, the event. At present Sweden is retraining the equivalent, in terms of the United Kingdom population, of one million people each year. The preservation of an ability to learn and an agility of mind is the only guarantee that obsolescence of skills will not lead to redundancy of people. In this connection, we should consider whether the battles that are fought by unions today are relevant to this decade, and whether the right to retraining and transferable pensions are not the new objectives for which they should strive.

"In my own firm which is moving fast in the technological field, we have found a need to retrain people on a massive scale. There have been interesting experiments. In some cases we have taken volunteers in their 20's and 30's and retrained them with some ease from mechanical to electronic skills. We have also deliberately taken people in their 40's and 50's, and chosen from the lowest quartile of the plant population, and put them through the same training. They needed more motivation and they required a longer course since they had to be taught basic arithmetic and algebra. They passed out however, with exactly the same ratio of success as the younger volunteers. We are concluding two things from these experiments. The first is that age and basic education are not in themselves a barrier to retrainability. The second is that our present acceptance of people for their ability to learn information in a prescribed time may be wrong, since with a longer training period they not only acquire the necessary skills, but may bring other qualities which younger people do not have."

Unfortunately, far too many governments are obsessed with the idea that they should subsidize uneconomic industry to keep people at work in the same jobs. A classical example is provided by the Durham ship yards and by some of the coal mining areas of the United Kingdom. Faced with a dying industry, so far as certain areas are concerned, the government has poured in tens of millions of pounds to keep the industries going so that the same jobs would be available for the workers in the areas. It would have been far cheaper to let the industries die, providing at the same time retraining for the employees for new industries which should have been introduced.

The sooner we are able to convey this message to our leaders, the better. And do we as university teachers yet recognize that further education for all citizens and reeducation in new disciplines will probably make up 75% of our teaching activities by the 1980's? The sobering thought upon which I conclude is that a training for 50% of the jobs that will be available in the 1980's has not yet been invented because we don't know what these jobs will be; we must be ready to train adults for them in the years ahead.

1. A. N. Whitehead, Presidential Address to the Mathematical Association, (U.K.), 1916. See also -- "The Aims of Education," (Mentor Books), 1949.

2. J. A. Hargreaves, "Bulletin of the Institute of Education -- London," 1970, Vol. 21, p. 16.

3. Peter Drucker, "The Age of Discontinuity," Heinemann (London), 1960.

Plenary Address

NEW PROBLEMS NEED NEW ANSWERS

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It was with more than a little trepidation that I consented to address the Golden Anniversary Symposium of the Division of Chemical Education. Although I have spent much of my life trying to educate chemists, it has been nearly seven years since I last taught a class, and it is in those seven years that many of the problems with which we will be concerned this week have come to a head. Nonetheless, I had an opportunity to observe the national scene and the changing picture for science and education at close range while I was in Washington, Indeed, I did more than observe and sometimes emerged a little bloodied, It is from that perspective that I would like to talk tonight of chemical education as part of a changing image of science in society.

Why are we holding this symposium at all? In part, the answer is easy. There is a long tradition, even longer than the 50 years of existence of the Division of Chemical Education, of examination and reexamination of the ways in which chemistry is and might be taught. We all know that it has been a growing and changing subject. In the present context I have wondered just when the Age of Turmoil began and decided that perhaps 1750, just before the War of Independence, might be appropriate for the U.S., at least. That led me to a little historical research and to the proposal circulated by Benjamin Franklin in 1754 which led to the formation of the American Philosophical Society. He proposed to bring together "learned and ingenious men" to advance a wide variety of useful arts, including assaying, making better wine, and brewing better beer.

I have also, as a microcosm of the development of chemistry in the U.S., looked at the history of Brown University. A professor of chemistry was first appointed as part of the medical program in 1811. Chemistry did not become part of the curriculum for liberal arts students until President Francis Wayland made it elective as part of his "New System" in the 1840's. By 1862 chemistry had its own building, and by 1890 Prof. Appleton had the assistance of three junior faculty members. Seven semester courses were offered, including organic chemistry, analytical chemistry, and medicinal chemistry, in addition to descriptive chemistry. I should not forget "Scouring and Dyeing of Wool."

By 1915, shortly before the Division of Chemical Education was founded, no fewer than 28 courses were offered, of which 22 were actually given that year. No less than 15 semester courses were given by Prof. Bucher, who must have been a man of prodigious energy since he was also the principal leader of the graduate program which had been started in 1887. The offerings included all of the modern topics, including physical chemistry, assaying, and industrial chemistry. Senior research was available for honors candidates.

This was the time of the emergence of chemistry in the United States. After the shock of World War I the subject took off, as a rapidly growing and research-oriented chemical industry began to develop. By 1935 the Brown faculty numbered 10, and there were seven graduate assistants. No less than 35 undergraduate and mixed courses are listed in the catalog, together with 15 graduate courses. Such proliferation is a nightmare to any administrator. Most interesting to me is that the offerings were substantially those of the present day, and research was expected from all concentrators in chemistry.

