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KEYNOTE ADDRESS

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For many years, the United States was the undisputed world leader in science, engineering, and technology. We became a great nation because of our inventive genius -- because we recognized, fostered, and nurtured technological innovation. Our landing on the Moon, the clean sweep of 1976 Nobel Prizes (and many more since then), and the fact that 80% of the Western world's aircraft are U.S.-built all attest to our leadership. We did, in fact, Americanize the world through our science and the engineering application of that science.

In becoming that leader, we have developed a unique partnership -- a partnership of industry, university, and government -- that has been responsible for the human resources, much of the research output, and some of the development leading to innovative new products and services.

Now our leadership is being challenged. We have lost our competitive edge in the world market. "Made in Japan" has replaced "Made in U.S.A." as the recognized standard of quality. Productivity, the source of all economic value, is lagging. We are importing prodigious quantities of manufactured goods and, for the first time in 100 years, we are incurring huge trade deficits.

The results, of course, are devastating: Inflation is eroding our standard of living; the dollar is no longer a stable world currency; and, instead of generating our wealth and then distributing it, we are seeking to distribute wealth we have not yet earned.

The underlying causes, it is generally agreed, are our declining productivity and, in many instances, the lower quality of the goods we produce or the services we render. The American consumer and, indeed, the world consumer seek excellent performance, often special "top-of-the-line" features, and always high quality at a competitive price. These elements depend on many factors, such as the availability of technology; the design and manufacturing quality; the investment in plant, tools, and equipment; the excellence of management; and the skill and dedication of the worker.

I consulted many papers and used many of the ideas expressed in those papers to prepare these remarks. The papers are listed in the bibliography at the end of this address.

Engineering education -- the subject of this symposium -- touches on many of these factors, but contributes most importantly to two:

- -- The availability, quality, and interests of the engineers whose responsibility it is to design and produce our wares.
- -- The research and development on which product design and manufacturing processes must be based.

In this address, I will examine areas of concern in engineering education and will describe the existing industry-university-government partnership, together with the reasons for its success. I will then discuss some specific university-industry interactions, as well as the role of government. Finally, I will recommend special steps the National Academy of Engineering should take to help nurture the best possible arrangements among industry, government, and the universities.

Current Concerns in Engineering Education

There are, of course, many concerns about how well we educators of engineers are doing our jobs. The nation's deans of engineering could, at any given time, provide a long list of current problems. However, I will limit my discussion to three, and present them only in the light of what might be done about them in the context of the industry-university-government partnership. They are:

- -- The supply of engineers with baccalaureate degrees and with graduate degrees.
- -- The tendency for many recent engineering graduates to have a penchant toward science rather than toward technology and innovation.
- -- The financial problems faced by our schools of engineering.

The Supply of Engineers

In the 10-year period from 1969 to 1979 in the United States, the number of recipients of bachelor's degrees in engineering increased from 40,000 to 52,600, and recipients of master's degrees rose from 15,000 to 16,000. Doctoral degrees granted in 1969 numbered 3,400, reached a peak of 3,800 in 1972, and declined to 2,800 in 1979. (This decline is even more serious than it appears; the number of foreign students has remained fairly constant throughout this time period; thus the number of U.S. students has dropped disproportionately.)

The overall supply of entry-level engineers with bachelor's and master's degrees is only slightly less than the demand, although there may be some serious spot shortages in specific fields. Also, shortages at this level are quickly corrected by the pull of the job market -- engineering today is virtually the only field in which a job is practically guaranteed with only 4 years of higher education. A longer-term problem may manifest itself as the total population of 18-year-olds decreases in the next 10 years, but even there the availability of jobs, together with the entry of more women and minorities into the field, should preclude a critical shortage.

The shortage of Ph.D.-level engineers is more serious and may be more long-lived. Its causes are many: the availability of jobs and high salaries paid for those with bachelor's degrees; the demand for more faculty members as undergraduate enrollments rise; the esteem (or lack thereof) in which engineering as a profession is held by the public at large; and the fact that the time constant for graduate studies is long and therefore less affected by supply and demand.

The net effect is a shortage of approximately 1,500 engineering faculty members on a nationwide basis. Since this shortage represents less than 10% of the total engineering faculty, it should be possible to manage it -- on the average -- by working a little harder, by borrowing faculty from other disciplines, or by making greater use of adjunct faculty members from industry (more about that later). There are two concerns, however: First, no department is exactly "average" and some departments are suffering much greater shortages than others. Second, in some institutions, there may be a tendency to fill vacant positions with less than the best and the results of such compromises can be disastrous over a very long period of time. (I might add that at my own institution we have avoided the latter problem by the simple expedient of not taking away vacant "slots" from our dean of engineering at the end of each year. He is, therefore, in no rush to fill vacancies, and can wait until a person of appropriately high quality becomes available.)

The Proclivity Toward Engineering Science

Of greater concern than sheer numbers, in my view, is the direction that engineering education has taken, especially for the best of our students. For many years now, the top students have been more interested in engineering science than in technology. The principal reason for this preference stems from the fact that, since World War II, the balance of funding for university research in engineering has switched from industry to the government, and government agencies generally tend to sponsor work that is fundamental rather than applied, as indeed they should. The natural consequence is that faculty members are working in fields of their sponsor's interest, and the best students follow the lead of their faculty.

Yet, as I mentioned earlier, the loss of our competitive edge stems not from a lack of theory or invention, but from a lack of productivity and innovation. The immediate need is not for more basic knowledge, but for better design, more productive manufacturing, and higher quality. An essential ingredient in meeting this need is a closer relationship between universities and industry. Such a relationship, in which students and faculty become involved in the excitement of an entrepreneurial venture, the elegance of a simple design, or the importance of solving a manufacturing problem, can quickly entice some of our best young engineers to seek jobs related directly to design and manufacturing.

Please do not misunderstand me. I am not advocating a basic change in curriculum; in this rapidly changing environment, a thorough grounding in the fundamentals is even more important than before. I am merely recommending that properly constructed university-industry relationships can change a student's attitude about the importance and excitement of the productive end of business. Nor am I advocating that this guidance is right for all students; we will still require, and should help lead, a substantial number of graduates into the basic engineering sciences.

