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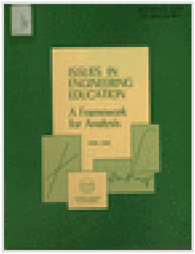

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Issues in Engineering Education: A Framework for Analysis
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ISSUES IN ENGINEERING EDUCATION

A Framework for Analysis

Task Force on
Engineering Education
of the
National Academy
of Engineering

Washington, D.C.
April 1980

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NATIONAL ACADEMY OF ENGINEERING 2101 CONSTITUTION AVENUE, N.W., WASHINGTON, D.C. 20418

TASK FORCE ON ENGINEERING EDUCATION

BRUNO A. BOLEY, *Chairman*
312/492-5220

April 24, 1980

Dr. Courtland D. Perkins
President
National Academy of Engineering
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

Dear Dr. Perkins:

For more than a year, a series of discussions on engineering education has reflected your interest in the subject as well as that of a substantial number of members of the National Academy of Engineering (NAE). The Task Force which was founded during these discussions has been active and enthusiastic in responding to the charge you gave us. The result of our deliberations is this report.

The general state of engineering education in our country is good. Undergraduate enrollments are up sharply, reflecting major changes in the attitudes of segments of the nation's young people. There are, however, issues which must be addressed if we are to maintain the vitality of U.S. engineering education. Among these is a major shortage in graduate degrees earned by U.S. students. This trend results in present and foreseeable major problems in filling university faculty positions, as well as senior positions in industry and government. Other matters which must be addressed include obsolete facilities and equipment, the need to improve preparation in secondary schools, public perception of the role of the engineer and of engineering as a career, the content of the curricula and the time required to reach journeyman status, and the need for much closer interaction between academia and industry. These and many other topics were covered by the many, excellent comments received in response to the Task Force's request for input from engineering professionals.

As you know, President Carter has asked for a report on science and engineering education. This led the Task Force to expedite its deliberations and issue this report. Nevertheless, we feel that we have been able to discharge our responsibilities successfully.

You will note that we make recommendations for immediate action as well as propose a framework for addressing areas requiring long-term attention. Of course, the material which we have gathered on

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engineering education is available for continued analysis by NAE, the National Research Council, and other interested bodies. I recommend that members of the Task Force be considered for further involvement in such efforts.

The other members of the Task Force and I welcomed this opportunity to contribute. We stand ready to discuss any aspect of our report and related matters with you and others in NAS/NAE/NRC , but otherwise we consider that this report concludes the task you assigned to us.

Sincerely,

Bruno A. Boley
Chairman
NAE Task Force on
Engineering Education

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EXECUTIVE SUMMARY

The National Academy of Engineering (NAE) Task Force on Engineering Education held two formal meetings. The first was in November 1979, the second in March 1980. This report summarizes the findings of the Task Force. Because of President Carter's recent request for assessments of the status of engineering education and education in the sciences, the report has been issued as quickly as possible.

Section I of the report, Introduction, reviews the genesis of the NAE Task Force and its charge. Section II discusses the approach taken by the Task Force which included a survey of engineering professionals in academia, industry, and government, as well as an analysis and synthesis of the survey results, as presented in Appendix C. Section III comprises a brief statement on the general state of engineering education in the United States. Section IV, Areas of Concern and Recommendations for Immediate Action, is the synthesis of the major issues in engineering education today. Some recommendations for actions that should be taken immediately to ensure the continued health of engineering education are incorporated. Section V defines a framework that the Task Force recommends as the most suitable approach to addressing the long-range issues. A brief closing statement is given in Section VI. The short-term and long-term recommendations of the Task Force are summarized below.

Recommendations for Immediate Action

- Special post-baccalaureate student support programs should be offered in engineering through the National Science Foundation and other agencies. Such programs would assist in fulfilling academic and industry needs by attracting more engineering students to advanced degree programs. It is suggested that such support be provided for a two-year term, thus allowing support during the student's thesis stage to come from research contracts and grants. In order to make the program attractive in comparison to industry employment, the stipend should be substantial.

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- A program is needed to update current engineering teaching and research facilities and laboratory equipment. While academic institutions and industry must share responsibility for addressing this problem, the federal government should take immediate steps to establish such a program. Provisions for matching funds from other sources should be included as appropriate, but a sufficient base must be provided to ensure prompt redress of the present critical conditions.

- New ways of increasing industry and federal, state, and local support for engineering education should be identified.

- The federal government should adopt policies and practices through both its executive and legislative branches that enhance the close interaction between universities and industry. The following are examples of specific actions which could be taken in support of this generic recommendation.

  - Through the National Science Foundation and technology-based mission-oriented federal agencies, university/industry cooperative research programs could be strengthened.

  - The companies that participate in the IRAD (Independent Research and Development) program of the Department of Defense (DOD) could be encouraged to include university participation in the projects they submit for IRAD approval.

  - The allowed rate of depreciation for tax purposes on equipment could be increased.

  - Tax credits could be provided for companies which fund university research.

  - The formation, through partial federal funding, of separate institutes or centers designed to foster the growth of particular fields of technology should be considered.

Recommendations for Long-Range Action

- A Standing Council on Engineering Education should be established to carry out the following functions:

  1. Monitor engineering education;

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2. Advise the engineering profession, the government, and, indeed, the nation of progress and perceived programs;
3. Recommend studies and directions; and
4. Identify opportunites and needs.

A joint governance for the Council by the National Academy of Engineering, the Assembly of Engineering of the National Research Council, and the American Association of Engineering Societies is proposed, with provisions made for future expansion. The Council should function as a catalyst for action. As such, the involvement of the various constituencies is essential.

- Simultaneously, four Panels should be established operating under the aegis of the Council. Each should be charged with responsibility for studying one of four broad areas of concern as follows:

  Panel A-The Objectives of Engineering Education;
  Panel B-Resources Required for National Needs;
  Panel C-University/Industry/Government Interaction; and
  Panel D-The Social Context of Engineering.

  Each Panel would report to the Council which would decide whether the then current needs require the continuation of the activities of each Panel or, perhaps, the creation of new or different Panels. Furthermore, in order to respond to the strong interrelationships among the four Panels' areas of cognizance, overlapping membership should be mandated. The overlapping members would be specifically charged with conducting liaison activities and providing explicit channels for the continuous flow of information.

In addition, the Task Force recommends that:

- The practice of seeking grassroot opinions should be widely adopted by the Council and the Panels. This may be done in a variety of ways, such as by soliciting written opinions (as was done by the Task Force) or by open hearings or forums. The benefits to be derived from procedures of this kind are not limited to the greater flow of ideas they generate but extend to the greater feeling of unity and participation they foster among engineers at large.

- The responses collected by the Task Force represent a valuable resource and should be made

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I. INTRODUCTION

The education of engineers and the availability and distribution of engineering manpower are topics of long-standing concern. There is no question that the quantity and quality of engineering professionals is directly related to the productivity and economic health of the nation. Therefore, it is eminently sensible for engineers to develop mechanisms for conducting evaluations of the health of engineering education in the United States.

This report presents the findings of the Task Force on Engineering Education which was formed under the auspices of the National Academy of Engineering (NAE). The report includes a summary of the deliberations of the Task Force, as well as the findings of an informal survey of engineering professionals.

History of NAE Involvement

The topic of engineering education has been addressed by many organizations, institutions, and societies over the years. While it is not possible to review all of these efforts in this report, the genesis of the NAE Task Force is described in this section.

In the early 1960s, two events occurred which were indicators of the national movement toward long-range planning for engineering education. The National Science Foundation (NSF) founded a Commission on Engineering Education in 1963 to address the problem of improving undergraduate education in the sciences, mathematics, and engineering. In December of the following year, the National Academy of Engineering was founded, and the status of engineering education became one of its earliest concerns. These two efforts were integrated four years later when the NSF Commission on Engineering Education was brought into the National Academy of Sciences (NAS), National Academy of Engineering (NAE), National Research Council (NRC) complex. As a result, the Commission on Education of the National Academy of Engineering was launched on January 1, 1969.

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The Commission concerned itself with broad aspects of technological education. Accordingly, one of its first undertakings was a national workshop on the need to introduce social, political, and economic considerations into engineering curricula. It also worked to support a program designed to help non-science students in secondary schools better understand technological concepts. Later, funding support from the U.S. Department of Health, Education, and Welfare enabled the Commission to prepare a planning document outlining a systems approach to delineating the major policy issues in educational technology. A 1973 Symposium on Minorities in Engineering, held under the aegis of the Commission, resulted in the development of a program geared toward increasing minority enrollments in engineering education by ten-fold within ten years. This volunteer program is financed through private foundations and companies.

Sharp shifts in government priorities, which began in the late 1960s, produced employment problems for the nation's scientific and technical community. In response to a growing need, NAE established an ad hoc Committee on Engineering Manpower Policy to study specific aspects of the problem of under-utilization of engineers and scientists. In 1974, the Board on Engineering Manpower and Educational Policy was formed by NAE as the successor to the Commission on Education. This Board was given a substantially expanded scope of activity. It was asked to help in defining a manpower policy which would result in more efficient utilization of engineering resources and to study and advise on national policies affecting technical education in general, and engineering education in particular.