Between then and now, though, the quantitative changes have taken a new direction. Although the faculty has doubled and the number of graduate students has grown to about 100, the course offering to undergraduates has dropped to 14 and the graduate courses to 10.

This history could be paralleled at many institutions. Quite aside from the growth in sophistication and quality of what students were taught, these 50 years have seen steady growth in the numbers of faculty and students and a sharp decline in the time devoted by individual faculty members to teaching undergraduates.

Of course, most of those now concerned about the state of chemical education and the plight of science know only the era since World War II, a period unique in our history which certainly will never be repeated. When I ask, "Why this conference?", the reasons given by most participants almost certainly relate to what has happened in that quarter century, and most particularly to the change which has taken place in the past decade. Many people feel a certain malaise. They sense a switch in student interest and insufficient enthusiasm by the Congress and the public.

The growth of chemistry between World Wars was surely tied to the growth of the chemical industry, the first modern research-oriented industry. The industry provided a market for the products of chemical education, funds for research, and fellowships for graduate students. Although small by modern standards, chemistry departments in the 1930's were a privileged group compared to other science departments. The new researches into natural products, their structure and their synthesis, fed a burgeoning pharmaceutical industry. The polymer revolution had begun, and synthetic organics found new uses as pesticides, herbicides, and medicinals. Physical chemistry established the foundations of quantitative chemistry and made the petrochemical industry possible. All of these industries needed growing numbers of chemical researchers in their own laboratories, which in turn demanded growing numbers of teachers and basic researchers to swell the flow of new ideas and fundamental understanding.

This demand sustained a growth rate on the order of 5% per year.

World War II generated a national awareness of the importance of research, basic and applied. Its aftermath saw health research take off, and new fields such as nuclear chemistry were happily embraced by the nation. For the first time, public money was put into research on a large scale. The growth was phenomenal. The funds available doubled every three or four years until now more than $2 billion per year of federal research money goes into universities, largely for basic research.

There is no question that this was a golden age, a happy age. The number of universities offering advanced degrees in the sciences proliferated to more than 200 as more and more faculties aspired to, demanded, and got graduate students to help them in carrying on their research. The postdoctoral became established as a large-scale institution, and more than a quarter of the

Ph.D.'s went on to postdoctoral research and training. Public money supported students and research and provided jobs for the new graduates.

This happy age coincided with another phenomenon: the rapid extension of our higher education system. The GI Bill built up the college population after the war, and the postwar baby boom supplied a flood of students who taxed our schools and colleges, producing an unprecedented demand for more teachers and new facilities. But the expansion in numbers of children was not the sole factor in the extraordinary growth of higher education. In this period the ideal of universal education beyond high school took hold, and the proportion of students going to college rose steadily so that, from less than 20% before the war, more than 40% of our high school graduates now continue with some form of further schooling.

All of this took place during a period of constant economic expansion.

This extraordinary state of affairs looked to many scientists as if it were the normal thing, and they adjusted their habits and their sociology accordingly. Now the boom threatens to turn to bust, and an urgent stock-taking is in order.

In the first place, by the early 1960's, when total annual research and development expenditures had reached $15 billion, and the research expenditures at universities had reached $1.5 billion, hard questions began to be asked. The research expenditures had not accelerated the economic growth rate, and the balance of payments problem still persisted. Research spending had not contributed particularly to the alleviation of regional economic distress. There had been magnificent advances in the health sciences, but they had not shown up in improved medical statistics. It became clear that the spin-off from the military and space programs was not of substantial benefit to industrial advance. As a result, a variety of congressional inquiries into research expenditures were under way by 1964. By 1967, research expenditures had peaked, the job market had started to decline, and a new phase had begun. I should say here that, in my view, Vietnam was only incidentally related to the shift.

Therefore, the following new factors have all come into play:

1. A leveling off or downturn in research expenditures.
2. A leveling off of the student populations in colleges and in a short time in graduate schools.
3. As a result of the much higher proportion of high school graduates going to college, a change in the mix so that the proportion of professionally-oriented, career-seeking students has declined.
4. A general shift in the country's attention in the direction of social problems -- poverty, urban problems, the environment, civil rights and race issues, and so forth.

How does this show up? The total number of bachelors degrees, including those in chemistry, nearly doubled between 1955 and 1965. However, physics leveled off in 1962, and geology peaked and then declined after 1959. The <u>proportion</u> of baccalaureate degrees in engineering, mathematics, and the physical sciences began a steady drop in 1961, and even the proportion in the biological sciences was about the same in 1968 as in 1954. The proportion in chemistry seems to have stayed about constant until 1964, and since then it, too, has dropped.