Financial Concerns

Finances are always of concern to institutions of higher learning, and, because of the cost and quick obsolescence of laboratory and research equipment, an engineering education is among the most expensive.

A study performed 2 years ago for the Association of Independent Engineering Colleges indicated that, for a school to stay current, an expenditure of $1,500 is required for every graduating senior each year for undergraduate laboratory equipment. This translates to an annual expenditure of $75 million -- a sum considerably greater than that spent by our colleges and universities.

The sources of funds are limited. Tuition in private institutions pays less than two-thirds of the cost of education. Sponsored government research pays only approximately 80 cents of every dollar expended by the university for that purpose. (Yes, we are subsidizing the government in our research programs.) Income from endowment and support from charitable foundations is decreasing (as a proportion of our annual budgets), because the return on investments made by these funds cannot keep up with growth and inflation. This leaves only private individuals, corporations, and the government to provide the necessary support -- another reason why industry-university-government relationships are so very important.

These, then, are the concerns to be addressed: on a national scale, our loss of competitiveness, brought about by a lag in productivity and by a lack of quality and, in engineering education, the availability of engineers with advanced degrees, the interest among engineering graduates in manufacturing, and the cost of providing the education.

Now, let us examine the existing industry-university-government partnership and how that partnership might address these concerns.

The Industry-University-Government Partnership

Any successful business relationship depends on an exchange of goods or services rendered in return for payment in some form. In the relationship among industry, universities, and government, this exchange can take many forms; nevertheless, it must exist if the relationship is to work.

One way to examine the current interaction among the three participants is to look at the sources of funds for basic research, applied research, and development--in the context of who performs the work. They are given in Table 1 and Figure 1.

Since universities are not significantly involved in development, I will limit this discussion to basic and applied research. Note that most of the funding for basic research comes from the federal government; the federal government and industry are both major funding sources for applied research. Universities are involved primarily in performing basic research and, to a lesser extent, applied research.

Because the government has been a major source of funds, especially for basic research, it is important to understand why and when the government's role in this area is justified. The rationale for government funding of basic research is based on the high uncertainty of results, the long-term nature of many investigations, the lack of ownership rights to the results, the "public good" character of the knowledge gained, and the fact that the performance of research leads to a national resource in terms of a supply of trained scientists and engineers.

The rationale for federal support of applied research is more tenuous. In my view, government support should be limited to areas meeting direct federal needs (e.g., defense, space, air traffic control, regulatory standards), general economic and human welfare needs (e.g., earthquake prediction, environmental protection, medicine, agriculture), and specific high-priority national needs (e.g., new energy technologies, advanced aircraft technologies). In most other areas, where industry benefits directly and ownership rights are easily defined, the support and funding for applied research should come directly from industry. In this manner, the marketplace will determine much of the direction and output of applied research, as it should.

It is interesting to note that the motives for supporting and performing research may have different priorities among the various members of the industry-university-government relationship. For government and industry, there are two principal motivations for sponsoring basic and applied research: First, the results of the research are important to industry and to the nation as a whole; second, the sponsorship of research leads directly to a supply of skilled scientists and engineers, since there exists a highly complementary relationship between performing research and educating technical people.

For universities, the principal motivation for research is the education of scientists and engineers. Students and faculty must both be involved in research: the students to learn to apply themselves as problem solvers, and the faculty to stay at the cutting edge of rapidly changing fields. A secondary motivation--less important to the educational process of the university, but highly important as a measure of its reputation--is the knowledge gained as a result of the research.

The rationale and the motivation just described explain why the industry-university-government partnership has worked. In fact, it has been fabulously successful. And even though industry's and government's primary interest may be the research results and the universities' primary motivation may lie in the education the research pro-

TABLE 1 Research and Development Funding Estimate for 1980

Source	Basic Research: Source of Funds	Basic Research: Performer of Work	Applied Research: Source of Funds	Applied Research: Performer of Work	Development: Source of Funds	Development: Performer of Work
Federal government	69.7%	14.7%	46.6%	18.7%	45.0%	10.6%
Industry	14.8%	16.1%	47.7%	60.1%	54.4%	84.9%
Universities	9.5%	51.9%	3.3%	11.0%	.2%	.8%
Non-profit institutions including university associated FFRDC's*	6.0%	17.3%	2.4%	10.2%	.4%	3.7%
Total funding (millions)	$8,230		$13,505		$38,640	

*Federally funded research and development centers

Source: National Science Foundation, National Patterns of Science and Technology Resources 1980 (NSF 80-308)

vides, the end result is the same. Therein lies the reason for this enduring partnership.

The partnership also has a built-in ability to change with time, because its major output is people -- people who are broadly educated and well-steeped in fundamentals, yet highly capable of solving problems in relatively narrow fields. As the nation's needs change and as new requirements are developed, such adaptive people will be able to address and solve problems in many fields. Whether or not an individual enters a specific field is much more a matter of attitude than a matter of capability or knowledge.

It is precisely this flexibility that allows us to address the problems at hand. If we accept the premise that some of the problems that have led to our loss of competitiveness can be solved by enticing larger numbers of our best engineering graduates into design and manufacturing, this can be done by strengthening the linkages between industry and universities. Strengthening these linkages, in this con-