For various reasons, insufficient funding and overly broad goals being notable among them, neither the Commission on Engineering Education nor the Board lived up to the expectations of the NAE membership. It was felt that national needs required a more intense approach. The last significant product of the Board was the publication of the Proceedings of a 1977 workshop on Modeling and Simulation in Engineering Manpower Studies.

Since that time, the interest and concern of the NAE membership about education and manpower have been expressed in articles and notes published in NAE's publication THE BRIDGE, as well as through the Founders' Award Lectures. The latter has included "A Few People From Many Lands - Alien Students of Engineering" by John R. Pierce, 1977, and David Packard's "Engineers and Public Affairs," 1979.

This report was generated in response to a proposal that NAE assess projections about the educational background likely to be required of engineers entering the industrial

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world in the next 5, 10, 15, and 20 years. This forward focus has been a major factor in the deliberations of the Task Force and was a significant consideration addressed by a number of those in the field who forwarded comments to the group.

Charge to the Task Force

The scope of the Task Force was established at a meeting in April 1979. It was concluded that the NAE group would be asked to identify key problems in engineering education and to propose a framework for their solution. The National Research Council, or other appropriate organizations, then would be able to undertake a search, within the proposed framework, for approaches to resolving the issues, as well as make relevant recommendations. The two objectives of the Task Force were reiterated at its first meeting on November 2, 1979.

With a broad mandate to identify key problems in engineering education and propose a framework for their solution, the Task Force felt that initially three pertinent questions would have to be addressed. Why conduct another study? Why conduct it now? Why should this task be undertaken by NAE? It was felt that developing answers to these questions would provide Task Force members with a common philosophical approach to the task at hand. Also, the many organizations and individuals concerned about and involved in engineering education would, properly, expect these issues to be addressed.

Why another study? The very proliferation of studies is evidence of a continuing need for a fresh and different look at this complex field. The charge to the Task Force was not to develop yet another set of proposed solutions to specific problems. Rather, it was to identify broad areas encompassing related issues and to propose a conceptual structure, i.e., a framework to aid in developing solutions. In other words, the Task Force was asked to develop a comprehensive approach for attacking the plethora of issues affecting engineering education.

Why conduct a study now? The present economic state of our nation is critical. We have been witnessing a decrease in national productivity, rampant inflation, and a worsening of the competitive stance of the United States vis-a-vis foreign countries such as Japan and Germany. National well-being and, perhaps, survival mandate that all factors affecting the productivity and economic health of the United States receive intense scrutiny. Certainly, one of the most important of these is the education of future engineers and the utilization and distribution of engineering manpower.

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Why should this task be undertaken by NAE? The high level of interest among the NAE membership in this topic, as well as the distribution of its members in industry, academia, and government, renders NAE a natural forum in which to formulate a cohesive approach. However, neither NAE nor the Task Force desired or intended to monopolize the field. Rather than seeing itself as replicating any extant efforts to address the problems of engineering education, the Task Force endeavored to cooperate with and learn from other interested and experienced organizations. The concerns and expertise represented by these organizations figured prominently in the formulation of this report.

Having prepared this report, the Task Force considers its job completed. It is the hope of the members of the Task Force that the analysis and the recommendations provided herein will prove useful to those groups that are charged with the very great task of resolving the problems and issues that face us today and will face us in the years to come.

The Report

The next section of this report provides an overview of the approach taken by the NAE Task Force on Engineering Education and an explanation of the events which led to a significant curtailment of the time originally allotted for completing its work. Section III contains a brief statement about the general state of U.S. engineering education. Section IV describes four broad areas of concern as identified by the Task Force and provides recommendations for immediate action on certain issues deemed to be of critical concern. Section V outlines a framework for a cooperative effort to address long-range problems. It is the hope of the Task Force that such an effort would both draw together those organizations with the required expertise and provide for a more systematic planning effort. A brief concluding statement comprises the last Section of the report.

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II. TASK FORCE APPROACH

From the beginning, the intent was to keep the Task Force small, while still ensuring reasonable representation from the academic, industrial, and government segments of the profession. In addition, an effort was made to include some individuals who had participated in activities of the many organizations concerned about engineering education. Representatives of the National Science Foundation (NSF) and the Sloan Foundation were asked to serve as Task Force members; the American Society for Engineering Education (ASEE) provided a liaison person; and the staff of the Commission on Human Resources of the National Research Council (NRC) was invited to observe the proceedings.

During the formative stages of the NAE Task Force on Engineering Education, a number of important issues were identified. These were summarized by the Chairman in a document prepared for the November meeting of the group. Also, early consideration was given to holding several public forums or seminars, perhaps one each on the East and West Coasts and one in the central part of the nation. This plan was postponed and later abandoned in order to speed deliberations, although the Task Force commends it to subsequent groups as a useful approach.

During the course of the meeting on November 2, 1979, the Task Force developed a plan for soliciting and collating the views of selected representatives of academia, government, large and small companies in industry, professional societies and associations, consultant organizations, and other broad categories of individuals. Over 1800 letters from the Chairman requesting input were sent to individuals actively engaged in some facet of the engineering profession. Several non-engineers whose perception of the profession would provide a useful perspective were also included. In addition, each Task Force member was asked to submit a list of five broad issues in engineering education that he considered to be of major importance to the profession.

One specific topic which was raised during the first meeting concerned postdoctoral research associateship programs in government laboratories. The intent of such

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associateships is to increase the attractiveness of research opportunities for engineers and to enhance the effectiveness of the engineer when he or she assumes a permanent position. Primary impetus for this program has come from federal laboratories where there have been difficulites in attracting candidates. It was decided that it would be worthwhile to address this issue separately. Accordingly, a special meeting of an appropriate group of individuals was held on February 13, 1980. The specific recommendations developed by the participants in that meeting, which are not part of this report, are expected to strengthen the associateship program administered by the Commission on Human Resources of the NRC.

Over a period of three months, Task Force members' comments were consolidated, and a summary of a cross-section of comments from approximately 400 individuals who responded to the Chairman's letter was prepared. These documents were available when the Task Force met on March 3-4, 1980, and a summary analysis of the responses to the survey is in Appendix C. The material presented in the balance of this report identifies the issues as defined by the Task Force using as a basis for its deliberations:

- The large volume of significant comments, reports, papers, and other material resulting from the canvass;

- Results of various meetings, correspondence, and reports gleaned from the past several years of work published by a variety of organizations; and

- The experience and perceptions of its members.

The original schedule of the Task Force called for a report by mid-summer 1980. However, the completion date was advanced in keeping with a February 8, 1980, Memorandum from President Carter to the Secretary of Education and the Director of the National Science Foundation. President Carter stated:

> "I am increasingly concerned whether our science and engineering education is adequate, both in quality and in number of graduates, for our long-term needs. Accordingly, I would like you to carry out a review of our science and engineering education policies at the secondary and university levels to ensure that we are taking measures which will preserve our national strength. Please submit a report to me, with your recommendations, by July 1, 1980."

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The Task Force therefore felt it was imperative to move its target date to April 1980; this had the effect of curtailing projected interactions with other groups interested in engineering education. Nevertheless, the broad-based survey that was conducted, as well as formal and informal meetings and discussions, provided the information so critically needed to formulate this assessment.

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III. OVERALL VIEW OF ENGINEERING EDUCATION

Too often, an assessment of needs, issues, and problems in a given area obscures strengths and sheds light only upon weaknesses. The Task Force wishes to emphasize that, until very recently, engineering education in the United States has enjoyed a period of growth and well-being. The current engineering manpower in industry and government, as well as the future generation of engineers currently receiving their education in U.S. universities and colleges, represent a tremendous national resource upon which our citizens may confidently draw.

Engineering education has exhibited remarkable flexibility in responding to changing demands and conditions during the last several years. Indeed, its flexibility is a source of the strength of U.S. engineering education. The Task Force felt, however, that by being continually responsive to changing demands the academic establishment may have become over-stretched. Therefore, it is necessary to focus upon certain issues which have rapidly reached a state requiring urgent attention. If engineering education is to continue to go well during the next ten years or more, and if it is to be ready to respond to possible sudden urgent national demands, steps must be taken today to update university engineering facilities and equipment, to make faculty salaries more competitive, and to ensure an adequate supply of post-baccalaureate students.

While a crisis in engineering education is not yet upon us, the very nature of the educational process requires early preparedness and long-range planning. The lead-time required between perception of a need, implementation of a change in engineering education policy, and graduation of the first group of students who have the benefit of that new policy may be as long as ten years. Given current economic trends and the perceived social needs, it is necessary to address immediately those problems that threaten the health of engineering education.

The responses received by the Task Force as a result of its survey revealed an extensive spectrum of concerns among individuals interested in engineering education. The respondents addressed detailed curricular matters, as well

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as issues that have wide-ranging national or professional impact. The Task Force noted, however, that few if any of the issues raised represented radical departures from those raised in the past. Indeed, many of the topics addressed have been the subjects of long-standing discussions; others have been the subjects of past formal studies. The need for immediate attention in some areas of concern should not detract from the holistic view that engineering is a vital and growing segment of the technological foundation of the nation both in universities and in industry.

