THE NATIONAL ACADEMIES PRESS

This PDF is available at http://nap.edu/20653

SHARE

Issues for Chemistry Departments of the Future

DETAILS

33 pages | 8.5 x 11 | PAPERBACK
ISBN 978-0-309-34704-4 | DOI 10.17226/20653

AUTHORS

Board on Chemical Sciences and Technology; Commission on Physical Sciences, Mathematics, and Applications; National Research Council

BUY THIS BOOK

FIND RELATED TITLES

Visit the National Academies Press at NAP.edu and login or register to get:

- Access to free PDF downloads of thousands of scientific reports
- 10% off the price of print titles
- Email or social media notifications of new titles related to your interests
- Special offers and discounts

Distribution, posting, or copying of this PDF is strictly prohibited without written permission of the National Academies Press. (Request Permission) Unless otherwise indicated, all materials in this PDF are copyrighted by the National Academy of Sciences.

Copyright © National Academy of Sciences. All rights reserved.

ISSUES FOR CHEMISTRY DEPARTMENTS OF THE FUTURE

Board on Chemical Sciences and Technology

Commission on Physical Sciences, Mathematics, and Applications

National Research Council

PROPERTY OF
NRC LIBRARY

Order from
National Technical
Information Service,
Springfield, Va.
22161
Order No. ________

National Academy Press
Washington, D.C., 1991

NOV 22 '91

NOTICE: The project that is the subject of this document was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. This document has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Frank Press is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Robert M. White is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Samuel O. Thier is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Frank Press and Dr. Robert M. White are chairman and vice chairman, respectively, of the National Research Council.

Support for this project was provided by the Basic Science Fund of the National Academy of Sciences, whose contributors include the Atlantic Richfield Foundation, the AT&T Foundation, BP America, Inc., Dow Chemical Company, E.I. du Pont de Nemours & Company, IBM, Merck & Company, Inc., Monsanto Company, and the Shell Oil Company Foundation.

Available from:

Board on Chemical Sciences and Technology
National Research Council
2101 Constitution Avenue, NW
Washington, DC 20418

Printed in the United States of America

BOARD ON CHEMICAL SCIENCES AND TECHNOLOGY

L. E. SCRIVEN, University of Minnesota, *Co-Chairman*
NICHOLAS J. TURRO, Columbia University, *Co-Chairman*
PAUL S. ANDERSON, Merck Sharp & Dohme
ALFRED BADER, Sigma-Aldrich Corporation
ALEXIS T. BELL, University of California at Berkeley
PETER B. DERVAN, California Institute of Technology
MICHAEL P. DOYLE, Trinity University
BRUCE A. FINLAYSON, University of Washington
JEANETTE G. GRASSELLI, Ohio University
MICHAEL L. GROSS, University of Nebraska
L. LOUIS HEGEDUS, W. R. Grace & Company
LESTER C. KROGH, 3M (retired)
W. CARL LINEBERGER, University of Colorado
JAMES W. MITCHELL, AT&T Bell Laboratories
JULIUS REBEK, JR., Massachusetts Institute of Technology
STUART A. RICE, University of Chicago
GERALDINE L. RICHMOND, University of Oregon
DAVID P. SHEETZ, The Dow Chemical Company
DOTSEVI Y. SOGAH, E.I. du Pont de Nemours and Company, Inc.
DANIEL I-CHYAU WANG, Massachusetts Institute of Technology

DOUGLAS J. RABER, *Staff Director*
WILLIAM SPINDEL, *Consultant*
PEGGY J. POSEY, *Program Officer*
SYBIL A. PAIGE, *Administrative Assistant*
MARIA P. JONES, *Senior Secretary*

COMMISSION ON PHYSICAL SCIENCES, MATHEMATICS, AND APPLICATIONS

NORMAN HACKERMAN, Robert A. Welch Foundation, *Chairman*
PETER J. BICKEL, University of California at Berkeley
GEORGE F. CARRIER, Harvard University
HERBERT D. DOAN, The Dow Chemical Company (retired)
DEAN E. EASTMAN, IBM T. J. Watson Research Center
MARYE ANNE FOX, University of Texas
PHILLIP A. GRIFFITHS, Duke University
NEAL F. LANE, Rice University
ROBERT W. LUCKY, AT&T Bell Laboratories
CHRISTOPHER F. McKEE, University of California at Berkeley
RICHARD S. NICHOLSON, American Association for the Advancement of Science
JEREMIAH P. OSTRIKER, Princeton University Observatory
ALAN SCHRIESHEIM, Argonne National Laboratory
ROY F. SCHWITTERS, Superconducting Super Collider Laboratory
KENNETH G. WILSON, Ohio State University

NORMAN METZGER, *Executive Director*

Copyright National Academy of Sciences. All rights reserved.

PREFACE

This document provides an overview of a meeting entitled "The Chemistry Department of the Future," held on August 12-14, 1987, in Washington, D.C., which was sponsored by the Board on Chemical Sciences and Technology of the National Research Council (NRC). This meeting arose from discussions that first took place at the Advisory Committee for Chemistry among members of the National Science Foundation (NSF), and was organized by three members of that subcommittee: Jacqueline Barton, Ralph Hirschmann, and Mark Wrighton. Mark Wrighton served as chairman of the meeting and was initially responsible for overseeing the preparation of this document. Unlike most NRC reports, this document does not make recommendations, but rather serves only to raise issues and generate discussion. The original plan to hire a science writer to "bring order to chaos" from the transcript was ultimately abandoned in favor of excerpting cogent summary statements of participants. Several participants (particularly Jim Kinsey and Jim Mathis) assisted me in the preliminary editing of the transcript.

The faculty members selected for invitation by a committee from the NRC and NSF represent a variety of age groups (and therefore stages in career), types of institutions, geographical areas, and scientific interests. Input was also sought from individuals with a background in chemical engineering and with significant industrial experience. The following list identifies the participants and shows their home institutions at the time of the meeting (as well as current affiliation if a change has occurred). Also shown after each name are the identifying initials used subsequently in this document.

- Hector D. Abruña *[HA]*, Cornell University
- Paul F. Barbara *[PB]*, University of Minnesota
- Jacqueline K. Barton *[JB]*, Columbia University (now at California Institute of Technology)
- Peter Chen *[PC]*, Yale University (now at Harvard University)
- Robert Cohen *[RC]*, Massachusetts Institute of Technology
- Fleming Crim *[FC]*, University of Wisconsin
- Scott E. Denmark *[SD]*, University of Illinois at Urbana-Champaign
- Peter B. Dervan *[PD]*, California Institute of Technology
- Michael P. Doyle *[MD]*, Trinity University
- Marye Anne Fox *[MAF]*, University of Texas at Austin
- Joseph S. Francisco *[JSF]*, Wayne State University
- John W. Frost *[JWF]*, Stanford University (now at Purdue University)
- Robin Garrell *[RG]*, University of Pittsburgh
- Clayton Heathcock *[CH]*, University of California at Berkeley
- Ralph Hirschmann *[RH]*, University of Pennsylvania
- James L. Kinsey *[JK]*, Massachusetts Institute of Technology (now at Rice University)
- James Mathis *[JM]*, Summit, N.J. (Exxon Corp., retired)
- Daniel G. Nocera *[DN]*, Michigan State University
- Kenneth R. Poeppelmeir *[KP]*, Northwestern University
- Robert M. Simon *[RS]*, National Research Council (now at U.S. Department of Energy)
- William Spindel *[WS]*, National Research Council
- Angelica M. Stacy *[AS]*, University of California at Berkeley
- Matthew V. Tirrell *[MT]*, University of Minnesota
- R. Stanley Williams *[RSW]*, University of California at Los Angeles
- Mark S. Wrighton *[MW]*, Massachusetts Institute of Technology.

The meeting began with provocative opening statements by Clayton Heathcock and Ralph Hirschmann. During part of the meeting, participants met in subgroups chaired by Peter Dervan, Marye Anne Fox, and Jim Kinsey for in-depth discussions of specific issues. The text that follows represents verbatim (or nearly verbatim, as permitted by clarity of taping and editing for correct usage) quotations by participants and discussion chairs. Many of the statements voiced by the three subgroup chairs represent not their own views but rather synopses of the subgroup discussions.

There were many problems raised and concerns addressed. The areas of keenest interest included:

- the implications of the widening breadth of chemistry (toward biology and materials science) for both curriculum and faculty composition,
- the relationship between academic and industrial research at both the intellectual and financial levels,
- serious concerns about the number and quality of students choosing chemistry as a career,
- increasing dismay at the burgeoning paperwork required for maintaining and financing an active research group, and its effect on the quality of teaching and research,
- possible modes for departmental restructuring,
- the consequences of abolition of mandatory retirement,
- alternative methods for financing graduate education and research,
- incorporation of underrepresented groups into the mainstream of industrial and academic chemistry,
- personnel issues among faculty, staff, and students,
- sources for adequate funding of chemical science, and
- the responsibilities of academic chemists in facing scientific illiteracy in the general populace.

The intent of this effort is not to put together a defensible, refereed article, defining norms by which all academic chemistry departments should operate. Frankly, there are many contradictory opinions voiced herein on various topics. What was envisioned rather was that the meeting would engender discussions both in Washington, D.C., and at the participants' home institutions. There was no intention to establish a set of rules by which chemistry departments should operate, but rather to identify and discuss pertinent issues.

Clearly, it is not possible for a document such as this to convey the intensity of feeling and the commitment to the field of chemistry that were exhibited by virtually all of the participants at this meeting. Nor does this document readily differentiate between those discussions resulting in widespread agreement and those that reflected multiple, strongly held, conflicting viewpoints. But that is of little consequence to the reader, on whose conclusions the specific opinions of the participants probably will not have a significant impact. What is important, however, is that this document stimulate thoughtful and extensive discussions among readers and their colleagues.

To hope that this document is coherent and that it accurately reflects the stimulating interchange at the meeting is probably overly optimistic. A more modest hope is that it will identify topics for more extended debate within the chemical community and among faculty at their own institutions.