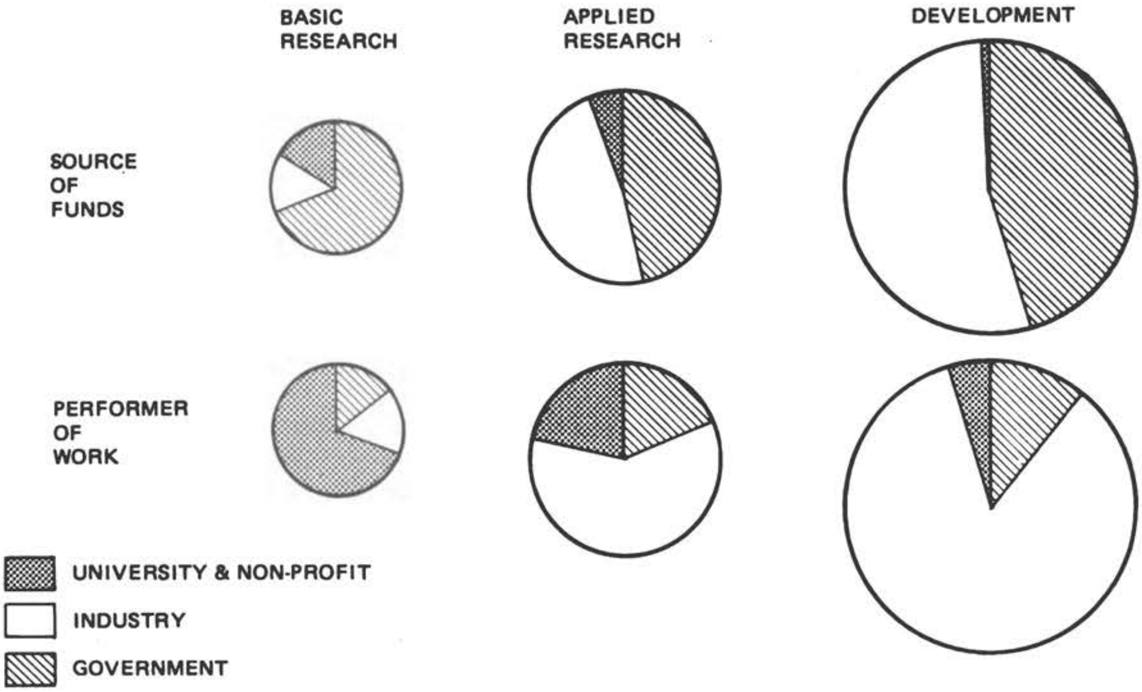

FIGURE 1 Research and Development 1980 Funding.

nection, means stronger ties in what is generally classified as applied research, but certainly not to the exclusion of basic research. The output will be a greater stream of graduates interested in solving practical problems, as well as research results in areas of direct and current interest.

The work at universities is limited by their capacities; thus, a swing toward more industry sponsorship may limit the amount of direct effort universities can carry out under government sponsorship. The funds released, however, are essential in at least three other areas: graduate fellowships to increase the number of engineers with advanced degrees; laboratory equipment and instrumentation; and full funding (instead of the current practice of partial funding) of research performed under government sponsorship.

Specific University-Industry Relationships

The many models for university-industry interaction generally fall into two broad categories: those based on a direct university-industry relationship and those that involve the government as a sponsor of the university-industry interaction.

Although generalization is always dangerous, I will nevertheless generalize so far as to state that the success of government-induced partnerships has been quite limited, whereas the success of direct university-industry interactions without government intervention has been great. (I am sure that there are exceptions to both statements.)

An early model of an outstanding university-industry interaction was that of the California Institute of Technology with the aeronautics industry in the "Von Karman years." This relationship was a major force in the development of the industry and supplied much of the engineering leadership.

A more recent example is the Silicon Structures Project of Caltech, wherein participating companies send their engineers and scientists to work jointly with Caltech students and faculty. The results include faculty research directed at current problems, training of students in a vital field, and direct transfer of research results into industrial innovation.

Two examples of individual companies' forming special relationships with universities are the Monsanto-Harvard agreement in the life sciences and the Exxon-MIT agreement in the field of combustion. Both arrangements are long-term in nature; involve the support of individual university investigators; provide for close relationships between the companies' own research efforts and those of the universities; and spell out specific arrangements for patents, royalties, publication rights, and so on.

Another example of an experiment in university-industry cooperation is the Manufacturing Productivity Center at my own institution. Here, our basic purpose is to attract some of the top engineering students (undergraduate and graduate) to the manufacturing disciplines. We decided that the best way to do this would be to have the students solve actual manufacturing-related problems provided by the sponsoring companies. Founding members in the Center -- Boeing, General Electric, and General Motors, to date -- provide research problems. Each problem is addressed by a team that includes a project engineer and several students and faculty members. The project engineer is responsible for producing results on schedule and within the negotiated cost; faculty members act as consultants; students do the work. The result is a group of students with a propensity toward manufacturing, and solutions for specific manufacturing problems.

A Time to Experiment

These are only a few of the many interactions between industry and universities, and the most important conclusion to be drawn is that many different forms of interaction can be successful. It is a time for experimentation.

Essential ingredients for success include agreement on the area of research to be addressed; great flexibility in working out areas of mutual concern such as patents, patent rights, and the freedom to publish; an attitude on the part of those university personnel involved that is best characterized as a "willingness to serve"; and a realization by industry that a university is a business that cannot provide a "free" service or free advice any more than any other business can.

The Importance of Human Interaction

The most successful of the programs just described involve interaction between people in industry and universities, generally in the conduct of research. Even more direct interaction can be attained through cooperative education programs, in which engineering students periodically spend time away from the university working in industry, and through various means of bringing industry personnel to the campus and faculty members to industry.

Co-op programs permit the student to get a working view of the practice of engineering while still going to school. The results for the student are a better appreciation of the relevance of specific studies and, often, an important change in attitude about the excitement of an engineer's work in industry. For the company, the results include better educated engineers and an opportunity to evaluate students over a period of time, rather than in only a 20-minute interview before making a job offer.

Beyond co-op programs, a much more active interchange between industry engineers and engineering faculty is highly desirable. Such interchanges could take the form of lectures or seminars by engineers and managers from industry or be more formal arrangements such as adjunct professorships. On the academic side, the method of interaction could range from individual consultation by faculty members, to summer employment, to spending a sabbatical in industry. In all cases, students and faculty would become more aware of industry problems and concerns and new ideas would be transferred to industry.

General Support from Industry

In addition to the direct relationships just described, general support of universities by corporations will assume greater importance as the flow of funds from endowments and foundations becomes a smaller proportion of our budgets. This support, which comes in the form of essentially unrestricted funding and from companies matching gifts of their employees, has for the most part been superb. The quid pro quo is a better educational process, and an output of well-educated engineers available for employment.

In light of the concerns stated earlier in this address, I would suggest two additional areas for corporate support. The first is laboratory equipment. I mentioned the enormous cost of acquiring and maintaining modern engineering laboratory equipment and instrumentation. Many companies are in a position to give new equipment or experimental equipment that is no longer needed and could immediately be brought into the educational process.