The Task Force felt that a summary analysis of the material received would be useful. Appendix C provides a brief overview of the issues mentioned by the respondents and proportional data indicating the frequency with which specific concerns were raised. The responses are valuable, but it should be noted that no attempt was made to construct a scientifically representative sample. Great caution must therefore be used in interpreting survey findings for statistical purposes.

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IV. AREAS OF CONCERN AND RECOMMENDATIONS FOR IMMEDIATE ACTION

The Task Force sought to organize the large number of topics clamoring for its attention into a workable and logical pattern. It was felt that the pattern should be broad enough to cover the great variety of issues and sufficiently flexible to permit further studies at different levels of intensity, timing, and detail. A two-stage process was designed to accomplish this goal. First, it was necessary to conduct an analysis of the responses received and available studies and reports. Then, a synthesis of this raw body of data was required in order to extract the general areas of concern.

Four broad areas of concern in engineering education were thus identified:

1. The Objectives of Engineering Education;

2. Resources Required to Meet National Needs;

3. University/Industry/Government Interaction; and

4. The Social Context of Engineering.

Each of these is described below, and, where appropriate, specific recommendations for immediate action are given. A framework for long-range consideration of these topical areas appears in the next section of this report.

The Objectives of Engineering Education

The technical expertise, breadth, depth, and flexibility among engineering graduates have long been debated. In general, there is a continuing need to examine the adequacy of fit between engineering programs and the needs of industry, academia, government, and the individual student. Since the range of needs is so diverse and since needs vary over time, attention to this area will always be required.

Of particular concern at present is declining U.S. industrial productivity. Thus, an assessment of the status of university training for industrial innovation and design

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is urgently required. In addition, there is evidence that increased emphasis on communication skills and on social, economic, administrative, and legal/ethical issues is a high priority. As might be expected, the chief difficulty appears to be devising ways of achieving the optimum balance in each academic program. At the same time, it is well to note that an engineering education is increasingly gaining acceptance as a sound general education for individuals who may later enter upon different career paths.

Engineers are called upon to play diverse roles. This places considerable burden on academia and is reflected in the existing variety of engineering schools and their many different types of academic programs. The Task Force applauds this variety but notes that efforts to clearly define the differences among educational programs and to delineate the characteristics of holders of Bachelor of Engineering degrees, Bachelor degrees in Engineering Technology, and the Associate degrees have not been entirely successful, nor have they gained widespread acceptance. Further study must be given to establishing useful lines of demarcation among the variously trained individuals and the functions which they should be expected to perform, bearing in mind that the needs and requirements vary greatly among the different engineering disciplines. Engineering schools must meet the dual demands of engineering research and engineering practice as levied by industry, academia, and the government. It may be that individual engineering schools should limit their scope within this broad range of requirements.

These issues are closely allied to two other important matters, i.e., accreditation of engineering and technology programs, and registration and certification of professional personnel. An in-depth study of present practices and future predicted needs is desirable. Generally, it is felt that the present accreditation process is serving the profession well in ensuring reliability of engineering programs, but little is known about the influence of the process on curricula, their quality and flexibility. In addition, comparatively little information exists on the reliance placed by industrial corporations on engineering professional registration, or on the use of persons with primarily science education to perform engineering tasks. Similarly, studies are desirable on the need to ensure updating of engineering skills through various forms of continuing education, and through periodic recertification.

Another fundamental concern is the general failure on the part of the public, policy makers, collectors of statistics, and even academic administrators to distinguish adequately between engineering and the physical and natural sciences. Too often, enrollment and graduate data are

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lumped under the heading "science and engineering." This practice does a disservice to both. For example, engineering enrollments are still increasing while enrollments in science majors are not. Both trends are obscured in current government statistics. Failure of the engineering profession to articulate clearly both the objectives of engineering education and its distinguishing characteristics will lead to continued obfuscation.

The Task Force believes that resolution of these concerns is necessary to ensure the effectiveness of engineering education in this country. It also would help to provide a greater measure of external recognition for the profession and to increase understanding among engineers themselves. Panel A, proposed in Section V, would have general purview of these matters.

Resources Required to Meet National Needs

American engineering education is financed by a variety of sources including endowments, private gifts, income from tuition and services, and federal, state, and local monies. While multiple funding is advantageous in that it provides a broad base of support, it does have certain drawbacks. During times of severe inflation, capital funds erode, tuition rates eat up scholarship endowments, and building endowments are no longer sufficient. Moreover, short-range funding problems often absorb the attention of administrators to the detriment of the equally necessary, long-range financial planning. Finally, while all university departments are seeking funding support, special conditions influence the economic health of engineering departments. Among these are the comparatively high cost of engineering education and the rapid pace of technology. It is not surprising that the timely availability of sufficient resources is likely to remain of fundamental concern in engineering education.

The effects of the constant search for adequate resources are pervasive. The physical plants in which many departments of engineering are housed are deteriorating. Outdated laboratories are common, some of which fall far behind those in industry, government, or even foreign establishments. Faculty salaries are not competitive with those in industry, and it is difficult to attract American graduate students. As a result, engineering curricula are showing signs of diminishing flexibility both in technical subjects and in the more general and/or societally oriented areas. The Task Force submits that the nation's engineering education complex has already begun to suffer from a lack of properly planned, reliable, and timely funding. Indeed,

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these problems are considered to be so serious that a more detailed look at their extent and effects is warranted.

Facilities

An extensive study would have to be made to document the magnitude of the problem of obsolete physical plants. For the last three or four years, however, these facility problems have been mentioned frequently by engineering educators whenever they are asked to discuss the future of engineering education. Some notion of the magnitude of the problem is suggested below, but it should be emphasized that the estimates given may err on the conservative side.

On the average, the physical facilities in which engineering colleges are housed are now about 30 years old. The federal government has not provided universities with funds for bricks and mortar since about the mid-1960s. For whatever reasons, the nation's universities have not provided for either amortization of their investment in buildings or proper maintenance and repair. This problem extends across entire universities and is not confined to engineering colleges; however, unless something is done about repair and modernization, the state of our physical plants will seriously damage the ability of the nation's engineering colleges to meet future needs.

The problem has been exacerbated by inflation as well as by new government regulations, such as those of the Occupational Safety and Health Administration (OSHA) or those referring to handicapped persons. It is, of course, recognized that there is a need for action in areas such as these. Nevertheless, in a great many cases, universities have not been able to comply in full. Many university buildings are built through private donations, and it is a fact that philanthropists are not interested in donating money simply to enable an institution to comply with government regulations.

There are, of course, notable exceptions to the trend of deteriorating physical plants. Some of the more renowned universities have been able to build new facilities through aggressive fund raising, unusual endowments, planning, or industry support. However, most universities are facing a critical problem in this area.

The magnitude of the facilities problem is largely unknown. There is, however, almost universal agreement that it is serious, and that engineering colleges will find it extremely difficult to mount programs in new areas of technological importance without substantial building

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modernization, as well as additional funds for at least some new facilities.

Laboratory Equipment

It is possible to be more specific about quantifying the need for more modern laboratory equipment since some studies have addressed this problem and some estimates have been generated.

Deficits in laboratory equipment affect both teaching and research. The need for instructional equipment may be even more acute than the need for research equipment because required research equipment usually can be obtained through grants and contracts, at least to a limited extent. In either case, however, the problem has been exacerbated by the acceleration of technological progress during the last twenty years, increases in the sophistication of the laboratory equipment required, and increases in costs. By in large, colleges have been unable to cope with spiralling costs. The result, particularly with respect to teaching, has been a growing gap between the equipment that students use in their instructional laboratories and the kind of equipment that they encounter in industry. Such gaps have always existed, but there is now strong evidence that the gap is becoming so large that the ability of engineering colleges to train students adequately for the future is seriously threatened.

In many cases, industry has been quite generous, but the magnitude of the problem far exceeds the amount that can be expected in the form of industry support. A new and common pattern, especially in the computer area, is for industry to make donations in the form of substantial discounts. This obviously helps but does not address the core of the problem.

Another factor which is extremely difficult to quantify is that new government accounting regulations make it more difficult for universities to acquire the equipment used on government-funded research projects. For example, it was once possible to acquire used research equipment at 5 cents on the dollar in some cases, but this is no longer possible.

Unless the trends change, engineering colleges will not be able to provide adequate training in many of the new, most important technologies without substantial help. For example, integrated circuit electronics requires equipment which is out of the reach of most engineering colleges, as do the new design methods based on computer graphics. Research in new areas in the energy field, as well as in

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manufacturing technology, also require equipment that is completely beyond the means of most engineering colleges.

Several years ago, the Engineers' Council for Professional Development (ECPD) studied the teaching equipment problem and estimated that the new equipment needed by an engineering college costs $100,000 per year per program plus $150 per student per year. Based on this estimate, a national program with 50,000 degrees per year would cost approximately $200 million per year.[1] Of course, costs now are considerably higher, and engineering colleges have nothing close to this amount of money at their disposal. The integrated backlog of the shortage that is being produced is now enormous and growing.

More recent studies demonstrate the severity of the deficit. Ohio State University recently estimated the cost of installing an adequate computer graphics system to teach modern design at $3 million plus 15 percent per year for maintenance.[2] Rensselaer Polytechnic Institute made a similar analysis and obtained similar results.[3] The computer graphics problem is just one of many, but it is an important indicator.