Marye Anne Fox
Austin, Texas

CONTENTS

Introduction 1

I. Education and Curricular Issues 1

A. Curriculum Themes, 1

B. Academic Research Themes, 6

C. "Pipeline" Themes, 8

D. Department Structure/Policy Themes, 10

E. Other Themes, 13

II. Research Support: The Research Group 15

III. The Academic Community 19

A. "Pipeline" Issues, 19

B. Tenure, 21

C. Where Will the Money Come From?, 22

IV. The Chemical Profession at Large 23

INTRODUCTION

The United States has an important stake in chemistry and must increase its investment in this area. We must be concerned about the number and quality of people entering academic chemistry and the profession at large. We are here as self-serving individuals working in a wide range of departments. What is best for Northwestern or MIT or Berkeley is not necessarily what is best for Texas or Pittsburgh or Minnesota. We wish to survey and record views, and hence identify issues, which will be important to the operative chemistry department of the future.

We can expect some general trends: the scope of what we call chemistry will be greater in the year 2000 than now. Long-term funding will be important. Academic chemistry in 2000 will be at least as strong as at the present time *[MW]*.

I. EDUCATION AND CURRICULAR ISSUES

A. Curriculum Themes

1. What must chemistry students know?

Wherever the best chemists work is the realm of chemistry. As far as colleges and universities are concerned, I think the principal goal must remain to train students to think critically and rationally, and to provide a training which gives the student a broad background in chemistry *[RH]*. We are going to have to give up the idea that we can teach you everything you need to know *[JK]*. I do not think we should expand without bound the things that we expect our students to know. I think we have been irresponsible in trying to have our students learn more and more and more *[MW]*.

The chemistry department of the future will be interdisciplinary. What we have to do to make that happen is to break down the barriers so that people can succeed in working between traditional subdisciplines in a chemistry department *[FC]*. Is there a common core that we require of all Ph.D. chemists? We get into some amazing debates, often very heated, on language requirements *[JK]*. The breadth of chemistry is so large that I do not know enough about my colleagues' areas to teach what their students need to know. Furthermore, we always wind up being a service for somebody else *[RSW]*. It is important in curricular matters to emphasize problem solving as well as writing and communication skills to a much greater degree than is being done now, although it may not be necessary to do this within the formal course structure *[MAF]*. One of the problems with American education is that there is too much passive learning and that is because of the class size *[MW]*. We are also now putting out chemistry majors who are functionally illiterate in everything else. Education is not just being able to know how the latest integrated circuits work, but rather, in general, how to think critically *[HA]*.

We really need to restructure chemistry in academia, so that education is germane to employment, but if industry were to say something collectively, we would need to be very wary of it. Industry is not a very good predictor of the future *[JM]*. A lot of businesses are finding it to their advantage to hire more technical people. Should chemistry start channeling some of its people into business? Should we encourage some of our graduates to take business management *[JSF]*? If we take this to the limit, we end up being utilitarian, in that we will only teach what is in vogue, and we will invariably be out of phase. By the time something that is in vogue in industry relates back to curriculum, it is already outdated *[HA]*. Whom the companies want to hire should not dictate what we do for research. There are many different modes of training for graduate students that are attractive to these companies. One successful area has been large-molecule total synthesis, but that is certainly not the only one *[PD]*.

Perhaps we have outlived the day of the four-year bachelor's degree and we need to think about a five-year bachelor's degree *[CH]*. The American Chemical Society (ACS) Committee on Professional Training (CPT) really does not have an accreditation-type role, so that it can define what should be taught *[JM]*.

2. How are new trends in chemistry being taken into account in the chemistry curriculum?

The strength of the academic enterprise is that new areas and new directions can emerge easily *[FC]*. Whereas you used to have a lead time from a breakthrough discovery which might be ten, twelve, fifteen years, that is down now to something like three years. This is because an understanding of the biomedical or pharmacologic mechanism of a breakthrough drug makes the discovery of a second-generation drug easier *[RH]*. The time required to transform discovery into technology is going to be shorter. Does that mean that graduate students will step out of their academic settings directly into groups in industry, where they will be pigeonholed into a development project based on the science they just did *[MW]*?

The scope of chemistry is broadened *[PD]*. Disciplines are constantly in flux *[JK]*. Not only will the costs be great, but, more important, the benefits to society are going to probably rise more steeply as the impact of the contribution of chemistry, in an interdisciplinary sense, makes its way into different kinds of industries *[MW]*. Organic chemistry will become more biologically oriented. This will not mean a lessening of the more traditional functions of organic chemistry. In biologically oriented organic chemistry, organic chemists address the solution of biological problems. Computers will play an increasing role in synthesis in the years ahead *[RH]*.

The most important chemistry meetings may likely be held in foreign countries in the year 2000 if current subinflationary funding continues in the United States *[CH]*. There may be more opportunities for U.S.-trained chemists to work in foreign companies *[JK]*.

3. Should the curriculum be revised to allow more interdisciplinary perspectives into undergraduate education in chemistry?

The function of the future university or college will be to train students with a broad background in chemistry. Barriers among research disciplines will become less rigid. In terms of formal teaching, many of us still want to wear disciplinary hats *[PD]*.

We are much more locked in on the curricular side, with old-fashioned and outdated ideas, than we are on the research side *[JK]*.

At the elementary level, it is always going to come back to identifying that vocabulary, that body of fundamental information that we are trying to impart, but we may not attract people into chemistry if we teach them solely about this very basic vocabulary *[FC]*. There is a need to prevent too much excessive specialization too early *[AS]*. The way you teach reflects your research effort. People are getting more multidisciplinary, and it is just going to creep in a very natural way into the curriculum *[JK]*.

I am not sure I really think that what is taught should be changed so much as how things are illustrated. I hope that, for example, physical chemistry will be taught in a way that illustrates better the profound practical value of physical-chemical principles to biochemical problems *[RH]*. If we come up with examples from materials science, to give some examples for the fundamentals, it would be better *[JK]*.

The ACS Committee on Professional Training is offering for chemistry department certification a major in chemistry with an emphasis in biochemistry as well as the one with an emphasis in polymer science and one with an emphasis in education. Hopefully, materials science, perceived as a separate entity, will come next *[MD]*.

What the American Institute of Chemical Engineers (AIChE) has decided to do is to take some of the institute's money and fund a cooperative effort in which textbooks and examples are being developed in the areas of biochemistry and electronics. The net effect of the curriculum deliberation in chemical engineering was to introduce a lot more flexibility *[JM]*.

4. Are interdisciplinary perspectives important in graduate education?

I think there will be a trend to question some of the standard subdisciplinary arrangements and to produce a new structure. Each chemistry department should do what makes sense within that particular department in terms of the particular skills and interests of the faculty in a given department *[RH]*. Mechanisms need to be established to recognize and secure support for the best and most innovative of the interdisciplinary research efforts *[MW]*. It is a fact of life that we are expecting a large percentage of our chemistry graduates these days to be expert, at a reasonably deep level, in more than just one area of chemistry *[CH]*. You add value when you get out of discipline straitjackets *[JWF]*.

It should be the NSF's public position that there are mechanisms to evaluate interdisciplinary research and provide funding for the outstanding research in crosscutting fields. The point is that chemistry may be called upon to fuel the next major advances in microelectronics. As the arenas for chemical expertise widen to include problems seemingly as diverse as genetic engineering and microelectronics, it will become all the more important to educate students in these other areas, to familiarize students with the techniques and language of the varied fields *[MW]*. The graduate curriculum should be a springboard for different areas of science, and it does not necessarily have to be expanded *[DN]*. If you want to foster people learning more than one area, a lot of it comes down to the personality of the professors involved *[JK]*.

Interdisciplinary courses ought to be offered as special-topics courses rather than as core curricula. Chemists should develop a way of thinking, a way of identifying problems and solving them, which should be cross-disciplinary *[MAF]*. Leading research universities usually have minimal course work requirements. There is almost a fallacy among graduate students: however you trained as a graduate student, your learning experience stops. In fact, if the tools are all there, students can apply them relatively quickly to move in any direction *[CH]*. But disciplinary labels are still important. When companies come, they want to know what your area of specialization is *[JK]*.

5. Are there barriers to innovation in chemical education?

The long tradition and the conservative nature of persons who call themselves chemists make them significantly resistant to change. A change, for example, was recently made in the perception of what a core for chemistry could be that increased the flexibility of the curriculum. The cry from the community was so loud that the ACS-CPT had to return the traditional core elements *[MD]*. If we allow our perception of the research establishment in the university to be dictated by what has been a traditional, and potentially very outmoded, way of teaching undergraduates, we are making a serious mistake *[JWF]*.

One issue that I see coming up again and again is the failure of the way we teach to reflect a long-range rather than a short-range view. If I can pick on the ACS accreditation standards, they are a straitjacket, and they are the result of a political process, where people are trying to protect territory *[JK]*. A lot of places twenty years ago would have had a big analytical section, but they do not now *[MW]*.

6. In a department with growing specialization, who will teach the core courses? (Are core courses viable?)

The future university college will still conduct formal teaching, with professorial teachers/researchers. There will be flexibility directed toward whatever works best, such as highly qualified, dedicated teaching staff governing large laboratory sections or large freshman courses. Video courses offer the possibility of self-study, with the professorial role reverting to the tutorial style. Team teaching will be more acceptable in chemistry as the scope of the field is broadened *[PD]*. There are likely to be some dislocations with respect to the traditional core areas. It will be harder to find people to teach the undergraduate organic and physical chemistry courses *[CH]*. We have an ever-increasing problem of finding young people to teach the core courses. I wonder if there are ways of bringing into teaching some of these young chemists, with the older faculty, perhaps via team teaching *[RC]*. Just because you are interdisciplinary does not mean you cannot teach the core courses in chemistry *[AS]*.