The second support possibility is people. The current shortage of engineering faculty can be ameliorated through the use of parttime adjunct faculty from industry. Depending on location and availability, such appointments could involve several hours per week or an essentially fulltime stay for a specified period of time -- say a year or two.

The only caution in both of these areas has to do with excellence. On the equipment side, we need the highest quality in our laboratories, just as industry does. A rejected "piece of junk" would do us no good, nor would it enhance the reputation of the company whose label is on it. This warning is even more important in the case of adjunct faculty. As a role model -- as one who, by example, should draw the best engineers to industry -- the adjunct professor should be an outstanding teacher and researcher. If these qualifications are met, then the benefits that will accrue to industry, to the university, and to the individual can be both synergistic and great.

The Role of Government

It is beyond question that much of the success of engineering education in the United States is a direct result of federal government support. The rationale for that support, especially in basic research, has already been noted. I believe that all of us would agree that there is good reason for the government to continue to support this work.

Recently there has been much discussion of the role of the government in inducing greater interaction between universities and industry. In my view, the government should not be a sponsor of specific university-industry relationships and should not be a broker or third party when a university and a company seek ways to work together. Past experience, in the main, has demonstrated that this role is not proper for government.

The government should, on the other hand, generally facilitate university-industry interactions, remove obstacles, and provide general incentives.

In this regard, an additional incentive for industrial support of university research can be found in the proposed Research Revitalization Act of 1980 (HR 6632). This act would provide a tax credit for contributions by companies toward university research expenditures. The proposed 25% tax credit would essentially have the after-tax cost of research support by industry, at the marginal tax rate of 46%. It must be presumed that, given the proper climate for interaction, tax credits such as those proposed in HR 6632 would increase the amount of research support by industry, yet still let the marketplace determine the directions of that research.

As already mentioned briefly, there are several areas where the government should take a stronger direct role in the support of engineering education. The shortage of engineering faculty, and the shortage of holders of advanced degrees in general, could be addressed through the sponsorship of graduate fellowships. It has been estimated that between 1,000 and 2,000 2-year fellowships, funded at $8,000-$12,000 per year, are needed to overcome the shortage. In the early days of the space program, NASA had a very successful program of this type to help replenish the supply of Ph.D.'s; other agencies adopted similar programs. However, funding for all such programs was drastically reduced by the Office of Management and Budget in the early 1970's.

As a national problem, the shortage of up-to-date laboratory equipment will require government funding -- perhaps on a matching-grant basis -- in addition to industry support. A request for such funding was in last year's National Science Foundation budget, but did not survive the budget cycle. The scope of this problem, ranging between $50 and $100 million annually, needs to be addressed now.

The current practice of government funding of university research through a cost-sharing arrangement requires the use of non-research resources -- a highly ineffective way to achieve research objectives. High on the agenda for any restructuring of university-government relationships should be the principle of full recovery of direct and indirect costs.

Concluding Remarks

I have addressed the present state of the university-industry-government relationship as it affects engineering education and have made certain recommendations designed to help the United States regain its competitive edge in the world market. In summary, these recommendations include:

- Closer ties between industry and universities, especially in the area of applied research, through:
  - A variety of interactions tailored to meet the needs of specific industries or companies, on the one hand, and specific universities on the other.
  - Gifts of equipment to modernize and revitalize engineering laboratory education.
  - The loan of industry engineers as parttime faculty members to ameliorate the current shortage of faculty; to translate current industry problems into the classroom; and to help draw students into specific industrial careers.
- Improved government support of engineering education through:
  - Tax credits to industry to provide an incentive for additional industry sponsorship of university research.
  - Fellowships for graduate students to address the faculty shortage.
  - Full funding of government research at universities.
  - Grants for equipment for engineering laboratories.

The National Academy of Engineering, in my view, can make a significant impact on the problems I have discussed by:

- Continuing discussions of engineering education among industry, government, and universities to heighten the awareness of problems and proposed solutions.

- Cataloging and describing the various university-industry interactions now in existence and distributing this information widely so that others can expand on the good, and not reinvent the bad.

- Preparing a formal document, for submission to the executive and legislative branches, proposing legislative changes and funding to address the problems at hand.

In conclusion, I want to reiterate that what I have described represents a marvelously successful partnership among industry, universities, and government -- perhaps the best in the world. I have recommended no drastic changes to that partnership, only minor ones that are already inherent in its flexibility. With these changes, we should continue to enjoy interactions that benefit our universities, our industry, and the general public alike.

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SUMMARY OF NAE TASK FORCE ON ENGINEERING EDUCATION

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The task force of the National Academy of Engineering on Engineering Education became a reality in November 1979 and issued its report in April 1980. In those 5 short months, it addressed itself to the rather ambitious task of examining engineering education in its broadest aspects, of identifying problems that might exist and, finally, of proposing some kind of framework within which the solution to these problems might be sought. This task was obviously to be approached with a certain degree of humility, particularly in view of the many previous and ongoing studies.

The job of examining the more than 400 responses elicited from concerned individuals in the engineering community at large, of studying previous reports and, above all, of distilling from the mass of information available the essence of the status of engineering education in the country was awesome enough. We were sustained in our task by the recognition of the importance of the mandate we had accepted and of the critical role that the education of future engineers and the utilization and distribution of engineering professionals must play in ensuring the future health of the nation.

On a somewhat less lofty plane, we knew that others were engaged in similar studies and were very much aware that, if we were not heard first, we stood a good chance of not being heard at all.

There is no need to review here the critical state of many aspects of the nation's economy. The problems of the decrease in national productivity, of inflation, and of the worsening competitive stance of the United States vis-à-vis certain foreign countries are well known; indeed, they have already been touched on today. It is important to recognize, however, that technological excellence is one of the key factors in the alleviation of these problems, and technological excellence cannot flourish without a firm base in a sound engineering education.

The very breadth of the mandate of the task force made us perhaps a little different from some other groups studying the same topic. We were attempting to give the broad field of engineering education a calm and, if you will, impartial look. We were aided in this search by the fact that we were not seeking specific solutions to specific problems -- the point at which the conflict of different interests is most likely to become pronounced.