A study of the equipment needs of material science departments was recently commissioned by NSF. The evidence showed that there is a great deal of obsolete and antiquated equipment and that massive equipment grants will be required if the material science departments are to provide the trained personnel that the nation needs.[4]

In sum, immediate action is needed to update existing laboratory equipment if universities are both to meet the needs of industry and the requirements of research and teaching. Moreover, new methods must be found for ensuring that the equipment available in universities and colleges keeps pace with advances in the field.

Faculty and Graduate Students

There is considerable documentation of the difficulties currently being experienced by university engineering departments in obtaining and retaining high-quality faculty. University salaries are simply too low. Although a few faculty members of the most well-known universities are able to supplement their incomes through consulting contracts, the average university teacher must rely on his or her basic salary.

Recruiting new engineering graduates on college campuses is currently at an all-time high. Opportunities available to new graduates are such that fewer and fewer students are

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continuing their studies and obtaining advanced engineering degrees. The number of engineering doctoral degrees awarded by American universities declined from 3468 in 1973-74 to 2782 in 1977-78, a 19.6 percent decline. Even more alarming is the steady decrease in the number and proportion of degrees earned by American students. During this same period, the number of U.S. citizens receiving engineering doctoral degrees declined by 24 percent.[5] In effect, the United States is exporting an increasing proportion of its technical training and education. Engineering colleges are in desperate need of these people as new faculty. A poll of 34 engineering colleges in the Fall of 1978 revealed 314 faculty vacancies.[6] The number is much higher now. National attention must be directed toward this problem.

Holders of advanced degrees in engineering are in heavy demand by industry, government, and the universities. It is clear that all sectors must be assured of an adequate supply of these people. The still insufficiently tapped resources of minorities and women must be increasingly utilized. In addition, engineering colleges should be encouraged to implement special undergraduate programs which will permit the more talented students to get a head start on graduate studies. These students should receive special counseling and have the opportunity to be involved in research programs during the early stages of their university lives.

Recommendations for Immediate Action

- Special post-baccalaureate student support programs should be offered in engineering through the National Science Foundation and other agencies. Such programs would assist in fulfilling academic and industry needs by attracting more engineering students to advanced degree programs. It is suggested that such support be provided for a two-year term, thus allowing support during the student's thesis stage to come from research contracts and grants. In order to make the program attractive in comparison to industry employment, the stipend should be substantial.

- A program is needed to update current engineering teaching and research facilities and laboratory equipment. While academic institutions and industry must share responsibility for addressing this problem, the federal government should take immediate steps to establish such a program. Provisions for matching funds from other sources should be included as appropriate, but a sufficient base must be provided to ensure prompt redress of the present critical conditions.

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- New ways of increasing industry and federal, state, and local support for engineering education should be identified.

Panel B, proposed in Section V, would maintain continuing review of resources in engineering education required to meet national needs.

University/Industry/Government Interaction

Three major and growing problems in the nation's engineering colleges arising from the lack of adequate resources have been outlined; the inability of the academic system alone to cope with increasing costs has resulted in deficient physical plants, obsolete laboratory equipment, and deteriorating numbers and quality of graduate students and faculty. It is clear that increased cooperation among universities, government, and industry is essential to solving these problems.

Universities and industry are related to one another in a most fundamental fashion; they are natural partners. Industry is vitally dependent on the student output of engineering schools, both at the graduate and undergraduate levels. Industry also relies on university research as a source of technical progress complementary to that achieved in industrial laboratories. Industry produces the goods and services that university-trained engineers conceive, design, and manufacture.

Universities are well aware of the functions they perform for industry. Nevertheless, they are careful not to lose sight of their other roles, namely the training of future researchers and academicians and the performance of basic engineering research. Such research often takes directions not necessarily in concert with industry's current perceptions. As a consequence, a noticeable divergence of views may arise between people in industry and in academia. On the one hand, we have accusations of unresponsiveness on the part of engineering faculty to "real world" needs; on the other, fears of loss of academic independence and complaints about the inadequacy of industry's support of universities. While recognizing the validity of some of these concerns, it is necessary to emphasize the crucial interdependence of the academic and industrial sectors. They are members of the same family, and internal differences must not be allowed to interfere with an effective relationship between them.

Nevertheless, strong traditional ties do exist between universities and industry and have formed a basic foundation upon which to build. Industry has participated in the

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educational program through undergraduate cooperative work-study programs, summer employment of students, grants of funds and equipment, industrial membership on university advisory committees, and some sponsorship of research and development projects. Universities have made part-time graduate programs available to industrial personnel via night courses, on-site courses, closed-circuit TV, and videotaped courses, as well as through the provision of short courses and special educational programs in new technical fields. University faculty consult for industry, as well as participate in personnel interchanges via summer employment and faculty sabbaticals. Similarly, industrial engineers obtain leaves of absence to spend time at universities, and industrially employed engineers often serve as part-time faculty members. Through less formal arrangements, industrial speakers are often invited to university seminars and colloquia, and faculty members participate in industrial conferences, seminars, and workshops. Finally, there are industrial associates programs at some universities, notably at the Massachusetts Institute of Technology (MIT), Stanford, and the University of California at Berkeley. These provide industry with systematic reviews of research results in specific fields of university expertise.

Although both universities and industry have profited from these interactions, it is evident that there is great potential for increased benefits through strengthening traditional ties as well as establishing new ones. New ties are needed because of a number of new problems facing the nation, such as increased demand for engineering talent due to the shortage of energy, increased international competitiveness, and a slow-down in the rate of industrial innovation.

Potential Benefits

Strengthening university/industry ties would benefit both high-technology fields and the more traditional fields. Some of the benefits which might accrue include:

> Increased availability of modern facilities for instructional purposes. As previously noted, in many fields of technology, the capital investments made by industry to carry out research, development, design, and manufacturing are orders of magnitude larger than the resources available for the purchase of equipment even in the strongest engineering colleges. Many of the important fields of technology are characterized by rapid changes in equipment and facilities as advances in instrumentation and data-gathering are made.

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Engineering colleges are faced with prohibitive costs if they attempt to develop modern facilities in many branches of technology.

Updating of both faculty members and industrial engineers. Through interchange of personnel for varying periods of time, engineers in industry can learn new analytical techniques; faculty members can be exposed to the current state of the art; and students can have an opportunity to encounter industrial priorities and viewpoints.

The undertaking of joint research projects. The capabilities of the university and industrial personnel frequently complement each other. In many fields, the university faculties include the foremost researchers in scientific and technical fields, but few universities have the extensive, modern facilities that companies maintain. Combining academic researchers with industrial personnel and facilities could enable more rapid technological progress.

The sharing of potential candidates for graduate work in engineering and science. At present, there are great financial inducements for the holders of baccalaureate degrees in engineering to undertake industrial careers immediately upon graduation. Colleges of engineering are effectively being stripped of full-time U.S. graduate students at the very time that they are seeking to respond to increased demands for educating more undergraduates. Industrial employees can participate in and contribute to the health of the educational programs in the universities if appropriate time-sharing arrangements are made by their employers.

An increased rate of technological progress in fields of lagging technology. Increased attention and activity is needed in technological fields where there has been relatively little change over a long period. Both the university communities and industry could engage in cooperative efforts to expose students to these fields. If capable graduate and undergraduate students can be encouraged to enter them, substantial progress will be made.

The development in university curricula of more cost-conscious engineering. This topic is often neglected at the undergraduate level and is rarely presented in graduate programs. Since the bulk of university research funds come from the federal

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government, university research tends to be directed more toward federal priorities and less toward industrial concerns, e.g., cost-consciousness in engineering design and manufacture. What is needed, of course, is not less federal research support but more industrial support.

Recently, a number of new university-industry interaction patterns have developed. In some cases, government funding has acted as a catalyst for these new arrangements. Others have resulted from private sector initiatives. Several of these may be cited as possible models for the future.

At some universities, multi-company support of research programs in fields of particular importance have been developed. For example, the Silicon Structures Project at the California Institute of Technology is directed toward the development of design software for very large scale integrated (VLSI) circuits. The six or so participating companies provide annual grants of $100,000 each. Also, an engineer from each company is detailed to Caltech for a year. MIT's Center for Polymer Process Research was initially partially supported by NSF but has proved so valuable to the industrial sponsors that it is now completely supported by industrial funds.

A major advantage of arrangements of this type is the very direct interplay between academic and industrial personnel. The academic concern for in-depth understanding and the industrial interest in identifying the problems of greatest relevance to future developments can be combined to maximize the rate of progress.

In a number of instances, a direct tie between a single company and a single university has been effective. The Harvard Medical School-Monsanto tie has had much publicity as a joint effort to foster developments in the biomedical area. The new program developed between Purdue and Control Data Corporation (CDC) is another example. It is focusing on the development of a university center for research in computer-aided design and manufacture. In both of these cases, a multi-year commitment has been made that will permit the systematic development of a field.

Carnegie-Mellon University (CMU) has developed a close relationship with the Digital Equipment Corporation (DEC). A program directed toward the use of small computers in arrays employs DEC facilities and CMU faculty and graduate student capabilities. In addition, some of the DEC executives hold adjunct faculty positions at CMU.