The young, virtuous, outstanding people are teaching the beginning courses. Many of the brilliant researchers are not broad enough or interested enough to teach freshmen and are teaching special topics in the narrow areas of their research endeavors *[MW]*. Bring in your National Academy members or your most exciting or best people and have them teach freshman chemistry, and really fire the students up *[RG]*. For a large institution, there really is not that much difference between having a professional staff presenting the freshman lecture and having a National Academy member giving it -- except in Puerto Rico. Most students do not know what the National Academy is in the first place *[MD]*.

It is very difficult to continue to teach physical organic chemistry at Berkeley. It is a very important course. We have a hard time continuing to offer that course because we do not have people who work in that area as their research area *[CH]*.

7. What are the problems and opportunities in recognizing undergraduate chemistry as a service activity to other departments?

Part of the strength of chemistry is, in fact, that we have an enormous service role. Academic chemistry had better take up and snare this responsibility, or we are going to lose an enormous degree of flexibility in the things that most researchers want to do *[MW]*. Chemists are service educators in a powerful position *[SD]*. We should treat service courses, then, more as a power position than as something that we do kicking and screaming *[MAF]*.

8. Can teaching and research be coupled?

The problem with undergraduate education is that the professor is on one side of the podium and the students are on the other side of the podium. What is nice about research is that you are on the same side of the problem *[JWF]*. I do not see a strong coupling between my own teaching of undergraduate courses and my research *[MT]*.

9. How can problems associated with the undergraduate laboratory of the future (facilities, costs, waste disposal, instrumentation, and computerization) be solved?

You learn science by doing science *[FC]*. We need to clean up the laboratories. We are going to have a lot of costs in waste disposal. Safety: that is going to cost us more and more money *[JK]*. The answer for undergraduate labs is going to be smaller-scale experiments *[CH]*. A miniaturized lab at MIT produced a payback in three years, in the reduction of the cost of buying chemicals and disposing of them. It is a very short-term payback *[JK]*. It is likely in the future that it will cost five times as much to get rid of a chemical as it did to buy it in the first place. Rather than paying $1.50 for a gallon of acetone, we are likely to pay $7.50 for a gallon of acetone, with $6.00 going to the disposal cost. Blanket arrangements with suppliers may help: a chemist calculates that he needs 17 grams of naphthalene to do a certain experiment. A supplier only offers naphthalene in 100-gram bottles for, let's say, $22.00. A chemist would then call the supplier and say he/she wants 17 grams of naphthalene. The supplier would package 17 grams and charge $22.00, doing away with disposal costs *[CH]*.

It has been suggested that organic lab be taught via a series of video cassettes that covers a whole year's course. The professor can be just as much involved with students. The only thing a professor would not do would be to stand up and give lectures *[CH]*. If this happens in the freshman/sophomore exposure to chemistry, does that mean that the junior and senior level, where undergraduate research is still very important, will become even more important, where they will then get hands-on research experience that needs more coordination and more funding *[KP]*?

If the labs have a staff, one secretary and one person who oversees the labs and helps to coordinate the whole effort, professors can show up and give the lectures, perhaps with a lecture demonstrator who can help with demonstrations *[AS]*.

10. How should computers be incorporated into the curriculum?

As chemical educators, we must train our students in the use of computers to solve chemical problems *[CH]*. Computers and robotics are certainly going to become more important. As everybody becomes more productive and there are more data coming out, how do we format them so they are retrievable by the chemistry community *[PD]*? In addition to direct utility in experimentation, theory, and modeling, computers are becoming increasingly important information links *[MW]*.

Computers in education can be overemphasized, at the expense of one-to-one interaction with faculty. Computers in education should be used to complement rather than to substitute in the educational process *[MAF]*. If I was faced with teaching by computer, and that was my only tool, I do not think I would want to be an instructor of chemistry *[AS]*. If you try to make computer-assisted education a substitute, for example, in a lab experience, I think that is a big mistake, particularly early on. I am not too uncomfortable when you have a computer that simulates an instrument. There are people who would simulate a whole experiment rather than do it, and I think that is when you get into trouble. One sees this kind of attitude with respect to graphics, as well. You can just tinker with the computer to your heart's desire, and you do not really have to delve into whatever experimental aspects you might be looking at *[JK]*.

We are starting to hire educators on the technical staff who are really well versed in computer programming, as well as know chemistry so they can start to do software development actually in terms of teaching *[JK]*. "Trash in/color graphics out." With a lot of this stuff going well beyond the capabilities of the nonexpert operator, we will not be able to tell the difference. Computer technology is moving much more rapidly than chemists' understanding of what is going on. Chemistry has an important role to play in the continuing advancement of computer technology. But highly quantitative things, where problem solving of a quantitative sort is done, are not things easily self-taught, and course work seems to be a good way of doing it *[MW]*. There has been a promise from theoretical chemists for decades that pretty soon I will not have to do experiments because they will be able to calculate it *[FC]*.

11. Should we teach physical chemistry differently?

We are all concerned that physical chemistry is not getting across. People are not learning it. Thermodynamics has been sacrificed greatly at the expense of quantum mechanics *[JK]*. One of the real challenges in teaching undergraduate physical chemistry is the lack of quantitative ability of the students coming up from high school *[PB]*.

12. Is the future of organic chemistry more biological- and materials-oriented?

Organic chemistry as a field represents the largest body of academic chemists who are working in applied areas. Working on materials is no less and no more applied than working on what I call single-function molecules which either come from nature or influence natural processes. Chemists who do synthesize new materials are looking for new properties which are not found in nature and which we need to understand, like composites for airplanes. A lot of chemists sniff at the notion of being involved in polymers because the proof that you have been successful is much harder to obtain. Chemists are the best people to do this *[MW]*. As more people do bioorganic chemistry, they are going to have to learn both fields *[CH]*. I think most of us would agree that is the right approach, rather than inventing boundary-crossing courses and diluting the fundamental background *[RG]*.

The objective of synthesis is not production of new compounds, but production of properties. Synthesis is not, in my view, an end in itself *[RH]*. In the area of synthesis, we are moving towards an era of discovery, to an era of invention. There will be multifunctional, multicomponent, molecule-based systems *[PD]*. I am amazed that people are still doing single-function synthetic chemistry *[JM]*.

13. Is problem selection an important, neglected skill in our teaching?

I do not think students are taught very well the importance of picking a problem where it makes a difference whether they succeed or do not succeed. I have the impression that many investigators do not spend nearly enough time on problem *selection*, considering the huge effort that follows in grant application writing and subsequent implementation *[RH]*. What is driving our problem selection? Each investigator is influenced by market pressures, particularly, the mission-oriented agencies. Is it a "Faustian bargain" -- "I will go work on this because I will get the money?" *[FC]*.

14. Should an industrial flavor be included in the curriculum?

It is important to have a closer contact with industrial research, not only in terms of financial support, but also in terms of what industry does *[MAF]*. I would like to see industry give some of their people more time so they could go out and do some work in universities. I would like to see some sort of affiliates program where somebody from industry would come in and not only talk to students but talk to faculty *[RSW]*.

A lot of departments have an industrial chemistry course, taught by qualified people from industry *[PB]*. One could formulate this as sort of a tutorial where all the undergraduates could be scheduled to see a visiting industrial scientist for half an hour to go over problems in their research *[MAF]*. Release time for industrial chemists -- whether it be a half-day, a week, a sort of pseudo-sabbatical, or leave time -- to interact more with undergraduate students has been suggested at this meeting as a mechanism for industry to help support academic programs *[MAF]*.

Industrial scientists could have adjunct professorships *[JK]*. Having people in the industrial segment come, in effect, on a sabbatical to visit a lab could be a really stimulating experience *[DN]*.

Xerox has developed some text and some standards for the design of integrated circuits. They arranged that students could actually design circuits in the classroom, and the information was sent electronically, in computer code, to Xerox in Palo Alto, and there the actual circuits were fabricated *[JM]*.

B. Academic Research Themes

1. Will chemical research in the future be more "basic" or "applied"?

Frank Press has said: "What's remarkable about science today is the rapidity of advance in so many different fields. The boundaries between science and technology are eroding, and in many core technologies the time between scientific progress and commercial use is shortening" *[JM]*. In many respects, "pure" chemistry research will likely become a smaller fraction of the research activity of academic chemists. People now get the impression that dollars to do basic research almost do not exist, and while they do exist, they are absolutely stagnant *[MW]*. The class of people who just are fascinated by science and understanding how things work or how to make molecules behave the way you want them to has to be protected *[CH]*.

Should the question be short-term versus long-term, instead of pure and applied *[PD]*? The question of applied versus pure seems to me to be totally irrelevant. We solve problems -- problem solution. Who cares which category the problem falls into *[JWF]*? Molecular biology, for example, has largely done away with the notion that everybody in academia is highly motivated to do pure research and everybody in industry wants to make a "fast buck," because so many academic molecular biologists have formed their own companies *[RH]*. In the year 2000 at Berkeley, the terms "pure" and "applied" will be irrelevant *[CH]*.

2. Should industry contribute more to basic research?

It is the exclusive domain of the university to do long-term basic research. Industry does not, should not, and cannot do long-term high-quality basic research. Industry is dependent on the universities for that function. An industrial structure is pyramidal, with a boss at the top. Industry excels at interdisciplinary applied research, but it is structured very differently from an academic environment *[RH]*.

In the area of global economics, I think all of us have a real question about the competitiveness of the United States *[JM]*. I do not think industry fully appreciates how highly dependent it is on long-term basic research *[RH]*. Industrial recruiters already are often looking toward fitting the specific needs of a research group *[MW]*. Industrial research in the United States is run by MBAs, accountants, and lawyers, whereas in a lot of other countries, it is run by scientists *[DN]*.

3. Is chemical research more effectively done in centers and collections of research groups or by individual investigators?

Single-investigator research will continue to be the main way that academic basic science is done *[CH]*. The sociology of chemistry is one investigator, one funding source. People really are very suspicious of collective-funding kinds of efforts *[JK]*.

Center-type research ought to be allowed to grow in a natural way and in a way that makes sense. It should be an add-on. This must happen without undermining the individual independent investigator *[RH]*. As the bigger multidisciplinary programs become instituted, we are going to sacrifice other parts of the program, like the single investigator. There should be a parallel growth in these two areas *[DN]*. Larger block funding is here; whatever chemistry does about it, the trend is not likely to be easily deflected in the near term *[MW]*.