I do not claim that we were able to generate anything approaching philosophical detachment, and we were fully aware that such a delicate flower could not long survive in the Washington reality. Nevertheless, we felt we were able to provide a useful step toward solving the continuing problem affecting engineering education.

If our report has one virtue, it is that it is brief. It is compact; often a single sentence is all that indicates the necessity for a rather important, focused study of a particular problem.

There are many aspects of strength in American engineering education today. It is performing many important tasks extremely well, and it represents a tremendous national resource on which our citizens may confidently draw. On the whole, it has exhibited remarkable flexibility in responding to changing demands and conditions during the last several decades.

At the same time, there is an undeniable concern that the continuing necessity of meeting varying and increasing demands in a progressively more difficult economic climate may begin to stretch the engineering education establishment too far. Certainly, there must arise a question in the mind of any thoughtful viewer of the technological scene as to whether the educational community could respond quickly and effectively to any possible sudden national emergency.

The different and sometimes conflicting requirements of efficiency, of economy, and of societal sensitivity are all well understood by engineers as requiring appropriate trade-offs, but it must also be recognized that they do nothing to alleviate the difficulties of modern engineering education.

Considerations of this kind make it abundantly clear that any questions pertaining to engineering education cannot be solved in isolation, but must be the common concern of the several constituents of the technological community. And it is therefore significant, and I think quite appropriate, that the interaction of academe, industry, and government was chosen as the topic of this very timely symposium. This particular topic represents formally only one of four broad areas of concern identifed by the task force, but the interrelation among the problems and the necessity for all to work in concert toward their solution were early recognized and receive continuous emphasis in the task force report.

A brief review of the four areas of concern to which I have alluded will illustrate this point. The first of the areas involves the objectives of engineering education. It refers to the concern for the adequacy and appropriateness of the various engineering curricula to thoroughly prepare sufficient numbers of young men and women for the various tasks that engineers are asked to perform in such different areas as design, production, manufacturing, research, teaching, management, and policymaking, to name just a few.

The distinctions among the functions that can best be fulfilled by holders of the various degrees (bachelor's degrees in engineering, bachelor's degrees in engineering technology, associate degrees, the graduate degrees -- or, for that matter, the tasks that can be performed by non-engineers) fall under this rubric, as do questions of accreditation, recertification, and updating of skills of mature engineers. Clearly, these questions all affect the educators as well as the users of engineering talent. Thus, the call for common action needs no elaboration.

The same is true of the second area of concern: namely, the adequacy of the resources required to enable engineering colleges and universities to discharge their mission in a manner that is both quantitatively and qualitatively satisfactory. The term "resources" refers both to human resources and to laboratory and physical facilities for teaching and research. These resources cannot be supplied by universities alone and clearly depend on the support of all the parties involved.

The third broad area of concern includes all the problems that can be grouped under the heading of the social or societal context of engineering. Questions here are as numerous as they are pervasive: They include the necessity of further increasing engineering graduates' exposure to and understanding of socially oriented subjects -- to matters of ethics, law, economics, the social and environmental impact of technology -- and certainly extend to the improvement of engineering graduates' ability to articulate, to communicate, and to convince.

Just as important, and in some respects perhaps even more so, is the necessity for nurturing the general public's appreciation of the benefits that technology has brought and will bring, and an understanding that there is a real difference between the aims, the scope, and the modus operandi of science on the one hand and engineering on the other. The problems in this area are both deep and enduring, and only converging efforts can begin to alleviate them.

The fourth area of concern is the topic of this symposium: the interaction among academe, industry, and government. The task force identified a number ways to bring about or improve such interaction. Many of these means were brought out in the keynote speech and will be discussed in detail later, so I shall not review them here. Suffice it to say that they include suggestions on such disparate topics as the joint use of facilities and personnel by industry and academe, the establishment of a favorable tax and patent climate for the necessary interaction, and ways to increase the efficiency of the educational process toward a common good.

The task force recognized that none of the problems in engineering education today are transitory. All of them have existed to some degree for a long time, and they are not likely to disappear in the near future. The task force recommended establishing some sort of continuing joint entity to act as advisor and coordinator -- certainly not as dictator -- and perhaps as advocate for the engineering profession at large. Such a panel would have to act with sufficient detachment to ensure credibility and acceptance; this task in turn requires that the several national organizations legitimately interested and involved in engineering education view coordinated action as a natural corollary of their common interests.

As in the matter of interaction among industry, academe, and government, one cannot overstate the importance of drawing diverse groups closer together and of creating an ambience in which all can work effectively, if not in unison, toward a mutual goal: the strong engineering establishment the nation needs and has a right to expect.

Such, ladies and gentlemen, is the spirit of the task force report, "Issues in Engineering Education."

PANEL A

IN-HOUSE INDUSTRY ENGINEERING EDUCATION ACTIVITIES

Panel Chairman

Allen E. Puckett, Chairman and Chief Executive Officer, Hughes Aircraft Company, Culver City, California

Panelists

John D. Caplan, Executive Director, General Motors Research Laboratories, Warren, Michigan

Jerrier A. Haddad, Vice President, Technical Personnel Development, IBM Corporation, Armonk, New York

Eugene F. O'Neill, Executive Director, Network Projects Planning, Bell Laboratories, Holmdel, New Jersey

F. Karl Willenbrock, Cecil and Ida Green Professor of Engineering, and, Dean, School of Engineering and Applied Science, Southern Methodist University, Dallas, Texas

Lindon E. Saline, Manager, Human Resources Systems Development, General Electric Company, Fairfield, Connecticut

DR. PUCKETT:

If our panel had a thesis, it might be something to the effect that those of us in some high-technology companies find that the product of the academic system doesn't necessarily meet all of our needs. It is desirable to supplement or complement those things that the universities do for us in the educational area with our own in-house efforts.

If that thesis turns out to be correct, it should not be a great surprise, nor should it necessarily be considered bad. I think we will find some things in the educational area that our own industrial organizations are better equipped to do than are the universities. On the other hand, we may find that there are some things that we wish the universities were doing better. Perhaps those themes will evolve as each of our panel members tells us a little about his company's in-house educational programs.