It is clear that at the bachelor's level something new began to happen in all the fields of science between 1960 and 1965, somewhat sooner than is commonly believed.

The effect was delayed at the Ph.D. level, and growth continued steadily to 1968 when the numbers graduated were almost three times those of 1958. Only in the biological sciences had there been a leveling off.

The problem in continuing the analysis is that after 1968 the effect of the draft makes it almost impossible to discern other trends.

What can we make of all this in looking ahead for chemical education? First, I will venture the following estimates:

1. The number of men and women who reach age 22 will

grow much more slowly in the 1970's than in the 1960's, will level off about 1984, and by 1990 will be less than in 1970. This much is a certainty, since the children have already been born.

2. Unless something new enters the picture, the proportion of undergraduates majoring in science, mathematics, and engineering will continue to drop, and the absolute number can be expected to level off in the 1980's and then drop.

3. There is no reason to anticipate a growth in research support exceeding perhaps 5% per year, a little more than the growth rate of the Gross National Product.

With this background we can see some parts of our changing task. In the first place, the country will continue to need a supply of the most highly trained scientists. But there will be a change. Because of the high rate of expansion of academic institutions, our training in the recent past has shifted in the direction of pure science and academic careers. That will change. Whereas about 40% of all Ph.D.'s in the physical sciences are now employed in academic institutions, the primary market for Ph.D.'s will shift increasingly to industry, government, and applied work. The orientation of Ph.D.'s will have to change to reflect that fact.

The typical Ph.D. in science is trained today for a career emphasizing research, particularly basic research conducted in an academic environment. That is, faculty members have tended to produce Ph.D.'s in their own image, with only minimum thought for the needs of the industrial part of the job market. Yet it is the industrial sector which must be depended upon to provide employment for the bulk of the Ph.D.'s in the decade ahead.

While industry has absorbed about half of the Ph.D.'s, it has never been entirely happy with the product. Thus, at a meeting in September 1969 attended by 70 of the Corporate Associates of the American Institute of Physics, 93% of those present felt that "the training of physicists at the Ph.D. level is strong but narrow," while 100% agreed with the statement, "Graduate research supervisors instill attitudes in their students that result in low prestige for applied research among young physicists."

I believe the same situation exists in chemistry, although the exact details vary from field to field, and from one thesis supervisor to another. Still, industry has genuine requirements for highly trained individuals which are not now being met. The industrial need is for broadly trained, creative people who are flexible in their outlook, capable of working in interdisciplinary teams, and prepared to work on problems that need to be solved rather than problems they invent.

The situation has been stated by the National Science Board as follows:

> "There is need for a basic reexamination of the assumption underlying doctoral training in the physical sciences. The present doctorate was designed primarily as training for an academic career...and is based on the assumption that there should be no difference in the training of those heading for a university teaching or research career and of those aiming primarily at... industrial research.
>
> "The problem may not be so much one of the content of the educational experience, as it is of the attitudes and values communicated by the graduate school...There is increasing belief that a somewhat different type of training, equivalent in intellectual stature but aimed more suitably for nonresearch careers, should be available. Such training would still involve basic research experience, but possibly with greater breadth and variety and less specialization than the present degree. In the light of evolving industrial needs and changing social priorities, a more nearly fixed time period, less sharp specialization, and less emphasis on an original discrete contribution to knowledge should all be considered as possibilities in any review of the doctoral program. Consideration should be given to providing the student with a wider diversity of opportunities as he pursues his education....Deep specialization in an original research contribution might well be reserved for post-doctoral experience."

A not inconsiderable challenge will be to interest enough first-rate young minds in chemistry, even the number required to meet the modest growth rate I project. In this connection, what is done in the college years may not be so relevant as what happens in elementary and high school, since most students who enter science professionally seem to make their decisions during their sophomore or junior years in high school, or earlier. The critical question, therefore, may be how to excite the best students during their school years.

A recent study by Snelling and Baruch shows that among students who took their bachelors degree between 1958 and 1967, about 50% had chosen science as their major field of interest before entering high school and 80% by the end of their sophomore year in high school. Only 5% made that decision after entering college. Naturally the choice of a field of science came later, 40% before the end of high school and 50% in the first two years of college.

Important steps have already been taken and new high school curricula devised and put into practice. I think it is generally agreed that the quality of high school instruction has improved; many students now enter college with advanced standing in chemistry. Yet, in common with the new curricula in biology and physics, the new high school courses have not attracted more students to study the sciences. In view of my prediction of a declining job market, this may not be bad so far as professionally-oriented chemists are concerned. I happen to think it is terrible, though, because the competition is not only for numbers, it is for the best minds. Chemistry has much to contribute, but its possibilities will only be realized to the extent that it continues to attract and stimulate the able, imaginative, and enterprising student. I leave it to you who are closer to the elementary and high school scene to say how it can be done better.