To the extent that one would have to develop a hierarchical relationship to approach a research problem in a center, there would be less incentive to choose an academic rather than an industrial career *[MAF]*. One should collaboratively research by maintaining central, expensive, specialized laboratory facilities, rather than forcing collaborative proposals *[PD]*. We will have a continuation of strong, individual, highly entrepreneurial, effort, and there will be, in fact, mini-centers within single departments *[MW]*. Some faculty members who are now supported by the science and technology centers are likely to have to get back into the traditional grant systems *[CH]*.

Is one going to be allowed to have the kind of independence and creativity that single-investigator research programs allow in a joint proposal? As senior people we must be sure that credit to young people is appropriately evaluated and that young people get credit for contributions they have made to joint projects *[MAF]*. Still the best advice to assistant professors is that they should go off alone, develop something on their own, and get involved in it. They can collaborate, but they have to develop some ideas which are clearly their own *[JK]*.

4. Can we predict important future trends in chemical research?

Two areas of chemistry, initiated by Merrifield and Khorana, only twenty years ago were pure research and long-term. Now, automated synthesis of proteins and nucleic acids is carried out routinely, not only in biochemistry laboratories but also in biology laboratories *[PD]*. There is still a great deal of creativity in how you put your molecules together, how you make your chiral centers, for instance. Automated synthesis is not so much going to be dominating in synthetic chemistry as it is in the gene area *[JWF]*. At Merck the best organic chemists, in the sense of mechanism-trained organic chemists, are in process chemistry. Those chemists who are charged with drug discovery and who generally divide their reading time between chemistry and biology are generally in "basic research" *[RH]*.

Real-time structure determination of reactions of large molecules is the tip of the iceberg *[MW]*. Ultrafast techniques are coming of age and are going to really allow us to look at reactivity in condensed phases. The goal of artificial intelligence is to take the knowledge of a large number of expert organic chemists and be able to access it *[FC]*.

C. "Pipeline" Themes

1. How do we change curricula and teaching to bring more students into chemistry?

The lack of talented and highly motivated students is the root of most of the problems that we have *[MAF]*. We are in a decline in the number of chemistry majors. The best and brightest students are going elsewhere. There has not been the encouragement from industry to say that we foresee a problem *[MD]*. Our most urgent problem is how to really attract the best possible people into chemistry *[RH]*. We recognize that the talent pool is a pipeline, which we should perhaps treat as a multistep synthesis in which we must boost the yield at every step along the way *[MAF]*.

We are losing a lot of people because of inadequate preparation in mathematics and because of the perception that there is nowhere to go in the sciences, that chemistry is not so personally rewarding as other professional careers. We need to provide materials to elementary school teachers to help them emphasize concepts: force (namely, physics) and materials (namely, chemistry). The only way to enhance the interest of students is to expose them to the excitement of chemistry. This means encouraging them before they reach the university. One problem with high school science education is that many teachers with inadequate training are assigned to teach the courses. We need to affirm to those high school teachers that chemistry is a viable career option. We need to produce materials to help high school science teachers have a feeling for newly developing areas and some of the excitement of research *[MAF]*.

The decline in majors is very closely related to the rigidity in our curriculum. We are missing a big opportunity by not revising our curriculum to, at the very least, include interdisciplinary topics, and topics currently receiving media attention *[RG]*. In attracting students to chemistry, it is much too late to do so by the time one is a freshman. We must invest a significant fraction of our resources to, in fact, enhance the attractiveness of chemistry for the very best and brightest, in all of our institutions, and provide them with a singular experience that draws them into the excitement of discovery *[AS]*. Undergraduate instruction could be improved if lab TAs were not first-year graduate students *[JK]*. The model for undergraduate students could be that the labs are manned by seniors who serve as teaching assistants *[CH]*. Or, heaven forbid, faculty members *[JK]*. Chemistry has done a tremendous variety of things: eradication of diseases, addressing problems in the Third World, and so on. People who write textbooks often do not indicate any knowledge of these topics *[MW]*.

Physics has a more nurturing environment, whereas chemistry tends to eat its young *[HA]*.

2. Can we do more to be role models for students?

There will be in the future, and already are, insufficient numbers and quality of academic-bound graduates into chemistry, and we are not doing a sufficiently good job as role models to encourage them to consider academic careers *[SD]*. We must more clearly promote the idea that chemistry is a career in which one can develop expertise which would enable one to have a productive, interesting, and intellectually stimulating life. When people address the question of a career choice early on, they think about the quality of life. We sometimes do not convey the joy and quality of life that we have as academicians. We need to convey better, I think, the intellectual stimulation that we get from our profession *[MAF]*.

We need to instill in students the perception that they will be given a lifelong set of credentials that are negotiable over the period of their careers, over their lives, that they can move around in the field as the world changes *[MW]*. They do not see the fun, the sheer fun of being involved in the scientific project, because the assistant professor is constantly worried about motivating the students. Students only hear all the bad things, and they get amplified, so that for students, there is no reason to want to go into this profession *[AS]*.

We do not do a good job of pointing out the rewards and pleasures of academic research. Nor do the students know what goes on in industry *[SD]*. The academic scientist probably has a far greater chance than the industrial scientist to control his destiny. If you are in industry, I think the latitude you will have is going to be somewhat lower. Students too often get the impression that professors push papers and run small businesses rather than doing science *[MW]*.

We should try to develop a mentor relationship with our students so that they can get the excitement of research early in their college careers *[MAF]*. It is the individual attention, the mentorship, that is necessary *[PC]*. Mentorship does, and should, include industrial participation *[MD]*.

3. Are we realistic in counseling students about academic research careers if funding is going to be tight?

We make a mistake if we hold out the academic career as the open channel for most of our students. There are lots of reasons, outside of talent, that people should not go into academia *[FC]*. You really have to let them know that the chances are one in three that they will obtain research funding, and the chances are better at MIT than they are at University X, where they might be more likely to get a job *[CH]*. MIT students I know pick their majors based on the experiences of their peers. A student was told here that one firm laid off so many thousand chemists because the company was moving into biotechnology: the perception was that instead of chemists being competent to move into that field, the firm had to get rid of them *[MW]*.

You have to tell students what it is like in industry to have a research project ripped away from you when you are just getting into the interesting part and to be told to go into a completely new area of science. Find out how many chemists have been laid off at certain companies, and it is starting to get through to graduate students that you do not have a secure life; do not kid yourself *[JK]*. If the economy is bad, we are just going to find ourselves in a period of retrenchment, continually trying to improve our situation at the margin *[RSW]*.

A challenge is to develop a plan for accountability for research that requires minimal time of the scientist *[MAF]*.

4. What is the role of primarily undergraduate institutions?

Undergraduate institutions have traditionally supplied a large fraction of the best U.S. chemistry graduate students. Only a small fraction of private liberal arts colleges that are suppliers of students are going to be able to attract the faculty that will be able to excite students in the future because they are not going to be able to locate qualified faculty *[MD]*. There is some realistic argument that the research money that is spread to some of the four-year colleges is, in fact, very well spent, because the undergraduates are coming out with some exposure to science that is research-oriented *[MW]*.

Faculty choose to work at primarily undergraduate institutions because they really love to teach, are very good at teaching, and want to do it. But many also view the prospect of going to a major university, and competing for scarce research funds, with abject terror. There are a lot of people who are not willing to put up with the hassle of a high-pressure research-oriented department. The life-style of a college professor in a non-Ph.D. environment is very attractive to a lot of people *[RG]*. Schools would not even interview me because they thought that I would not want to go there since they knew I had already interviewed at Berkeley *[AS]*.

D. Department Structure/Policy Themes

1. Should departments consider a six-year B.S./Ph.D. program in chemistry?

Are we saying that having taken core requirements in the first year, five years later a student can graduate with a Ph.D. in chemistry, and we get the student to foot the bill *[MW]*? Some things would be left out of the six-year program. I would be very concerned about the loss of repetition that I think is important for a Ph.D.-educated person *[RC]*.

One of the great downsides of a joint B.S./Ph.D. program is a lack of a healthy exchange from one geographical/cultural center to another. Chemistry should do everything possible to encourage changing institutions between undergraduate and graduate degree programs *[MW]*. If a combined B.S./Ph.D. program were adopted, students should switch from one faculty advisor to another during their training, so as to have two separate exposures, often to two different areas, to have breadth in their education *[MAF]*.

2. Should we consider lengthening the time to get a Ph.D. or changing the nature of the postdoctoral experience?

Could we consider a program where the Ph.D. is fairly well locked into a four-year program, but there is an increased amount of course work directed toward giving students the background that is necessary to become adept in several fields, and where the research requirements do not necessarily expand? Perhaps a residency requirement, but more fixed than it has been, with a minimum two-year experience in a particular area *[MD]*? If your average Ph.D. were to go from four-and-a-half to five-and-a-half years, it would mean 20 percent more buildings *[CH]*. We really should not be increasing the length of the Ph.D. We have already done that by going to postdocs *[JB]*.

3. Does the traditional divisional structure in departments have a future?

The new people being hired will primarily be oriented toward the interdisciplinary areas, divisions in biochemistry, materials chemistry, and polymer chemistry *[CH]*. Divisions in the future may emphasize essentially synthesis and measurement, rather than subject areas. Chemistry departments have probably evolved along two different lines, synthesizers and measurers *[MAF]*.

There are problems associated with the present divisional structure *[MD]*. Divisions create problems, more so than perhaps they have been solving *[JK]*.

One reason for divisional structure is the necessity in very large departments to address a smaller set of issues in order to reach a consensus. A division can define what a reasonable core exposure is within that subdiscipline, to ensure that students going through any single research group do not become too narrow *[MAF]*. If your department works on a consensus basis, you cannot go into faculty meetings with majority votes without divisions. The matrix you are dealing with is smaller *[JK]*. Divisions are absolutely necessary, not because you want divisional people, but for administrative purposes, because they are much more efficient *[SD]*.