MR. CAPLAN:

I'm always a little surprised at how often we treat engineering education as a monolithic entity that can be criticized as being too theoretical or too applied or too this or too that. Last year, we hired about 800 newly minted engineering graduates, and the last thing we needed was uniformity. Some were hired at the B.S. level to enter manufacturing supervisory training in a stamping plant, and others were hired at the Ph.D. level to enter the research laboratories. Given our employees' diversity of backgrounds, assignments, career paths, and individual interests, their continuing education and their remedial education needs both varied widely.

Of these 800 new graduates, 250 -- nearly a third -- were educated in engineering entirely by General Motors. As far as I know, General Motors Institute (GMI) is the only industrially owned and operated institution that grants accredited undergraduate degrees in engineering. All the professors and all the students are GM employees.

Why do we do this? Historically, GMI filled a void in the background of engineers who were educated and trained to contribute to the general field of manufacturing. Yesterday, as today, it was difficult to find young engineers who could design, much less know how to manufacture, items of commerce that sell not for $1,000 a pound or even $100 a pound, but for $1 a pound.

In the 1950's and 1960's, nearly 80% of GMI graduates were in industrial engineering. Today, GMI's engineering student body is only 20% industrial engineers; the balance is in mechanical and electrical engineering. The emphasis on manufacturing is not as great as in the past, but the emphasis on design training remains.

Today's GMI graduates are also experienced engineers; they are products of a 5-year cooperative education program in which they spend alternate 12-week periods in one of GM's operations assisting in or practicing real-world engineering.

I might add that GMI also presents a very financially attractive package to prospective students; thus, GMI can be selective and enroll those who are academically able. It also provides a very real opportunity for increasing the participation of minorities and women in engineering; this fall's entering class was 19% minority and 33% women.

Let me now turn to our internal educational programs. One of the reasons for these rather formal programs is that, unfortunately, we graduate many engineers who are not dedicated to a lifetime of continual learning. They think they have completed their education. In our personnel activities, we have groups who run regular awareness programs for the not-so-recent engineering graduates to keep them updated. For the most part, GM staff members provide this instruction. We find this internally operated program much more efficient than similar programs offered by outside institutions.

However, like many other companies, we do have a tuition refund plan that allows engineers to take parttime graduate study at nearly any university. We have a graduate fellowship program (for which our employees become eligible 1 year after employment) to a select group of schools that varies with the field. We give about 65 fellowships a year, on a competitive basis. Incidentally, nearly two-thirds of the engineering graduates choose to go for an M.B.A. rather than for advanced degrees in engineering.

Finally, we have a liberal leave-of-absence policy to encourage individual educational activity. We see a tremendous movement in this area, particularly in those parts of the corporation where engineers with B.S.'s discover about a year or two out of school that their education is not complete, and that they could use a better grounding in some of the fundamentals.

We have the usual assortment of other programs. We make use of the TV instruction networks provided by some of the universities. These are wonderful because they can be given in the home plant, and they can be taken for graduate credit or for non-credit. We find this technique especially useful for engineers who need some interfield and interdisciplinary training -- for example, mechanical engineers working in areas where additional expertise in electrical engineering is desirable.

We have a number of in-house courses, taught by professors from national universities. We find this program extremely helpful-- where a new subarea becomes important to a unit and the staff must be trained or upgraded in that particular specialty. For instance, we recently had a course in modern optimal control theory for mechanical, chemical, and electrical engineers, whose educations were supposedly complete.

Let me address one more point: report writing, taught internally. If we have any single recurring criticism of engineering education at all levels, it's the lack of preparation in both oral and written communication.

Incidentally, we also run special writing and speaking courses for engineers whose first language is not English. Due to the makeup of the engineering student body, particularly at the graduate level, we have large numbers of such people joining the company. Even though they have completed their university education and written and defended a thesis, they cannot communicate.

Before I leave the subject of remedial courses for recent engineering graduates, let me cite another educational deficiency. We find that most engineers were, at some time, exposed to a course in microeconomics, but they do not connect it at all with the real world. Solid training in economics, especially that taught in the engineering school by engineering professors and applied to engineering problems, is needed.

Finally, probably the greatest educational task we have with our engineers at all levels is to teach them to become problem solvers. Although engineers must be problem solvers, they don't come out of school that way. They have not really learned how to use a variety of facts and a variety of disciplines to deal with extremely complex problems. They also may not have learned how to take a complex problem, dissect it, find those elements that represent something they can do a research project on, and select the parts that constitute a problem of manageable size. This ability is best taught at the mother's knee; but, in this case, it's taught by senior engineers who serve as mentors for young graduates and really teach them how to be engineers.

Enough of our in-house programs. Now, let me give you just a few suggestions with respect to better university-industry interactions. We would like to see more graduate students do their theses in industry and government laboratories. We think that this practice would offer at least a partial solution to the problem George Low noted earlier, that of equipment deficiencies in universities. For some reason, unfortunately, it seems to be administratively difficult for the universities.

We would like to see more seminars, such as those in the physical sciences, in graduate engineering education. We would like more industry and government speakers in these seminars, and especially we want more speaking experience for graduate students so they can present their own seminars. We would like industry and government engineers to serve as adjunct professors, both in graduate and undergraduate courses. We would also like more engineering educators to serve as industry consultants and summer employees. Again, it is my impression that such participation occurs proportionally less for engineers than for physical scientists.

And, finally, we would like to see less emphasis on institutional meetings and arrangements and more emphasis on individual conversations and agreements by people in academic institutions, in industry, and in government.

MR. HADDAD:

I have a slightly different slant, perhaps because computers and cars are a little different. Of course, none of us can presume to speak for all of industry. At IBM, the largest portion of our in-house education is training our people with regard to new products, new design techniques, new automatic design systems, new technologies that are coming to the fore, et cetera.

We have gone through quite a number of generations of new technology in my career, from relay-type equipment to vacuum-tube equipment, to vacuum-tube and magnetic cores, to transistors, to integrated circuits, to large-scale integrated circuits -- and things are still changing. Obviously, with so many changes in technology, with the components with which we design and the products for which we design, we have had to have an extremely large in-house job-training program to enable our engineers to continue in their jobs of circuit design, logical design, computer design, or packaging over their career lifetimes.