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A different type of example is provided by the innovative undergraduate program developed at Worcester Polytechnic Institute in which many undergraduates undertake an extensive research project with active industrial participation.

The final example is somewhat different. A new electronic technique, the use of switched capacitors, was developed by faculty members at the University of California at Berkeley. After prototypes were developed at Berkeley, the Intel Corporation, working with the faculty, furthered the techniques and brought the ideas to successful commercial realization.

Fostering Increased Interaction

There are, then, a number of models for increasing university/industry interaction that mutually benefit both parties, although clearly not every model is applicable to each engineering college and industrial concern. Nevertheless, a fundamental conclusion of the NAE Task Force is that great benefits can be realized through the fostering of existing and new ties between universities and industry. While many of these ties are not dependent on government, the federal government is in a position to enhance and encourage such interactions through its policies and practices.

It also should be stressed that neither the universities nor industry should wait for federal action before working to find new means of strengthening their mutual involvement. Each could take a number of constructive steps today. As noted above, there are models of successful, mutually sponsored programs. The applicability of these models to other universities and companies should be explored. This will require increased flexibility on both sides. Academicians need to become more willing to respond to industry priorities and direction. Industry must address the issues of patents and proprietary rights in new, innovative ways.

The ability of the universities to contribute to a systematic increase in productivity or to industrial innovation probably can be enhanced by some experimentation along this line, and this is worthy of an investment in time and funds. Some university and industry groups should seek to integrate the technological and management resources needed to attempt to grapple with this problem in specific sectors. It is also possible that independent, not-for-profit research institutes could play an important role in such an effort.

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Recommendations for Immediate Action

- The Task Force recommends that the federal government adopt policies and practices through both its executive and legislative branches that enhance the close interaction between universities and industry. The Task Force has identified a number of specific examples of actions that the federal government could take in support of this generic recommendation:

  - Through the NSF and technology-based mission-oriented federal agencies, university-industry cooperative research programs could be strengthened.

  NSF's Industry/University Cooperative (IUC) program is an example. The U.S. Air Force's ICAM (Integrated Computer-Aided Manufacturing) program, the Department of Defense's (DoD) VHSIC (Very High Speed Integrated Circuits) program as well as many others undertaken by DoD, the Department of Energy (DoE), the Department of Transportation (DoT), the Department of Commerce (DoC), and the National Aeronautics and Space Administration (NASA) could be made more effective in fostering university/industry ties if the companies bidding for such projects were encouraged, or possibly required, to include university participants.

  - The companies that participate in the IRAD (Independent Research and Development) program of the Department of Defense could be encouraged to include university participation in the projects they submit for IRAD approval.

  Since IRAD projects usually relate to the advancement of current technology and the exploration of future possibilities, it would be most desirable to encourage joint participation of company and university personnel. It is recognized that there are frequently proprietary aspects to such projects, but there are a number of examples of successful resolution of such issues between companies and universities. Flexibility by both participants can make such arrangements workable.

  - The allowed rate of depreciation for tax purposes on equipment could be increased.

  Such a policy would encourage companies to invest in new equipment, thereby allowing universities to obtain equipment which is closer to

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the current state-of-the-art. The effects of increased depreciation on potential tax write-offs for donations of equipment to universities would, of course, have to be taken into account.

- Tax credits could be provided for companies which fund university research.

Measures of this type would provide strong incentives for industries to support university research in fields important to their technological progress. It is noted that such a bill has been introduced in Congress (H.R. 6632 and S. 2355). With the exception of the NSF, which has the broad mission of ensuring the health of the nation's science and engineering enterprises, there is little federal funding available in technological areas which do not match the specific targets of a federal agency. As a result, some technologies of importance to the economy can be slighted in university-based research, with a consequent low output of young engineers with interest or expertise in these fields. The fact that the United States is lagging in its rate of technological advancement in several areas is likely to be caused, at least in part, by this phenomenon. Some industrially advanced foreign nations have demonstrated their ability to identify these areas and compete very successfully with U.S. companies both in international and in domestic markets. If U.S. companies could initiate and support research programs in universities through long-term funding, they could contribute to their long-term technological health and compensate for the short-term nature of most present industrial research efforts. Programs of this sort would be of great benefit to colleges of engineering since they would constitute a balance for the present dependence on federal funding.

- The formation, through partial federal funding, of separate institutes or centers designed to foster the growth of particular fields of technology should be considered.

Some such institutes have been successful in West Germany and other countries. The Materials Processing Center at MIT is an example of such an operation. It involves several academic departments, includes industrial and governmental personnel on extended residence, and develops both research and instructional programs in materials processing. The success of such institutes in

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selected environments points to the need for a study to determine whether the experience gained to date could be extended to new technological fields and geographical areas.

It is undoubtedly true that other options are available to Congress and the executive branch than those outlined above. The key issue is to find methods of facilitating the development of stronger traditional and non-traditional university/industry ties. The Task Force urges that such methods be systematically identified and that Congressional staff members and federal agency program managers take appropriate action.

In Section V, Panel C is proposed as the group to review and make recommendations on the subject of interaction among government, industry, and the universities and colleges.

The Social Context of Engineering

According to the public stereotype, the engineer is immersed in technical complexities, oblivious to societal or economic concerns, and is unable to communicate his or her ideas. Certainly, no stereotype should be endorsed. However, it should be noted that, in spite of various studies of the issue and the efforts of many universities, problems associated with the public's perception of the profession remain.

To the degree that the stereotype of the engineer as an individual with narrow perspective is accepted by the public, people with an innate ability to take a leadership role are repelled from engineering as a career. As a result, the profession often fails to have an appropriate impact on public policy.

Steps should be taken to enable future engineers to deal more effectively with the public. The exposure of engineering students to socially oriented subjects must be increased, and this must be done in such a manner as to impress upon the students the important role such subjects play for engineers. Courses should be offered in ethics, law, economics, and the social and environmental impact of technology. Finally, and perhaps of most importance, engineering students must understand the need to learn to articulate, to communicate, and to convince.

A related and equally important issue is the attitude of the lay public toward technology itself. We are living in a highly technological world which the lay public cannot adequately comprehend; technology is regarded with a mixture of awe, mistrust, and hostility. As a result, the

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electorate and its legislative representatives are making crucial decisions based on an insufficient understanding of the impact of their actions.

Engineering schools must engage in efforts aimed at acquainting non-engineers with the engineering approach to problems. This is distinct from providing the lay public with a rudimentary acquaintance with science. Rather, it refers specifically to an acquaintance with engineering, with its problem-solving basis and capabilities, with the concept of engineering accuracy as opposed to that of a philosophical certainty, and with a general understanding of the role that engineering plays in everyone's lives. This is a very difficult task. It involves not only the engineering profession but also a much wider, not necessarily receptive, audience. Nevertheless, the effort must be made. The preliminary steps that should be taken include convincing non-engineers of the importance of the subject as well as developing suitable courses, seminars, and other teaching vehicles.

Finally, it must be noted that the lack of an understanding of engineering on the part of the public at large is accompanied by a generally low assessment of the impact of engineering as a profession. Although a favorable upward trend in the public's esteem of engineering has been noted in recent years, the public as a whole does not recognize that the practice of engineering vitally affects its well-being, health, and daily experience. Further enhancement of the public's perception of the engineering profession cannot be achieved by emulating other professions such as medicine and law, however. Engineering has a character of its own, one which encompasses a tremendous variety of situations ranging from industrial employment to individual entrepreneurship, and its professional status must be achieved and appreciated on its own unique foundation.

The tasks of Panel D, proposed in Section V, would encompass all of these areas.

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V. RECOMMENDATIONS FOR LONG-RANGE ACTION

In the preceding section, four major areas of concern in engineering education were outlined, and some immediate steps needed to effect a rapid amelioration of currently critical issues were detailed. This section presents the recommendations of the Task Force for actions that should be taken to ensure the future well-being of engineering education.

Before discussing the recommendations, three general observations should be made. First, the concerns expressed by the Task Force are not transitory. Rather, they can be expected to remain as active issues in the profession for many years to come. Second, although each of the four broad areas of concern identified represents a distinct set of issues, they are interrelated to a considerable extent. A good case could even be made for one common study of the four areas, although such a proposal would undoubtedly be impractical. Third, as noted in Appendix F, a variety of different organizations has expressed and has a legitimate interest in engineering education. To give an admittedly incomplete list, one might note the National Academy of Engineering (NAE), the Assembly of Engineering (AE) of the National Research Council (NRC), the American Association of Engineering Societies (AAES) and its constituency, the Accreditation Board for Engineering and Technology (ABET), the American Society for Engineering Education (ASEE), the National Society of Professional Engineers (NSPE) (and indeed every professional engineering society), the National Science Foundation (NSF), many private foundations, and so forth. One cannot expect any general framework for examining engineering education to be even moderately successful or accepted if it does not in some way take cognizance of this broad constituency.

The Task Force proposes establishment of a general framework for fostering the continued health of engineering education and it believes the proposal is responsive to the general requirements outlined above. The recommendations for the framework are as follows:

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A Standing Council on Engineering Education

- A Standing Council on Engineering Education should be established to carry out the following functions:

  1. Monitor engineering education;
  2. Advise the engineering profession, the government, and, indeed, the nation of progress and perceived programs;
  3. Recommend studies and directions; and
  4. Identify opportunities and needs.