If the discipline of chemistry is on a course where its boundaries are getting broader and more diffuse, how do you handle issues like the intellectual life of a department *[RS]*? More dangerous is the complacency of physical chemistry students who just refuse to learn anything organic. The practical thing to say to departments is that people should not be required to belong to one division only *[JK]*.

4. Will barriers between chemistry and other departments become less rigid?

The traditional barriers between subdivisions of chemistry have been crumbling. You see that between organic and inorganic in almost every department, for example. I think we may be starting to see that happen between departments *[CH]*.

I highly recommend a college of chemistry. Our college of chemistry will include more than two departments, with different focuses. Basic research in biochemistry has been transferred from the traditional biochemistry departments to chemistry. The same thing has been true with materials chemistry *[CH]*. There are not any disciplinary boundaries to chemistry. Universities might really be better off if there were just faculties of science *[MT]*. There is a question of people moving away from chemistry departments because they would be more comfortable doing interdisciplinary work outside of chemistry departments *[JK]*.

We have lost a couple of biophysical chemists to biochemistry departments, for the primary reason that they would have a lighter teaching load *[CH]*.

5. Will the average department of the future (with an approximate size of 20 faculty) be much less well-rounded in its coverage of chemistry?

The scope of chemistry is very likely to be broadened. But academic departments are, by necessity, going to have to make priorities within their departments, within the constraints we are going to work with -- few new buildings, no expansion in faculty. There will be little or no growth. You will see more departments which are not the well-rounded departments that we have today. There will be very careful hiring; the resources for faculty, even at the most richly endowed universities, are too low, and a way to make the quality of life of chemistry faculty better is to reduce faculty size *[MW]*. Some people will have been hired away to other countries, primarily to Germany and France, because of opportunities and an improved standard of living in Europe *[CH]*. Another challenge is to strengthen the faculty situation. There are too many unfilled openings in chemical engineering faculties *[JM]*.

6. Are we creating a two-tier (or three-tier) faculty at research universities?

Because of huge faculty set-up costs and reduced numbers of graduate students, we are likely to develop a two- or three-tier faculty. One will have people who are primarily involved in research, a research faculty; a second faculty, who are involved with lower-division teaching; and a technical staff, who will be involved in research, but not as faculty principal investigators. The faculty who concentrate on undergraduate teaching are not going to be, particularly, the ones who drive front-line research, but they are the ones who will interact with first- and second-year students. *[MAF]*. Three-tier staff seems likely. We will have one that will do undergraduate teaching, one that will do research, and one to manage technical aspects of it *[JK]*.

I think it would be very bad if we had this two-tier system. I consider myself a teacher *[JB]*. We should stay as teachers and researchers, because this is best for the education of students *[PD]*. When we start parcelling off undergraduate education, I really feel we are cutting ourselves off from our roots *[JK]*. You want the same person doing both undergraduate teaching and advanced research and graduate interaction. Otherwise, the undergraduate instruction suffers *[FC]*.

If you build a large, subtechnical structure into teaching undergraduates, even with faculty overseeing them, you see an immediate drop in the number of students who are going into chemistry *[JK]*. From a pedagogical perspective, since teaching is their primary function and occupation, a dedicated undergraduate teaching staff do a far better job. The students who are exposed to these people are usually unanimously enthusiastic about their teachers, and they actually get disappointed when they come in touch with the research faculty and find that they are not nearly as interesting teachers as the people who make it their profession *[SD]*. Some of the time burden for the large courses could be diminished with an appropriate support staff *[MAF]*.

7. How can chemistry departments best accommodate the abolition of mandatory retirement?

The average chemistry department faculty will probably still number about twenty-three (remaining constant in 2000). In 1986, Congress abolished mandatory retirement, and so people, by and large, may not retire anymore, so that the vacancy problem will be cured. The average age of a faculty member in my department in 1987 was forty-seven years old; by 2000 it may be fifty-three-and-a-half, and growing year by year *[CH]*.

If large numbers of people elect to continue to be active professors beyond age seventy, it is going to cut back on the number of younger people we can bring in, with a deleterious effect on rejuvenation of the field. It obviously has an effect on trying to increase the number of women and minorities *[CH]*.

No-mandatory-retirement is incompatible with the notion of lifelong tenure. When you are given tenure in the future, it will have to be for some period of time. At the end of that time, there will be some kind of cyclical review. There will be a lot more time and energy spent by people evaluating other people. People will tend to be humanitarian and keep older colleagues in active roles even if they feel it would be in the best interests to recycle that position *[CH]*. If mandatory retirement is really taken away, there must be some sort of capping of traditional tenure, after which a review would have to occur *[MAF]*. Teaching and innovation in research often come from the younger people. If, indeed, the new law with no mandatory retirement age comes into effect when there are limited resources, that means that every person over age 70 blocks two assistant professors *[JK]*. When someone is tenured, that might be for some long but finite period of time. At the end of that time there would be periodic reviews, say five-year reappointments to the tenured position, or something of that sort *[CH]*.

The culture in the department is that you must continue to do research to be one of the primary members of the department. We philosophically put these research-inactive people out to pasture. I am not sure that is a very good use of our resources *[FC]*. The dissolution of mandatory retirement might give rise to a natural evolution of new missions that these people can find, besides research, and it might prove more successful than we can even conceive of at this point *[RG]*. Older or retired professionals have the time and interest to do something to strengthen the profession. We should consider them a very valuable resource and encourage their active participation in guiding prospective students at many levels *[MAF]*. If you, by mandate, throw people out the door when they are older, you are sacrificing an enormous amount of perspective and experience, and it is not necessarily clear to me that younger people are necessarily better. You do not want to limit the option of those people who may be very productive: they should stay on *[JK]*.

Legal ramifications of lack of mandatory retirement are not being sufficiently clarified by most university administrations *[MAF]*. Anything that says that you cannot do something at age 70 that you could do at age 69 is illegal. In a tenured line, it does not mean that your salary would have to be sustained *[JK]*. The compensation package is probably going to be an answer to how one deals with mandatory retirement *[MW]*. Why not simply say that all salary increases cease at age 60 except in some very unusual cases? A better solution is to encourage the government about ten years from now to offer attractive early retirement for professors *[JK]*.

I do not think you would want most faculty members teaching undergraduates when they are 85: most people lose their sparkle, and are not really up-to-date on modern things at that point in time. But it would be impossible -- *impossible* -- for anybody in our department to go to such a person and say, "You are going to have to quit. You cannot do it anymore." It would just be shattering to him/her, and none of us could do it. If you look at all university professors across all disciplines, you will find that not many people do not take timely retirement, or even early retirement, if offered the opportunity *[CH]*. The reality is that if a faculty member has been around for 30 years, it is going to be hard to terminate that person.

8. What is an appropriate role for support staff?

NSF-funded instrumentation has operated on the assumption that if NSF provides the hardware, the university can provide the upkeep. This policy must be looked at very carefully, particularly in regard to the large number of technical support staff who must be hired. NSF should shoulder some of the burden associated with the need to have highly educated personnel and staff to run and to maintain chemical instrumentation *[MW]*. The days of having an NMR machine that could be run and maintained by graduate students are over *[JK]*. The equipment has to be maintained and upgraded by staff, and it will be very expensive. Currently there is no way to fund that person, except by a tax on our individual research grants *[JB]*. If one were to decouple education and research, some of the people would move some of their resources to people they can depend on, on a pseudo-permanent basis -- more research technicians, more professional staff operating within groups -- and this is going to be a much larger fraction of the budget at NSF *[MW]*. As one develops a larger technical staff, senior people in departments must assume more of an administrative burden *[MAF]*.

E. Other Themes

1. Should industry provide more research support?

Industry ought to be picking up a bigger piece of the tab *[JK]*. If you include all federal agencies that support basic research in universities, the NSF provides about 45 percent; the NIH and DOE and DOD supply most of the rest. The total amount of money in chemistry from all federal agencies is about $225 million per year. To put that in perspective, that is probably one-third of Merck's budget for research. This is about half of du Pont's research budget. Divide that $225 million by the number of graduate students. American industry is not paying nearly its share of the cost of training the Ph.D.s. The German system is that each company sets aside a percentage of profits into a fund, called the DFG, which supports academic research. Training a Ph.D. chemist is a particularly expensive proposition *[CH]*.

The university/industry interface is weak in the United States and must be strengthened *[JM]*. I know that in Switzerland and Germany there is a much larger percentage of industrial support for academic research. We must convince industry to come up with a larger fraction of the necessary money, which will make us competitive without the kinds of strings attached that make it applied rather than pure research *[SD]*. The amount of industrial support to the universities has about doubled since 1980, from 3 percent to about 5 or 6 percent. For chemistry departments as a whole, it has also about doubled, but from about 5 or 6 percent up to 10 or 15 percent. For chemical engineering departments, it has gone from 10 to 15 percent to over 30 percent. The European system provides more industrial support in lieu of support from agencies like the National Science Foundation *[JM]*. Japanese companies are now interested in coming over here and putting money into specific research groups here in the United States. What they are interested in is return on their investments. So they are going to target individuals. Non-U.S. companies coming in and investing in U.S. research may represent a new source of non-federal support *[RSW]*.

Frankly, I think it would be a large challenge to develop an interest on the part of industry to do this *[JM]*. It seems clear that a major increase in academic funding will not, and probably cannot, come from industry, and therefore the academic enterprise will require increased government support if the strength of U.S. chemistry is to be maintained *[MW]*.

The government has to remain the principal source of the funding of basic research. If someone is going to, as you suggested, take the money out of a research budget, the people making that decision want to see that money go into an area they think is pretty closely aligned to what they would be doing in-house *[FC]*.

The major corporations of the world are going to go wherever they can find the best individuals doing the things they would like to see done. I have no moral dilemma, myself, in interacting with any foreign company that is a for-profit enterprise *[MW]*. A given company likes the one-to-one relationship, because it means that the company's name is identified with a new instrument, lab, or whatever *[RH]*. I think it is easier to solicit money for the "Industry X Center for Relevant Chemistry," or whatever, than to ask them to contribute $50,000 to the start-up of Joe Blow *[HA]*.