Our in-house programs of generic courses are a very small part of the total amount of company-supported education. And we have a number of plans similar to those of other companies, so I'll just mention a few. We have a graduate work-study program for people who want to go after a master's or even a Ph.D. That assumes they are going to be working fulltime or close to fulltime. We have a tuition refund plan for people who want to take courses that are not necessarily degree-oriented. We have a resident graduate study program, used much more in past years, in which we take engineers with bachelor's and master's degrees and give them the opportunity to go to some institution full-time to get a master's or a doctoral degree. We regularly send people to the Sloan School, to MIT, and to Stanford. We have worked out a special sort of update course with UCLA and several dozen of our older technical employees atttend that.

One interesting sidelight on education has emerged from our studies of who makes the best employee, who progresses the fastest, who goes the farthest, and so on. We end up agreeing that, by and large, the top people are those who came to us with bachelor's degrees and received master's degrees on the job.

Now, the one big exception we have to this outside education practice is the IBM Systems Research Institute in New York, which we formed in 1960. It's modeled exactly on a university research and computer science department. In 1960, we essentially had to write the book. Today, of course, there is much less need for an independent computer science institute. However, we still put through three groups of 150 people each per year. That's almost 500 people. About half of these employees work with our customers in designing systems; the other half come from our headquarters and laboratories.

We have recently arranged with the State University of New York at Binghamton for students taking academic courses at the Institute to receive graduate credit from SUNY and, in some cases, to transfer these credits to other institutions. The Institute program relies heavily on our own faculty, but takes advantage of guest lecturers and people from colleges and computer science departments all over the world who spend sabbaticals at the Institute.

Now, with respect to IBM's relationships with engineering education in general, it's rather hard to separate what we do for science and what we do for engineering. We don't really try. Many of our programs combine IBM and university education. We have a big postdoctoral program in which we bring people into our research lab for 1 or 2 years. We have a program of grants and fellowships. We have a rather liberal program of matching grants.

We recently instituted a program of independent departmental grants. For worthy university departments of note, we have given each department a fixed sum -- $25,000, I believe. We started the program this year with 20 institutions, as I remember, and plan to expand it next year to 40. We hope to renew these grants annually for 3 years and then find other noteworthy departments.

We go in for co-op programs rather significantly. We have recently tried to double our summer employment of engineering students, so that we are doing more than merely hiring students between their junior and senior years. We hire a number of faculty members on sabbaticals and also outstanding academic personnel for consulting jobs. And we are desperately trying to decrease the complexity and increase the range of the R&D contracts we place with university departments.

Quite a number of IBM people act as visiting or adjunct professors. My group recently made a study of 46 colleges and universities and found that 41 IBM people were in one way or another involved with those 46 institutions, as visiting or adjunct professors.

Well, are we happy with all this? The answer is yes, but we could be happier. Most of our university relationships are in research, not engineering. We would also like more of the relationships to be at a personal level. Too often, our engineers are adjunct professors merely to alleviate financial problems or shortages of faculty, which I guess are good enough reasons. But I have the notion that we ought to do with our industrial people what they can do best, and people in academe ought to be doing with their faculties what they do best. It seems to me that the ordinary engineering courses are probably better taught by academic personnel. The unique contribution of the industrial engineer is, I think, the experience brought from on the job -- and there's more than one way to get that to the student.

It seems to me, however, that the only way to communicate the sweep and excitement of engineering in industry to engineering undergraduates or graduates is to take a large job, write a case on it, and expose them to it -- if possible, have them discuss it with someone who was a principal in it. This would bring home to the students the complexities involved in bringing together the sales people, the marketing people, the financial people, and the manufacturing people -- and, for that matter, all the various subfunctions within manufacturing -- to make a product or process design go from a piece of paper to something tangible.

I believe that a greater interplay between industry and engineering colleges is indeed desirable, but I think some accommodation has to be made. An engineer in industry doesn't work alone; the job is highly dependent on other jobs, and other jobs and results are highly dependent on the engineer. An engineer's job cannot be "put on ice" while that employee goes off to help an educational institution for a semester, let alone a year.

So I believe that academe has to make some accommodation in this area. Short courses, say 5 or 10 weeks -- or maybe even 2-week segments, especially if they are of the case-study variety -- could be a workable compromise and gather momentum as we go into the future.

MR. O'NEILL:

Bell Laboratories is somewhat different from the other large corporations represented here today in that we are entirely an R&D organization. That may make for a somewhat different relationship with academe than that of my co-panelists' organizations.

I would like to concentrate on our in-house programs. We view these as complementing and supplementing university programs and university educations. They don't replace university programs, and we don't try to make them replace those programs.

For many years, we have regarded the master's degree as the basic requirement for members of our R&D staff. Although we hire as many holders of master's and doctoral degrees as we can, we have always hired many with B.S.'s as well, partly because there aren't enough people with advanced degrees to go around and partly because many with baccalaureates look more promising than do some with postgraduate training.

We have experimented over the years with a variety of in-house programs to bring new employees who don't have M.S.'s or higher degrees to a master's equivalent level. But we have now settled entirely on on-campus training to the master's level, in contrast to our General Motors associates here.

Recently, we have been hiring about 400 bachelor's-level graduates each year. About 300 of these have been sent back to school fulltime. Their tuition and expenses are paid, and they receive about 60% of their salary. The remaining 100 elect to go parttime to nearby local universities. This group is paid full salary. (Needless to say, there is a high correlation between the marital status of new employees and which option they elect.) In both cases, we give the participating schools an additional grant equal to the tuition.

We regard these people at school as our employees, not as people on fellowship. During semester breaks and summers, we bring them back to Bell Laboratories at full salary and treat them in every way as regular employees. We try to keep in touch with them, even though they may be at very distant schools. And that works out pretty well. (We would like other people to treat them as our employees, too, particularly the schools who often consider them promising material for further graduate programs.)