The central problem of education in the sciences at all levels is how to communicate with a broad spectrum of people. It is an incontrovertible fact that science permeates every facet of the modern world -- agriculture, medicine, materials, communications, transportation, and so on. As a result of practical advances based on science, every one of these areas has been completely transformed during the lifetime of the Division of Chemical Education. Many of us believe that this evidence should be enough to convince every student and every adult that he needs to know and understand science.

Why, then, doesn't he? I rather suspect that for the most part he takes it for granted, like economic advance and taxes. He doesn't study economics, either, although he ought to for the same reasons. He assumes, to a great extent correctly, that the system is geared up to produce constant advance, that there are people and organizations who will do it, and that he doesn't have to worry about it until something goes wrong.

And that is what he now begins to perceive may happen on a large scale. This may contribute to renewed interest. I refer, of course, to the problems of the environment, the new problems of technological assessment, and the social implications of alternative avenues of scientific advance. I say may advisedly because although students and adults alike have shown a missionary zeal in wanting to get after the "theys" who are responsible for our trouble, they have shown no corresponding urge to get into the problem themselves. Enrollments in "hard" courses in Sanitary Engineering or Environmental Science are still dropping.

Our job is to change this because it has to be done. We have just begun the transition from the exploited environment to the intelligently managed environment. Awareness is here; relevance is here; but adequate knowledge and understanding are not. We face growing clashes between the desire for a better life in material terms, and the cost in environmental terms — or vice versa. As scientists, we will have to branch into new channels and open new frontiers to provide that knowledge. As educators, we have to get the scientific principles across which will make public discussion and public decisions rational and meaningful. The task of this symposium and of the years ahead is to find ways to do it.

In this connection I do not believe it to be at all fruitful to belabor the distinction between pure science and applied science. Except for the defense of pure science budgets, where I think it may be self-defeating, it serves no useful educational or practical purpose and puts science in a defensive position.

The fact is that there is a spectrum ranging from philosophy and metaphysics at one extreme, through science as the construction of a body of knowledge and understanding, to science as a means of practical advance. They are all important, and each demands the others.

It is sometimes argued that history has justified the utilitarian importance of science, but history has also demonstrated the philosophical impact of scientific ideas. Witness evolution and cosmology — the proverbial man on the street is aware of both and may be more interested in the latter. Despite our fears, the proportion of federal expenditures devoted to basic science has been rising steadily, even during the crisis of "budgetary restraint." Some of the arguments for pure science sound in Washington not unlike the pleas of highway contractors for more road construction.

So many problems cry out for more knowledge and understanding, as well as a sense of purpose and values, that the case for pure science is made better, in Washington, in our schools, and in public media, by focusing attention on what we don't know or understand and what we need to know and understand, as part of the great human adventure, spiritual, intellectual, and material.

My own inclination is to believe that the time to instill the language of science, the basic facts and principles of science, and the basic attitudes of science is in the elementary school years, not only by course instruction but through TV, field trips, publications such as Science Newsletter, and discussions of ecology, the environment, and all of the many questions involving science. At this level and for this purpose there can scarcely be much disciplinary orientation. Rather, an awakening of wonder about nature, an appreciation of the facts of nature, and a realization that nature can be approached in rational terms must be the principal goals, and all of the sciences must enter as appropriate.

In observing my own children and their friends, I am impressed that great progress is being made in this direction, and if this is generally true it may be that much of what we are saying about present trends in high school and college may prove very wrong in the years ahead. In any case, the problem offers great scope for competent imagination.

Another frontier, I believe, is the continuation of general science education on a more sophisticated level in high school and at post-high school levels. I don't want to belabor this point; science for the nonscientist has been on the agenda for many years. But I do believe it has a new complexion. What is new is the different "mix" of people who are now and will increasingly be the bulk of our post-high school students. In the past, discussion has tended to focus on the middle and upper class professionally oriented nonscientist. Now we must do something meaningful for the growing numbers of lower income, culturally and materially disadvantaged nonprofessionals who will be found not only in four-year colleges and universities, but in community colleges, junior colleges, and two-year technical schools. The possibilities in this new area offer a real challenge to us all.

Finally, I would like to observe that discussions of science education tend to focus on choice and sequence of subject matter, structure of professional curricula, and organization of courses. I suspect that, important as all these are, they are not the heart of the matter. Even perfection in all these aspects will be no substitute for dedicated and inspiring teaching. The most important matter of all may be how to increase the numbers of knowledgeable and inspirational teachers at all levels from elementary school on up. It could even be that the declining market for university research people will make this job easier. But of one thing I am sure: it is the quality of the people who work at it that will determine the course of the next 50 years in chemical education.

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