University/industrial relationships will be improved to maximize benefit to both parties and will become international in scope *[PD]*. We should try to instill into industry that it is in their own self-interest to be supporting all of this work *[HA]*. Income tax incentives should be given to industrial consortia willing to fund departments or train future chemistry Ph.D.s *[PD]*. My research group has had very good experience with industry. Instruments have become available; companies have taken my graduate students and paid for them to stay a week at the companies and use instruments for my research; I have gotten a lot of funding *[AS]*.

Has industry really bought the idea that keeping academic departments healthy is important *[FC]*? The National Academy of Sciences might want to consider sponsoring a conference on this issue, trying to bring together the key people from industry, and lay all this stuff out on the table before them, get them interested in it, and see if it is possible to generate some real sympathy and action *[JM]*.

Industrial money has to come in unrestricted. It has to come in a way that it does not fashion what you do *[JB]*. The model that I think would be better is if the industries would drop back a little bit from this need to have a common project, but also match that with an unrestricted commitment that maybe goes into a common pool *[MW]*. That bridge of our communicating the real need that you see has to be built to industry *[JM]*.

The Presidential Young Investigators (PYI) program at NSF has not been successful in bringing in a lot of new industrial money to chemistry departments. So one might look to what failures have occurred there and ask, what is wrong, and how are we going to solve that problem *[PB]*?

The university's job is to disseminate information, and the company's job is to conceal it, insofar as it is possible *[JK]*. Any company that is getting involved with university researchers is hopelessly naive if it thinks they have a secret. There are few secrets in academic chemistry, and I do not believe there should be any *[MW]*. Companies are very concerned about bringing their samples on to university campuses. There is a real problem of proprietary interest *[PB]*. Some U.S. universities have started to allow classified research on campus. I think that is a lamentable direction to go *[JK]*.

I think everything about the interface between universities and industries is fine, except one thing. Companies take and do not give. They need to put in more money. American industry does not put enough money into the universities. The University of California is very reluctant to even accept certain industrial money because of the appearance of strings. A private school can afford to be a little more entrepreneurial than a public one *[CH]*.

The principal product that we provide for industry is personnel *[MD]*. Can you think of how many problems it would solve if every company ponied up, let's say, $200,000 to the school from which it hired a Ph.D. chemist? It would reward the productive departments *[CH]*.

The only good way for industry to financially support small colleges: an instrument-donation incentive that the federal government had in place until last year *[MD]*.

Many departments have appendages -- the Whitehead Institute for Biomedical Research, the Fusion Research Center, the Microfabrication Facility, for example -- that represent resources, instrumentation, a connection with industry *[MW]*.

2. Is fraud in chemical research a significant problem?

There is probably no more or no less fraud in chemistry than in other sciences *[JK]*. It is necessary to develop absolute ethical standards, which we should not simply assume that our students know about. We should communicate very often to them, and we should speak the unspeakable: deviations from ethics are not tolerated. We should recognize what we might call passive fraud, that is, the tendency to omit from papers negative experiments or to not be completely honest in describing experiments that do not fit a preconceived approach that we are pushing. There is more self-deception, I think, than fraud *[MAF]*.

In the old, old literature you could write: this worked, this did not work. What you do now is suppress everything that is not working because you do not have any explanations for it or it will not be accepted in the literature. Other research groups heading off in that direction are unaware of what you really do know: that is the fraud I worry about. Are research groups getting so large that we cannot supervise? Senior investigators are now sometimes involved with work that they are greatly detached from. I am not saying people are more dishonest, do not get me wrong, but things are now more tightly coupled *[JK]*. Have we developed research patterns in which we have groups which are too large to supervise *[MAF]*?

If you had even two people, you could not supervise them at every ten-minute interval. If someone wants to be dishonest, they are going to be. As a profession, we insist on absolute integrity. In the biomedical profession, there is an incredible drive to be first and in trying to be first in this, they might be a little sloppy *[JK]*.

II. RESEARCH SUPPORT: THE RESEARCH GROUP

1. Should graduate student support derive from sources independent of research grants?

We must develop a new mechanism of support for graduate students *[JK]*. The average grant in 1987 supported only an average of half a postdoctoral co-worker and about one-and-a-half graduate students *[CH]*. More fellowships could be very good for chemistry, from primarily the point of view of public relations. I still remember the feeling I had: here is a field that wants me. I have been recognized. I had *carte blanche* to talk to all the faculty. There were the national competitive fellowships and there were co-op fellowships *[CH]*. The way things used to be, research groups did not have to raise large sums of money. The graduate students came with their own money. It also gives support for a time period consistent with that needed to complete the degree *[JB]*. Any discoveries that I make are just gravy.

My real mission is to train students. The funding ought to be uncoupled *[CH]*. The burden of running the research program has fallen completely on the professor. Perhaps we should redistribute that burden: put some of the responsibility on the student *[PD]*. University professors are spending large fractions of their time raising money, not only to buy equipment and to pay for supplies for research, but also to pay students *[CH]*.

Why not just ask the students to pay the bills entirely *[MW]*? I love the idea of returning to the past, where the students got the money, rather than all of us having little kingdoms and having to raise money for the students *[JB]*. Concerning ways of separating funds for student support from other kinds of research funds, there is some sentiment for the idea of moving toward a system where faculty would not support students, where students would finance their graduate education in another way. Part of the problem with the students is the anxiety. You take on a student and make a moral commitment that you are going to see that student through four years. Nobody has four years of funding in his pocket at any time *[JK]*. In Japan, graduate students are not paid. Most graduate students in Japan work in school up to the point of the master's degree, and then they go into an industry *[RSW]*.

An argument advanced against student fellowship programs is that all the students would go to the best places *[MW]*. The major problem is the question of how they would be distributed *[KP]*. Our peer review system is very much more able to identify good research programs than to identify promising students. Our track record in identifying the best graduate students is not nearly as good *[JK]*. The NSF fellowship program has not attracted young people into the field of chemistry, or into any other field. They are already committed by the time they are making application for the fellowships *[MD]*. Maybe we should make the fellowships for the last two years of graduate study, based on evaluation by a group of faculty inside the department *[MW]*.

The thread of continuity in research groups in academic departments is the professor. The transitory nature of the entire group is a strength and a weakness of the system. The system is not off by a factor of ten in the funds available to keep programs viable *[MW]*. We are all leveraged in many different ways. The trade-off of lower research grants in exchange for more student fellowships is another way of leveraging the money that we have coming in *[RSW]*. There are already a lot of very marginally funded research programs. If you do not have to pay for the graduate students, there might be a great temptation to take on too many graduate students and to pay too little attention to their progress *[JK]*. It does not mean that every principal investigator is going to develop a huge operation. But there are some people who can handle it and who are going to be good at it *[MW]*.

A good feature of fellowship support to students is that it gives students a greater freedom of choice in selecting a mentor. However, there is some considerable evidence that students with their own support might not choose to work with new professors, considering that people who have postdoctoral fellowships do not bring them to work with assistant professors *[MW]*.

In the 1960s, there were both competitive national fellowships and the cooperative fellowships. Those were placed in universities. If a training grant is given by an institute of the NIH to a department to support thirty students, then it is the department's responsibility to place those grants with the deserving students *[CH]*. But the other side of it is that if a department has one of these things, then individuals in that department may not apply for student support in NIH applications. Foreign students coming in are not going to be identified and given fellowships: how will they be supported *[RSW]*? Even if graduate fellowships were financed in this way, we would still have to have a parallel program of independent funding and would have the same problem regarding proposal writing and paperwork again there *[MAF]*.

A postdoctoral fellowship program should be established to promote the broadening of education of scientists *[MW]*.

2. Would longer funding cycles reduce the paperwork burden on grantees?

Many people are now operating with subcritical funding for their programs. There should be a commitment to not fund programs with subcritical resources. Where justified, continuing grants should be longer in duration *[MW]*. There has been a very strong sentiment at this meeting that everybody would be very much better served if the federal funding agencies could be persuaded to go to five-year or longer-term funding cycles. This would relieve a lot of pressure, not only on the investigators, but also on program officers and the whole review system. Otherwise, going to a generally longer cycle, having more flywheel on the graduate student support, it seems to me, would make a lot of sense. The anxiety that one is going to be able to continue to support students takes its toll *[JK]*.

Short-term funding fosters short-term research *[PD]*. Peer review does work very well in the sense of identifying those who should be supported, but the presumably small resource pool and the ever-increasing inflation on what people say about things in order to promote funding for a given program -- all of that seems to be leading to a great deal of conservatism in science. Conservatism is built in further by the three-year grant program. People are not taking major risks, and if they do and it does not work, there is no room for failure. The need for long-term funding is one consensus conclusion that we have come to at this meeting. Longer-term funding is not necessarily going to cost more, and it would be of enormous benefit to the whole enterprise *[MW]*.

The reservation in the NSF is that it reduces their flexibility qualitatively. Nonetheless, the White House Science Council's report, the Packard-Bromley report, recommended longer-term grants, five years at least. The NSF advisory committee has recommended five years *[MW]*. I would like to put out a recommendation that says five to seven years for the usual grant *[CH]*. "Creativity extensions" can address this problem *[JK]*. Fewer than 10 percent of the grants now can receive a special creativity extension *[MW]*.

The downside for the principal investigators is that they are likely to get less of an increase if they are doing a good job, in the five-year cycle *[MW]*. Even on multiyear awards, you have to exactly zero-out on a twelve-month basis. The net result of that is a lot of frantic and creative bookkeeping. Investigators would be much better served by saying they cannot overspend, but they can underspend and carry that over into another year *[JK]*.

Under the present system, faculty find themselves spending more time gaining the resources to do what they want to do than doing what they want to do *[MW]*. A system which forces a research director to seek multiple grants to support his/her research will have to tolerate tighter reporting requirements and allocating a large fraction of the principal investigator's time to paperwork. Paperwork and administrative burdens on the individual faculty member are likely to increase even further if confidence in continuing funding erodes. This will cause a shift of faculty time away from that which would have been available in other times for teaching *[MAF]*.