The Council would generally act in the capacity of coordinator, advisor, planner, and advocate; it would not perform as a manager or dictator. The Council should be established under the aegis of respected engineering entities with broad cognizance of the affairs of the profession. Three such entities immediately come to mind: the American Assocation of Engineering Societies, the National Academy of Engineering, and the Assembly of Engineering of the National Research Council. This tripartite arrangement would allow the full participation of the many various societies that form the membership body of AAES including, of course, the American Society for Engineering Education and its various councils.

The Task Force proposes that these three groups join in sponsoring such a Council and urges that a meeting among representatives of the three groups be held at an early date to establish a suitable charter and modus operandi. At that time, the membership of the Council should be examined and the inclusion of broadly based organizations such as ABET should be considered.

Perhaps the Council could comprise three component groups: a Standing Committee on Engineering Education in the National Academy of Engineering; a Board of Engineering Education in the Assembly of Engineering of the National Research Council; and a Standing Committee within the American Association of Engineering Societies. The groups could meet as a joint Council, but each could preserve its own rules for membership selection and, on occasion, meet on an independent basis as appropriate. The Task Force further proposes that the National Science Foundation and private foundations be encouraged to provide the necessary financial support for this effort, with participation by professional societies as appropriate.

The Council should issue a yearly report on the state of engineering education as well as address specific issues through ad hoc special reports.

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Establishing Panels on Specific Areas of Concern

One of the important functions of the Standing Council on Engineering Education would be the formation of Panels to examine specific issues and to recommend solutions to specific problems.

- The Task Force proposes that, simultaneously with the creation of the Council, four subsidiary Panels be established. Each would be charged with responsibility for studying one of the four broad areas outlined in Section IV. Thus, the Panels would be designated:

Panel A-The Objectives of Engineering Education;
Panel B-Resources Required for National Needs;
Panel C-University/Industry/Government Interaction; and
Panel D-The Social Context of Engineering.

Each Panel would report to the Council which would decide whether the then current needs require the continuation of the activities of each Panel or, perhaps, the creation of new or different Panels. Furthermore, in order to respond to the strong interrelationships among the four Panels' areas of cognizance, overlapping membership should be mandated. The overlapping members would be specifically charged with conducting liaison activities and providing explicit channels for the continuous flow of information. Again, the Task Force proposes that the National Science Foundation and private foundations be encouraged to provide the necessary financial support, with participation from professional societies as appropriate.

General Recommendations

The Task Force also recommends that:

- The practice of seeking grassroot opinions be widely adopted by the Council and the Panels. This may be done in a variety of ways, such as by soliciting written opinions (as was done by the Task Force) or by open hearings or forums. The benefits to be derived from procedures of this kind are not limited to the greater flow of ideas they generate but extend to the greater feeling of unity and participation they foster among engineers at large.

- The responses collected by the Task Force represent a valuable resource and should be made

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available to the Council and to the four proposed Panels.

- A central clearinghouse and repository for information on activities and programs in engineering education should be established by the Council at an early date, with provisions for maximizing availability of its facilities and their use by the profession at large.

- Sponsorship and financial support for the activities of the proposed and future Panels should be sought from interested bodies, including, as appropriate, private foundations as well as federal agencies.

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VI. CLOSING STATEMENT

The issues approached by the Task Force are deep and pervasive, and the many earlier efforts devoted towards their solution must be gratefully acknowledged. The Task Force was not asked to propose specific solutions, although some of the immediate problems did prompt recommendations for immediate action. Rather, the Task Force was asked to propose a framework to ensure the long-term health of engineering education. In spite of very narrow time constraints, the Task Force feels that it succeeded in proposing the outlines of a structure that would prove effective in guiding the future course of engineering education, while still maintaining the vital American qualities of freedom of action and approach on the part of the several engineering constitutent groups. The Task Force ventures, in fact, to hope that the implementation of its recommendations will help in drawing these diverse groups closer together, create a more meaningful professional identification, and thus assist all in working effectively toward the strong engineering establishment which the nation needs and has the right to expect.

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APPENDICES

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Appendix A

NAE Task Force on Engineering Education

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Appendix B

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Appendix B

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Appendix C

Analysis of the Responses to the Survey

In January 1980, over 1800 letters were sent by the Task Force Chairman to individuals actively in or concerned about engineering education. The responses to the Task Force's survey provided significant background for its deliberations. A quantitative content analysis was conducted using the 315 responses received prior to the March deadline. The results of the canvass are presented in this section. The content of the letters received is summarized on an issues basis in an aggregated form; the analysis is followed by a table showing the proportion of respondents who mentioned each issue. Following the March deadline, an additional 81 responses were received, and an analysis of the affilitation of all respondents is presented in Appendix D.

The total number of initial respondents (315) was categorized into three major sectors: academia, government, and industry. Academicians, including some in university administration, and industry respondents were about equal in number (153 and 145 respectively). There were 17 respondents affiliated with government, all but 5 at the federal level and the remainder at the state level.

Caution must be exercised in interpreting the information provided below. No effort was made to establish a scientifically representative sample of respondents. Moreover, the frequency and percentage data presented here does not include the 81 respondents whose replies were received after the deadline. Thus, a high frequency of responses on a particular issue may not necessarily be related to the importance of that issue, nor should a low frequency of responses be taken as indicative of the relative lack of importance of an issue. Finally, the views expressed here are those of the respondents and not necessarily those of the members of the Task Force.

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Engineering Education

The topics discussed under this heading have been divided as follows: Pre-college Preparation; Undergraduate Education; and Post-baccalaureate Education.

Pre-college Preparation

Content analysis indicates that the pre-college environment was addressed fifty times by survey respondents. Two major categories of issues were mentioned: inadequate preparation in mathematics and science; and counseling in career decision making for high school students. Among those who mentioned the first item as an issue, the overwhelming majority are affiliated with universities and industries. They were unanimous in deploring the level of student achievement in mathematics and the sciences. Some, especially those in academia, noted that the current trend is toward declining skills in these areas.

Although there was no uniform pattern of discussion among respondents who addressed the issue of secondary school career counseling, most were critical of the process for a number of reasons. Counselors are not advising the most appropriate students to pursue an engineering education because counselors are not sufficiently knowledgeable about mathematics, the sciences, and engineering. Other respondents attributed the cyclical nature of engineering enrollments to the lack of coordination among the nation's secondary school counselors and to their lack of adequate information about variations in manpower demand.

Undergraduate Education

Eight issues in undergraduate engineering education were identified. They will be discussed in the following order: Quality of Education; Engineering versus Engineering Technology; Engineering Curricula; Communication Skills; Non-technical Curriculum Content; Cooperative Programs; Recruitment of Minorities and Women; and Use of Computers.

A. Quality of Education: This issue was mentioned by 17 respondents, 6 affiliated with universities and 11 with industry. In general, respondents felt that the universities are doing a good job in training baccalaureate engineers. Graduates were considered to be well-able to embark upon the practice of engineering. However, some respondents, primarily some affiliated with industry, perceived an overemphasis on research at the expense of technical problem-solving skills. They felt that graduates

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must receive extensive on-the-job training in order to be valuable to the private sector.

This issue has ramifications beyond the narrow concern of educational quality, for it reflects differences in philosophical views of engineering education. It raises the question: Education for what? Respondents were nearly equally divided between those advocating education for continuous learning and adaptability to future technologies and those advocating career-oriented training to meet current industrial demands.

B. Engineering Versus Engineering Technology: The respondents observed that there is considerable confusion over the various engineering degree offerings at the undergraduate level. Twenty-six respondents suggested that an effort be made to clarify the nomenclature for and educational components of the BSE (Bachelor of Science in Engineering), the BSET (Bachelor of Science in Engineering Technology), and the two-year program leading to an Associate degree as an Engineering Technician. They also felt that the career opportunities afforded recipients of these degrees should be clarified.

This issue also relates to the philosophical dialogue mentioned above. Several respondents suggested that the BSET degree might, in certain cases, best serve to train students to meet the immediate needs of industry, while holders of BSE degrees might be better utilized in research, academic pursuits, and in companies occupying the forefront of new technological development.

C. Engineering Curricula: This issue was mentioned by 116 respondents. Forty-nine are affiliated with universities, 7 with government, and 60 with industry. Most of the controversies about curricula center on the content of BSE programs. A number of respondents from industry and academia suggested an increased emphasis on the engineering sciences. They noted that the essential training of an engineer should enable him to be a problem-solver in virtually any area of engineering whether it be planning, design, or implementation. They stressed that the availability of technicians and computer software makes it possible for the engineer to use his time conceptualizing and reviewing and interpreting results.

Others disagreed. They stated that recent graduates are unable to apply their knowledge to development and design. They are unable to build a new product which will fill a need and work reliably. The trend toward a more theoretical, research-oriented curricula evident during the last twenty years is seen by some as detrimental to industry. As a consequence, some industries are beginning

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to demand more graduates for engineering technology programs and/or BSE graduates with specialized training.

Many felt that technological innovation in industry is out-pacing academia in many areas. If universities no longer lead the field in engineering and technology, their teaching tends to become less and less current. Many respondents felt that if universities are to regain their position in the forefront of innovative research, they must be given the resources needed to support improvements in facilities and equipment, as well as higher faculty salaries.