A great advantage of the American scene is that if you get rejected at NSF, you can go to a number of other government agencies for support *[MW]*. If NSF gave out all monies, there would be a lot of the leading people who would not be able to function, because NSF does not give very large grants. Large programs would have a hard time if they had to deal only with NSF *[CH]*.

3. Will upgrading facilities to an acceptable level involve staggering costs?

The Westheimer report in the sixties highlighted instrumentation needs *[WS]*. The cost of instrumentation in universities will probably have increased by another order of magnitude by 2000

[RH]. The newest NMR instruments are easier to operate but have a very high cost *[CH]*. We are going to have to increase our funding base in the United States, as equipment gets more sophisticated, and industry is a place to look *[DN]*. Already, the NSF chemistry division is putting 20 percent of its total money into shared instrumentation. But that will not be enough to keep up with the cost *[CH]*. The level of funding is not likely to go up proportionately with costs *[JK]*.

How will new buildings be funded? The major source of funding will continue to have to come from the government *[RH]*. Staggering costs are out there for upgrading of substandard facilities. Most chemistry departments are probably currently operating in violation of the law *[JK]*. Of the forty chemistry departments ranked at the top in the most recent American Council of Education study, 31 need new buildings, estimated to require $1.4 billion. Brick-and-mortar-type money requires federal help. The problem is greater than the states are going to be able to handle. Our buildings were built in the mid-1960s. However, they are totally inadequate by modern standards of ventilation *[CH]*. We are going to have to have federal support of bricks and mortar *[JB]*.

There is a rotating "black hole" at the senior level among faculty in the United States, made necessary because that is the only way now that senior people can get major funds necessary to upgrade their own instrumentation *[MAF]*.

4. Do regional equipment facilities make sense for some kinds of major equipment?

Interdisciplinary centers will provide an opportunity to focus on a research problem in a cohesive manner, rather than with a scattered, fragmented, and subcritical funding level *[MW]*. There must be interdepartmental cooperation for programs that require a fair amount of capital investment in terms of facilities and individuals to support those facilities. You cannot have a chemistry department with its own facility for single crystal growing when there is another one in geoscience or physics, and so you have to pool resources in that respect *[JK]*.

5. Do present funding patterns freeze senior professors out of the funding system and torpedo their morale?

I do not know how many of the 4300 people on the faculties do not have a research grant, but I would be surprised if it is not as high as 2500, maybe even 3000. There is no way any of those people can do research except with undergraduates or with their own hands. By the way, not everybody at the top ten or twenty or thirty schools has a research grant, either. I am sure I could find seven faculty even at Berkeley who do not have research grants *[CH]*. Before about 1950, virtually nobody had grants. But most of us have grown up in a system taking them for granted. Since 1970, I think maybe the number of grants has remained steady, or has even declined, while the number of professors has gone up *[CH]*. Students are seeing not only assistant professors struggling with tenure and with raising money, but also advanced researchers who have been drummed out of the system for not being able to continue to support their programs. These stand as a lasting image to students, which makes them reconsider the long-term prospects of an academic career: what happens even beyond the strain of getting tenure *[SD]*. Research is more expensive now. The dollar pool is going to be shrinking and the number of people with research funds is going to be decreasing *[PB]*. Are there departments in which a faculty member who loses support from federal agencies would then be unable to do research *[MAF]*? I think the prospect of that person attracting a graduate student against active, vigorous groups is not realistic *[SD]*. If the fraction of faculty members doing research decreases, then the fraction of undergraduates being exposed to research will decrease. The impact of low funding, in a majority of the chemistry departments, on more than two-thirds of the faculty members will affect morale, and ultimately the ability to recruit people into chemistry *[PB]*.

The Research Corporation has instituted a program, Research

Opportunity Awards, for unfunded investigators at the senior level *[MD]*.

6. Is the quality of government research management slipping?

The management of government research is now being done by a group of people who, by industry or academic standards, are grossly underrewarded. It is not obvious to me that the government can continue to attract the best people *[MW]*.

7. Is peer review adequate to maintain appropriate professional excellence?

One trend that I find disturbing is to get money by appropriation rather than by review. The other one is to get into what I call the high-energy physics mode *[HA]*.

The Track Record Renewal proposals: we took a dim view of it, because the community was not reviewing these things well *[MW]*.

It is important to our profession to review both critically, confidentially, and within a timely time frame, and we have an obligation to do so. If you go through a simple mathematical calculation, you will find that for a journal such as *JACS*, which has a 40 percent acceptance rate and typically requires two or three reviews per manuscript, you should be reviewing seven papers for every one that you publish, without feeling that you are being imposed on at all *[MAF]*.

III. THE ACADEMIC COMMUNITY

A. "Pipeline" Issues

1. How can we reward those on our faculties who reach out to minorities, women, undergraduates, and high school and elementary students?

Departments should develop a reward system to encourage members of the faculty to assume a more direct role in explaining the merits of our profession to the general public *[MAF]*. Department evaluations and tenure evaluations not only fail to reward going out and talking to high school students and making efforts in all those other areas, but also actually discourage them. The evaluation system needs to be adjusted, to accommodate all these things that we are now recognizing we have to do to maintain and advance the field of chemistry *[RG]*.

If I do not put time into it, then I really have no right to complain about the quality of graduate students that I am working with *[JWF]*. Outreach for high school students or undergraduates or improved teaching to motivate students or minority recruitment or any of these all take time. I know that I am hired basically to do research, and I will teach because I like to teach and they need professors, but I do know that if I do not spend a lot of time in lab, I do not have a prayer of making it in the academic world *[PC]*. We, as young faculty members, have to extend ourselves in so many directions. Then still what is counted in the end are publications and funding and teaching *[JSF]*. Nobody can do that because what brings recognition is that this person published 50 papers and has $2.5 million in NSF support and a group of 30 people. You can say that we need all these other things, but if we do not change the structure, that is not going to change *[PC]*. This is basically it. You never have the time, but the field needs this. I am the only Hispanic at Cornell. For anyone who is a minority, X, Y, or Z, they say, talk to this kid! I always go, and that will get me zero brownie points, but it is something that if I do not do, I cannot expect anybody else to do. That happens with women in my department, too *[HA]*.

Writing for the general public must be encouraged. In the current system research productivity is often the only criterion on which major promotions are based *[MAF]*.

2. Should chemistry faculty do more to reach out to high schools to bring more students into science?

High school teachers are the ones that are in the trenches, and are we not being somewhat patronizing in trying to tell them how to do their jobs *[RG]*? Increasing concerns about laboratory hazards and OSHA kinds of things have gotten more and more of the high schools to drop demonstrations and to reduce the laboratories so that chemistry becomes dull *[JK]*.

3. Can we do more for women and minorities?

What sorts of students will the universities have? By the year 2000, one in every three Americans will be non-white. We have fewer than 2 to 3 percent of minorities being educated in the sciences. With that particular forecast for population, that is where our new work force and education force will be *[JSF]*. The issue of minorities and women in science is a serious one. There is a growing minority work force, highly educated, that we are missing or for whom no role models exist to attract them to science *[DN]*.

Is it difficult to get blacks or women into the sciences because it is too late at the college level *[HA]*? There is a critical need for role models. If everybody in the front of that classroom is a white male, then the image that a student gets is that only white males go into chemistry, physics, and math *[JSF]*. It will be necessary to provide additional support for supplementing the backgrounds of nontraditional students who come from less rigorous undergraduate programs *[MAF]*. Over the last five years, a number of minority undergraduates have taken our chemistry courses and are very good and essentially indistinguishable from the student body at large *[AS]*. Can we provide initiatives to attract minority students into the profession, perhaps by post-baccalaureate training provided prior to beginning graduate programs *[MAF]*?

We bring in one or two students each year from a traditionally minority school, students whose background might not be what we would normally accept into our graduate program. We send them to a special program which brings them up to speed as first-year graduate students and then we put them in with our graduate students *[RG]*. A post-baccalaureate program designed to take students, say, from some small historically black colleges, give them evaluation examinations to find out what are their weaknesses, and then put them in courses for one year to help them overcome their deficiencies before they apply to regular admission programs is what is needed to ensure that they can compete without special dispensations *[JSF]*. We have taken more aggressive recruiting measures to encourage minority students. We must provide funding for undergraduate research opportunities at a national level. Role models are important, and women and minorities have a particular obligation to show themselves as active members of the profession *[MAF]*. A large number of faculty must make that effort to seek out minority students, take them under their wings, and continue to mentor them in the system *[MW]*.

The loss of mandatory retirement will lead to be about half as many entry-level positions in 2000 as in the mid-1980s. Unfortunately, this change comes about just at the time that the pool of highly qualified women chemists is beginning to increase significantly. The percentage of women on chemistry department faculties will therefore continue to be less than 10 percent *[CH]*. The loss of mandatory retirement will not just have a negative impact on women. It will be unfair to the field, because I think there is and will be a lot of talent out there that we are missing *[RG]*. The more women faculty members you have, the more you are likely to attract women students *[MAF]*. Increasing the number of women faculty thereby serves the needs of chemistry, by attracting more talent into it. If you talk to girls in high school, you find that they do not even imagine themselves as chemists. The importance of role models must not be underestimated *[RG]*.

4. Where are the women Ph.D.s going?

I have been, frankly, astounded at the pool of the people who have applied the last couple of times that we have hired at UCLA. There were no women in this group, and most of the males were blond haired and blue eyed, and that does not jibe with the people who are graduating *[RSW]*. In physics, for men and women, roughly the same percentage of Ph.D.s go on to academic careers. In chemistry, five times fewer women Ph.D.s go into academics than men. What message are we giving them along the way *[RG]*?

Most women come with a professional male, and they have to have a position. I considered Illinois very seriously but there was absolutely no job for my husband. Women recognize that there are other fields where they have more influence: in law, business administration. There is a serious problem in flexibility for females coming up through the ranks who may be interested in having families *[AS]*. As one goes up through the academic ladder, women are still discriminated against. Other departments are doing much better than chemistry in terms of encouraging women. It is an additional pressure, I believe, on an assistant professor, to be a woman, in most chemistry departments. Historically biology has been more nurturing with its graduate charges in terms of ongoing commitment to people coming up in academics than has chemistry *[RSW]*. The two-career marriage partners have to manage to get two jobs within twenty-five miles of one another *[MW]*.

Why is it that although we are turning out 20 percent female Ph.D.s, we do not yet see them represented in nearly that fraction among faculty applicant pools? We have an obligation to realistically talk to our women students as they are finishing programs about opportunities in the profession *[MAF]*. It is clear women and minorities are not being brought into the academic system as faculty at a rate consistent with their participation as students *[MW]*. Women and minorities, because of their extended role as role models, have to be very visible. They have the added pressure of going out into the community. But being visible is important to eradicating negative images of the role of women and minorities in the sciences *[JSF]*.

5. Should we admit more or fewer foreign students?

We are substituting a large part of our graduate population more than ever with foreign students *[RSW]*. Both of my parents came from National Taiwan University's chemistry department. They did an informal head-count some years ago at their class reunion -- which they had at Cornell, incidentally -- and it appeared that most of their graduating chemistry class is in the United States. Rather than hurting us, it is helping us *[PC]*.

Foreign students in the United States -- which, of course, is a nation of immigrants -- have contributed very dramatically to our nation's scientific expertise. But several indicators suggest that the quality of intellectual experience and research opportunities may be eroding in the United States in comparison with other countries, so that we may also lose our foreign students *[MAF]*.

6. Major research-oriented institutions should establish liaisons with quality liberal arts colleges.

Research institutions should maintain close contact with faculty at small liberal arts colleges and encourage access to instrumentation. They should be made to feel that research can be done at their home institutions *[MAF]*.

7. Targeting potential new faculty while they are still graduate students has its pros and cons.

The tactic of hiring assistant professors while they are still graduate students, farming them out as postdocs, and then bringing them onto the faculties is increasingly prevalent *[RG]*.

B. Tenure

1. Should the tenure clock be extended for interdisciplinary researchers? How do you evaluate someone who is creating a new area of chemistry?

Awarding of tenure may be difficult in some complicated situations -- for example, multi-investigator, large programs, and specialty programs *[MW]*.

We may have to think about extending the tenure clock and giving them more time to establish themselves in that field *[CH]*. When people come up for tenure, there is a tendency to discount collaborations, because you are not sure about relative contributions *[PD]*. If you are trying to do something new in an interdisciplinary field, people may not realize the significance in the time frame in which you are trying to get recognition *[AS]*.

We make tenure decisions by asking the opinion of the community. If the community endorses interdisciplinary research (and you do not send the letters to the wrong people), then I think you get the answer back *[FC]*. There is a problem of turf sometimes, too. Intruders are sometimes resisted. An organic chemist tries to break into biology and is not taken very seriously *[CH]*.

Unsuccessful organic assistant professors turn out to be quite highly sought after by companies, and sometimes move into group-leader positions in pharmaceutical or agricultural chemicals *[CH]*.

2. Is tenure viable?

The thirty-year tenure truly encourages long-term research *[PD]*. The tenure system has its merits. I think the only reason to consider changing it would be because of the legal requirements that the government is imposing on us *[JK]*. I think we would all be better off if we were not locked into tenure at all *[CH]*.

3. How should teaching ability fit into tenure decisions as a criterion?

In most institutions teaching is a very prominent portion of the promotion, as is a reputation for doing good science *[JWF]*.

I do not believe that teaching evaluations are a significantly positive part of the promotion process. I believe all they can do is hurt a person *[FC]*. There is currently no incentive for an assistant professor to be a good teacher at a major research institution *[RG]*.

C. Where Will the Money Come From?

1. Is it economically feasible to set up 5000 assistant professors over the next 20 years?

A thorough, case-by-case assessment should be made in order to determine how the change in faculty composition in chemistry (recruitment of senior faculty from overseas and industry) will strain funding agencies' resources. The exciting prospect is that there is room for qualitative change in academic chemistry departments *[MW]*. The start-up cost for a new faculty member has been doubling on about a three-year cycle. In the year 2000, the low end of the start-up cost will be $1.2 million. Clearly, the set-up problem is getting close to being out of control *[CH]*. Set-up costs are so high that they are eroding our ability to do maintenance on departmental instruments and to provide matching funds for instrumentation for either departmental or individual faculty needs. It is nearly no more expensive for us to hire senior people than it is to hire beginning people *[MAF]*.

The Research Corporation is backing out of supporting young faculty because it cannot pay them enough to make any difference *[JK]*. I do not think American university presidents have any idea what is happening on set-up costs. It is sufficiently competitive out there now that you would not dare offer a guy less than he says he needs. If you look at the lists, there is nothing unreasonable, but it is incredibly costly *[CH]*.

Hiring is still going to be a competitive thing in 2000 *[CH]*.

2. How many departments can this country support?

Financial considerations and the student stream suggest that the number of Ph.D.-granting institutions might go down *[MW]*. If access to equipment is key to staying competitive, it is going to be tougher for weaker departments to survive. The number of major research institutions capable of maintaining viable Ph.D. programs will decrease *[PD]*. If the overhead system worked right, if everybody was being honest about it, the university would document indirect costs for supporting this research and could provide some assistance *[JK]*.

The credibility of cutting-edge research without major facilities and research resources will prevent the bottom third from doing anything *[JK]*. Because of limited resources and the need for larger instrumentation to do cutting-edge research, there will be fewer graduate departments doing it *[WS]*.

How many Ph.D.-granting programs in chemistry is it realistic to believe the United States can support? How does one go about phasing out the marginal ones? There really are not one hundred and eighty-eight now. Of those one hundred and eighty-eight, 43 percent graduated fewer than five Ph.D.s in the last two-year period. It does not seem politically realistic or desirable to try to impose a reduction in the number of Ph.D.-granting institutions; it will probably take place very naturally *[JK]*. Is it reasonable for us to expect to continue to have one hundred and eighty-eight schools giving the Ph.D.? I think one reasonable number would be about half that. The real problem, then, would be to find a way to keep the faculty at the other half of the schools, who would then be teaching only undergraduates, involved in what is going on, and find opportunities for them to be involved in research *[CH]*.

Some of the smaller programs will specialize and not try to cover every area. One thing that could be done would be to strengthen the programs of federal support for undergraduate research in non-Ph.D. institutions. One can even envision a place that has been fooling itself about the viability of its Ph.D. program which would suddenly say, "Look, if we will just admit that we are not going to do Ph.D.s, we will be eligible to apply to this non-Ph.D.-institution funding pool" *[JK]*.

3. How can we assure support for excellence in research and teaching in primarily undergraduate institutions?

If the best departments in terms of undergraduate education are the non-research universities, the good liberal arts colleges, why don't you just advocate a totally separated two-tier system *[JM]*? Excellent undergraduate schools have regular sabbatical programs in which the faculty are encouraged to go somewhere and do research *[FC]*.

4. Are faculty salaries sufficient to provide a realistic lifestyle appropriate to a professional?

We deserve to be paid at a much higher rate, even if we are now close to industrial salaries *[RC]*.

Freedom for consulting constitutes small business opportunities among faculty, which relates again to the general question of remuneration and status within the community of academic personnel *[MAF]*.

Consulting is usually for very special people at a more senior level *[KP]*. I serve on the science advisory panel for one of the pharmaceutical companies. I go there twice a year for half a week and just review all the projects. It is not consulting. It does make me feel a certain loyalty to this company *[CH]*. You see many fewer kinds of freewheeling consultants, where somebody will come in without any very specific charge *[JK]*.

IV. THE CHEMICAL PROFESSION AT LARGE

1. Can we contribute to solving the problem of the public perception of chemistry?

Our nation is becoming technologically illiterate. Chemistry gives something to the gross national product. It gives a positive balance of trade, and it provides efficient benefits to mankind -- that is, health, energy, materials -- that are really not recognized among our general population *[MAF]*. The chemistry community does have a very big problem with public perception of the discipline *[DN]*. We must launch an effective public relations campaign *[CH]*. Senior members of the academic community who do not have research grants should be encouraged to use some of their available time to write some articles that are accessible to the public. I think the word "chemistry" is out of every major corporation but Dow *[WS]*.

There is a tremendous misconception out there in terms of what chemistry is all about *[PD]*. An honest analysis of the best that academic and industrial careers have to offer could not only pave the way to a more meaningful relationship between industry and academia, but it might also start us on the road to improve the image of chemistry in the public mind. NSF should make a conscious effort, involving well-known industrial leaders, to acquaint the public, and especially young people not yet in college, with major benefits of chemistry *[MW]*. National Chemistry Day represents a possible public relations opportunity. One way is to make visits to high schools. Bring high school students in. Write at a level that will reach high school students *[WS]*.

There is an apparent lack of a real perception of what industry is involved with, with regard to chemistry, and what the academic people are doing with regard to industry *[JM]*. ACS produces a lot of information that can be used by undergraduates in choosing career paths, even in fields that are nontraditional. I am not sure that the ACS does a very good job of telling anybody that they have all this information *[RSW]*.

2. Can we do more to lobby Congress for larger government budgets for chemical research?

We must educate the people in our Congress. We have been content with letting our own greatness speak for us -- that somehow it is recognized universally that we are a wonderful investment. The difference between chemists and physicists is that when the physicists want something, they take their wagons and they circle them and they shoot outward, but chemists tend to circle their wagons and shoot inward at each other *[RSW]*. Physicists adopt a mode where they pool resources and really manage to get a lot of attention and funding from the government *[HA]*. We must seek to increase long-term funding, to encourage interdisciplinary activities, to make the industry-academic interface better, to convince people that the cost/benefit ratio is very attractive, to increase the role of minorities and women in academic science, and to improve the public perception *[MW]*.