A related concern was the failure of engineering programs to include sufficient course work related to improving productivity. While most industrial engineering curriculum focuses on improving productivity, other engineering disciplines often avoid this important issue to the detriment of their graduates and the nation. Many respondents suggested establishing a much higher priority on courses covering management skills, decision-making criteria, and cost-benefit considerations to enable graduates to understand the economic parameters of engineering decisions. Others pointed out that engineers also must be prepared to cope with the rules controlling design work in industry. They noted that, today, federal, state, and professional regulations have an increasing impact on engineering practice.

D. Communication Skills: Twenty-six respondents, the vast majority from industry, stated that graduates are deficient in vital communication skills and urged that universities place much more emphasis on these areas. The ability of the engineering to communicate well verbally and in writing was seen as essential to effective performance in industry. In addition, the need for engineers to increase their participation in the formation of public policy was noted. The public is no longer unquestioningly receptive to engineering developments. Therefore, the engineer now must assume an additional role as an advocate of technology and as an educator of the public and its representatives.

E. Non-Technical Curriculum Content: In addition to improving communication skills, many felt that engineering graduates must learn to participate in the entire range of complex societal processes related to development of new technologies. As advocate and educator, the engineer must be able to interact successfully with the entire spectrum of important societal actors. A large number of respondents (87) recommended that engineering education emphasize course requirements in such areas as ethics, the social sciences, history, the arts and humanities, and business management.

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They felt that the engineer must be capable of understanding a variety of social viewpoints in order to be successful.

F. Cooperative Programs: Cooperative programs provide employment experience in industry, usually for one term each academic year for students at upperclass levels. The ten respondents who mentioned this issue strongly supported the concept and suggested that this university/industry partnership in education become more widespread. Some suggested that "co-op" become a required part of engineering curricula.

G. Recruitment of Minorities and Women: The number of women adopting engineering as a profession has increased dramatically in recent years. At present, the proportion of women in engineering programs is approaching the 20 percent mark. However, the engineering profession has a paucity of minorities in its ranks. In order for the profession to meet its overall purpose of improving the general welfare, it must better reflect the society it serves. Sixteen addressed this issue and recommended more active recruitment of minority and female students.

H. Use of Computers: The emphasis on computers in undergraduate engineering education had its supporters and detractors among the 46 respondents who mentioned the issue. A number of respondents felt that too much empasis is placed on computer modeling and analysis and too little is placed upon laboratory research. An opposite point of view was expressed by those who felt that micro-processors are the inevitable wave of the future and that their potential has barely been tapped. They felt that engineering programs should emphasize computer work, but not necessarily equally for all students or at the expense of other important elements of the curriculum.

Post-baccalaureate Education

A total of 83 respondents addressed one or more aspects of graduate education. Three categories of issues were mentioned: Quality of Graduate Education; Retention of Graduate Students; and Foreign Student Enrollments.

A. Quality of Graduate Education: Twelve respondents, representing industry and academia equally, commented on the quality of graduate education issues.

Two major issues were discussed related to the curriculum content of advanced degree programs. First, many graduate programs are thought to be too research-oriented. As a result, there is a dearth of professionals with advanced degress who are suitably prepared to take on the

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complex development and management problems of industry. Several respondents indicated that graduate programs in "applied engineering" should be encouraged. They maintained that industry will gladly hire those with appropriate advanced degrees.

The second issue relates to the perceived utility of the in-depth study required for preparation of a graduate thesis. Some maintained that such an experience teaches the graduate student how to delve to the bottom of a particular topic and contribute to the knowledge base. These skills can then be applied to almost any problem that is within the individual's specialty. Others maintained that the topics chosen for theses are too often highly esoteric. As a result, the holder of an advanced degree often knows a great deal about an essentially unimportant topic.

B. Retention of Graduate Students: Fifty professionals, the majority affiliated with universities, felt that the issue of low graduate enrollments by U.S. engineering students is of significance and has negative implications for the future of engineering education and research. Currently, the most attractive post-baccalaureate option is employment in industry. It is believed that the majority of graduates choose this route because the job market demand has driven entry-level salaries up to $25,000. Faced with such an opportunity, the recent graduate puts aside thoughts of acquiring further education immediately and anticipates returning to the university at some point later in his or her career. If American students are not attracted in sufficient numbers to advanced degree programs, then the current shortage of American engineering faculty members will be exacerbated.

C. Foreign Student Enrollments: Twenty-one respondents felt that the issue of foreign nationals enrolled in graduate education programs is of importance. Their number is currently substantial and is growing. The graduate education of foreign nationals absorbs a substantial part of the capacity of current advanced degrees programs. There was some concern that language barriers, for example, may force reduction in graduate education standards. In addition, many foreign nationals are recruited to fill faculty vacancies. Some felt that the effects of cultural differences on the education process should be studied further.

Continuing Education

Continuing education in engineering refers to the fully employed professional seeking to update obsolete skills or to develop new skills by enrolling in one or more courses,

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workshops, or seminars. The courses may be part of a regular curriculum, or of a specialized program held for the purpose of professional updating. The need for such programs was mentioned by 29 survey respondents, the majority from industry. Many felt that such programs are particularly important today since rapid technical obsolescence occurs among engineering personnel. Several mentioned that engineering faculty also rapidly become obsolete, given the rate of technological innovation.

Institutional Support

As might be expected, the issues related to institutional support were mentioned chiefly by academicians. Thirty-eight individuals made general comments about the need for more financial support for educational institutions. In addition, comments were often made in relation to four specific areas: Laboratory Equipment; Junior Faculty; Senior Faculty; and Student Support.

Laboratory Equipment

Obsolescence of laboratory equipment was of great concern to academic respondents; 27 mentioned this issue. It is generally recognized that deficits in this area will plague universities well into the next decade. The problem is complicated by a number of factors, not the least of which is the rising cost of necessary new equipment. The increasing levels of sophistication alone have made the cost of some laboratory and computing equipment prohibitive for most universities. Inflation only makes matters worse, and the need for new equipment permeates the whole range of engineering education, including those areas characterized by lower levels of technology. Equipment presently available in most schools of engineering no longer matches that in industry. Many felt that there is no practical way for engineering schools to maintain modern equipment without a massive infusion of funds, probably from the federal government. If this situation is not remedied, academia will increasingly turn out students who are ill-equipped to move into industrial enterprises and make positive contributions without extensive on-the-job training. A number of leaders in the field placed this issue near the top of their lists of most pressing problems.

Several respondents also mentioned obsolescence of engineering education physical plants as a problem. Aging, deteriorating buildings do not have the capabilities and flexibility that quality education requires.

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Junior Faculty

As was mentioned in the section on post-baccalaureate education, young American engineering baccalaureates are attracted to industry because of lucrative entry-level salaries and challenging job assignments. They are not choosing to pursue graduate engineering degrees that may lead to academic careers because university pay scales are not competitive. Further, industrial salaries have lured many junior faculty members away from academia and it appears this trend will continue. Forty-three respondents viewed this situation with alarm. University affiliated respondents especially were intimately aware of the difficulty of recruiting highly qualified faculty, and several cited instances of vacancies remaining unfilled.

Senior Faculty

Today, all university disciplines are seeking increased funding support. However, engineering departments have special problems. Nineteen addressed this issue. The cyclical nature of undergraduate student enrollments is often ignored by college administrations, and engineering departments receive a standardized "fair share" of each year's annual budget. Even if student enrollments were stable, this would present difficulties because an engineering education entails significantly greater laboratory and equipment costs than most other undergraduate fields. In addition, engineering education requires individualized instruction in design, problem-solving, and so forth. To be sure, faculty salaries account for the major portion of departmental budgets, and university salaries are not keeping pace with inflation. This imposes a hardship on many senior faculty members, particularly those in engineering. The discrepancy between industry and university salaries is simply too great.

A number of respondents suggested alternative approaches to the problem of dwindling university financial support. Many suggested stronger industry support of faculty and students. For example, industry could be asked for long-term commitments to provide periodic employment of faculty during summers or sabbaticals. Such employment opportunities would satisfy a number of needs. Faculty would be assured of continuing opportunties and supplemental incomes. Industry would benefit from the input of experienced professors of varying backgrounds who could provide significant assistance with short-term projects, as well as from the assurance that young graduates would have received some training from faculty with practical experience.

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A number of respondents addressed the issue of federal grant support for university research. Many considered federal support essential if schools of engineering are to survive. Others were concerned about preserving latitude in university education and research and were wary of undue federal influence.

Student Support

The issue of student support was addressed in four letters. They felt that financial support for students at both the undergraduate and graduate levels has declined in recent years as a result of changing federal priorities. Suggestions for sources of student support included cooperative programs, industry and community support, and increased federal government support through loans and research grants.

University/Industry/Government Interaction

Several respondents expressed their observation that relationships among unversities, industry, and government are, at times, erratic or even adversarial. Twenty-nine commented on this issue and urged that closer ties be developed for the welfare of the nation and the institutions.

Societal Needs

The issues under this heading are: Supply and Demand Forecasting; Accreditation and Certification; New Societal Concerns; and The Prestige of Engineers in Society.

Supply and Demand Forecasting

Fifteen experts commented on the need for accurate forecasting of both the future demand for engineers and the projected supply. Given accurate demand models, respondents felt that output from engineering schools at all degree levels could be adjusted.

Accreditation and Certification

Educational programs are accredited by professional organizations vested with recognized authority. Professional bodies also certify or register professional personnel; usually, periodic renewal of such certifications is required. States may license professionals whose

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activities bear a relationship to public health, safety, or welfare, and such professional licenses are often issued for life. Most of the 20 respondents who commented on these issues focused on the process of accrediting academic programs. By and large, they felt that the process is working well in maintaining high standards of quality, while at the same time permitting the program diversity that many believe is required. Some respondents recommended that the accreditation process be studied to ascertain the nature of the influence that accreditation plays upon programmatic aspects of engineering education. In addition, a few noted that further examination of the professional certification process is needed. This might shed light on the degree of importance placed on it by industry.

New Societal Concerns

There were several (18) comments concerning specific areas in which the engineering profession must increase its future efforts. These included energy, food, pollution, resource management, improvement in American industrial productivity, and regaining the competitive edge in technological innovation and development vis-a-vis such nations as Japan and Germany. These issues emerged in the 1970s and are expected to remain pervasive societal concerns throughout the 1980s.

The Prestige of Engineers in Society

The image of the engineer in society was mentioned by 37 of the respondents. The profession, in general, has been subject to mistrust and skepticism as a result of such events as structural failures in bridges, design or operating failures in the fail-safe components of nuclear power generating plants (e.g., Three Mile Island) or of aircraft (e.g., the DC-10), and what appears to be an indifference to environmental degradation by industrial processes.

The respondents felt that engineers will not only be required to address the technical side of future problems but also they will be required to become spokesmen. They will have to put issues and choices on the public agenda, make recommendations, and become advocates for their positions.

A Proportional Analysis of the Responses

Percentages were calculated for the initial 315 respondents from academia, industry, and government who

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addressed each issue. They are given below. As previously noted, caution is suggested in using these data.

	Percent of Respondents Acad. (N=153)	Govt. (N=17)	Industry (N=145)
1. Engineering Education Issues			
1.1. Pre-college Preparation			
1.1.1. Preparation in Science and Mathematics	5	6	4
1.1.2. Counseling	13	12	10
1.2. Undergraduate Engineering Education			
1.2.1. Quality of Education	4	0	8
1.2.2. Engineering versus Engineering Technology	8	6	9
1.2.3. Engineering Curricula	32	41	41
1.2.4. Communication Skills	1	18	15
1.2.5. Non-technical Curriculum Content	18	29	37
1.2.6. Cooperative Programs	1	6	6
1.2.7. Recruitment of Minorities and Women	6	0	5
1.2.8. Use of Computers	14	24	15
1.3. Post-baccalaureate Education			
1.3.1. Quality of Graduate Education	4	0	4
1.3.2. Retention of Graduate Students	75	12	7
1.3.3. Foreign Student Enrollments	8	12	5
1.4. Continuing Education	8	12	10
2. Institutional Support			
2.1. General Support	19	6	6
2.2. Laboratory Equipment	14	0	3
2.3. Junior Faculty	24	0	4
2.4. Senior Faculty	11	0	1
2.5. Student Support	1	0	1
3. University/Industry/Government Interaction	10	6	9
4. Societal Needs			
4.1. Supply and Demand Forecasting	5	12	3
4.2. Accreditation and Certification	7	6	6
4.3. New Societal Concerns			
4.3.1. Energy	8	12	7
4.3.2. Food	1	0	1
4.3.3. Other	3	6	4
4.4. The Prestige of Engineers in Society	5	12	6

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Appendix D

Analysis of Sources of Responses

In all, responses were received from 396 individuals, not counting written contributions by Task Force members. (Eighty-one responses were received after the March deadline and were not included in the analysis presented in Appendix C.) In some cases, a person sent more than one letter; these were counted as one response. In seven instances, however, individuals responded both from a personal viewpoint and as an official of an organization; these were counted as two responses. Hence, a total of 403 responses is tabulated below.

Analysis

Affiliation	Number	Percent
Engineering Educator	186	46.1
Professional Society or similar organization	31	7.7
Industry	108	26.8
Other	78	19.4
TOTAL	403	100.0

The breakdown of Other is:

Researcher		8
Consultant		39
Retired		5
Government		21
Federal	16	
State & local	5	
Miscellaneous		5
TOTAL		78

Of the 403 responses, 158 (approximately 39 percent) of the respondents were from members of the National Academy of Engineering.

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Appendix E

Bibliography

Responses to the Chairman's letters brought forth citations of a number of recent and forthcoming significant papers and reports pertaining to engineering education. Members of the Task Force are involved in several, related activities of other organizations or groups and were able to provide further important references.

The following bibliography does not purport to be comprehensive. Rather, it attempts to indicate the scope of references that are available now or will be available shortly and to suggest the breadth of organizations giving attention to the subject. In several instances, a single paper may be noted from a program which included several others papers concerning engineering education. In these cases, it is suggested that full proceedings be obtained or more details sought from the parent organization.

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G.H. Millar, Engineering Education Needs as Seen for Agricultural and Construction Equipment. Paper to be presented at the ASME Conference in San Francisco, August, 1980.

James F. Young and L. C. Harriott, The Changing Life of Engineers. Background paper prepared for discussion at

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the ASME Convocation on Strategies and Structures for Century TWO, August 25-27, 1978.

A task force of IEEE composed of several representatives from industry developed a model curriculum for electrical engineering which might be used as a reference for further discussions between industry and academia. For more details, consult Mr. John Wilhelm, Staff Director of Educational Activities, IEEE, New York.

William R. Kimel, The Feasibility of Professional Schools of Engineering in Missouri. Paper presented at the 86th Annual Conference, American Society for Engineering Education, University of British Columbia, June 19-22, 1978.

Reports and papers are understood to be in preparation and activities currently scheduled are as follows:

The Industrial Research Institute Research Corporation has completed a study of needs for continuing education in a project with Dr. George Schellinger of Polytechnic Institute of New York under sponsorship of the National Science Foundation. This report is scheduled to be available May 1980.

The Committee on Science and Technology, U.S. House of Representatives, asked AAAS to assist the Committee in identifying major future science and technology issues, assigning them priority, and determining which lend themselves to - or need - legislative treatment." The Committee on Science, Engineering, and Public Policy (COSEPP) of AAAS is coordinating the AAAS response which will be submitted to the Chairman, House Committee on Science and Technology, within the next few months.

ASME has scheduled a Workshop on Engineering Education, August 18-19, 1980, San Francisco, as part of ASME's Century II - Emerging Technology Conference.

A Design Engineering Education Conference is scheduled for August, 1980, in San Francisco, sponsored by ASME/SAE.

A study by the Office of Personnel Management on standards for hiring engineers for the federal government will be available summer 1980.

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A survey was conducted by the Louisiana Engineering Society on relevancy of engineering education. Responses are currently being analyzed.

A major mission statement is reported to be in preparation to the President, University of British Columbia, and to the Provincial Government of British Columbia with respect to engineering education.

The Academic Affairs Committee of AIAA is canvassing 56 Aerospace Engineering Departments at American colleges and universities to determine the ratio of foreign nationals in aerospace graduate programs. It is believed that the proportion is 70 percent or higher.

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Appendix F

Organizations Concerned with Engineering Education

The Task Force members were keenly aware of the large number of associations and societies with a strong and continuing involvement in matters pertaining directly to engineering education. Many of the members are now or have been participants in the activities of such organizations and remain closely tuned to their programs and objectives.

Viewpoints among the professional and technical groups vary as to the directions and needs of engineering education. One respondent offered the comment:

> "Some of these speak to engineering education, while others foster discussion among engineering educators. Unlike other fields of endeavor, such as pharmacy, architecture, or dentistry, there does not appear to be an institution that speaks for engineering education with a clear voice. I would suggest that an examination of this question would be worthwhile."

This is a thought-provoking statement; nonetheless, there is complete agreement on the need for strong engineering education programs in our country, as well as a general consensus on their current state and the issues involved in maintaining their vitality.

The following organizations were cited several times as being particularly important in general matters pertaining to engineering education:

- American Society for Engineering Education
- American Association of Engineering Societies
- Accreditation Board for Engineering and Technology
- National Society of Professional Engineers

Specific interests of discipline-oriented professional and technical societies, and the importance of their

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education related activities, were highlighted by a society president who commented:

> "This discussion points out the fact that 90% of the accredited programs in engineering come under the disciplines of 9 major engineering societies, i.e., the 5 founder societies: AIChE, AIME, ASCE, ASME, and IEEE, and the additional societies, AIAA, ASAE, AIIE, and ANS. Likewise, these 9 societies account for 90% of the Bachelors Degrees in engineering. The disciplines of the 5 founder societies account for 79% of the 4-year degrees in technology and account for 70% of the 2-year degrees in technology."

Responses were received from officers and staff of several of the above mentioned societies as well as from many other important, similar organizations. In addition to their useful comments and recommendations, these letters cited other significant work underway and enclosed recently published (or drafted) papers. A number of these are included in Appendix E.

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Issues in Engineering Education: A Framework for Analysis
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