One thing I would like to mention that has bothered us for a long time is the thesis requirement for a master's degree. Perhaps because we are an R&D organization, we feel that people can do work in our own labs that is more valuable to us and to them than is a thesis project. (In fact, I'm a little skeptical that doing a thesis for a master's degree helps in other occupations either. But I know I am at odds there with some eminent institutions represented here.)

We have tuition refund plans at all levels, undergraduate to the master's and toward the doctoral degree. We also have doctoral support programs in which a very few selected people are sent to school fulltime.

I would like to spend a few minutes more, however, on the in-house program. (By the way, I note that our audience includes Charles Elmendorf, who did more to formulate and direct these programs in Bell Labs and AT&T than anybody else I know. He has had a profound effect on our continuing education programs.)

We started a major in-house continuing education program in the late 1960's. Incidentally, this was a top-level decision, and I doubt that a program of this kind could work on any other basis. Company policy must support it all the way up and down the line.

We had some very specific objectives. We wanted to encourage the continuing professional growth of our staff. We wanted to broaden them. We wanted to be prepared for radical redirections, like the transitions from vacuum tubes and relays to solid-state technology. And, of course, we wanted to fight educational obsolescence.

I mentioned that we experimented in the early days with a lot of formats and methods for in-house education. We now have some very definite conclusions as to what should guide these programs. First, the curriculum should be relevant to the work a person does or may be asked to do. We support a large number of out-of-hours, voluntary programs of courses that do not meet that criterion, (such as foreign languages), but they are another matter entirely.

Second, you have to maintain what we call "academic quality" -- and that is a compliment to academe. Many in-house programs we have examined fall somewhat short in that regard, so we have tried to maintain rigorous standards.

Third, we believe that participation must be voluntary. People who are well established in an ongoing job are not always enthusiastic about the competition and comparisons that arise in an academic atmosphere, so it is important that they participate voluntarily. We believe that the program must be responsive to what people want and must be free of the kinds of stresses that a typical graduate or undergraduate academic program provides.

We also believe, however, that the commitment must be a shared one. The programs are given in-hours, but we expect our people to work at least an equivalent time out-of-hours on homework and study. We have adopted a rather formal approach to this. We offer two 15-week semesters, one in the fall, one in the spring. We have pre-course meetings. Classes meet once a week for about 2 hours, and we give homework. Exams are given and corrected, but not graded. We record only successful completions. No record whatsoever is kept of people who start and drop out for one reason or another.

About 80% of the instructors come from our own staff. The other 20% are brought in from university faculties, and we find that they provide a very useful leaven to this program.

We get about 30% employee participation, up to about 20 years of work experience. We get a fair amount of participation right up to the final years, but it drops to about 15% for employees over 50 or 60 years of age.

Finally, our approach to being responsive is, I think, worth bringing to your attention. We formulate our course offerings -- about 200 -- partly out of experience, partly out of volunteer suggestions, and partly out of a series of monitoring committees. We catalog them and survey employees as to their intention to participate. We offer about 100 of the 200 in-house, those which look like the best match to what people are seeking and are willing to participate in.

We get about 70 to 75% completion in these courses. It has been a source of dismay to the administrators from the start that the dropout is as large as that, but I think it is inherent. There are meetings, field trips of one kind or another, and job pressures that inevitably prevent some proportion of any class from completing the course.

Therefore, in recent years, we have been moving increasingly toward individualized learning with videotape recorders; people can "go to class" at their own convenience. In fact, if the program is purely audio, they can take the cassettes and study books home. We think this approach is paying off. We have about 1,500 participants in programs of that kind and, gratifyingly, the completion rate -- for the same level of courses, often the same courses prepared in this format -- is about 85%. So we think we have something worth doing here.

PROF. WILLENBROCK:

It's clearly inappropriate for me as an academic representative to discuss in-house industry educational activities, except from an external standpoint. I would like to entitle my remarks "In-house Industry Engineering Educational Activities as Viewed from the Out-house."

The first question I would like to raise is a rather tough one that I think both the industrialists and the educators ought to ask themselves. As we have been hearing this morning, industry carries out a considerable amount of in-house education. Is this a message to the university community, particularly to the schools of engineering, that they are wide of the mark in some of their curricula? Or is this in-house education just specific on-the-job training that is not appropriate for a university environment?

Another issue that I think is very important was mentioned yesterday: the distribution of the 1.2 million engineers in the United States. Some 78% are in industry and business and 4% in universities. Although university people like to think their 4% is very significant, much knowledge generation and new technological directions come from the 78% in the engineering community. There is no systematic, effective way to get that new knowledge and those technological advances back into the academic curricula.

Let me cite a few examples of successful feedback of knowledge from the industrial sector into the academic community. In the early 1950's, Bell Telephone Laboratories ran a 2-week school on transistors when they were the latest thing on the market. It was an historic experience, for some of us who participated, to have lecturers like John Bardeen and lab assistants like Walter Brattain and Gerald Pearson. Holding this school was an important event. The Bell System and most of the electronics-oriented companies did not need more experts in vacuum-tube circuit design. The industry needed people who understood semiconductor electronics.

More recently, Hewlett-Packard ran a series of invitational programs on microcomputer system design to fill the gap between what HP engineers were doing inside the company and what the engineers coming out of the universities were learning. Industrial companies might well undertake this sort of educational effort systematically.

To cite another example, Texas Instruments is currently providing Southern Methodist University instructors for three courses on very large-scale integrated circuits. As you know, that's a tough field for a university to get into. This program is advantageous both to the on-campus students and the students from the various participating companies.

Obviously, this problem of keeping a university up-to-date is not trivial; it is particularly difficult in technologies where the products and systems are changing rapidly.

Do the large-scale, in-house educational activities of the industrial sector indicate that the universities are not keeping up-to-date? The industries represented on this panel have a tremendous range of capabilities. However, there is a wide variation among companies within the industrial community with respect to educational policies and practices, and there are significant differences among the various industrial sectors too. On the university side, there are also substantial differences in size of institution and areas of technical strength. Generalizations are therefore difficult. However, the possible mutual benefits to universities and companies justify making a major effort to overcome the barriers to closer university-industry interaction.

As some of my fellow panelists indicated earlier, a number of effective interrelationships exist and have produced some very worthwhile results. One model that seems promising is to emulate what the military services did immediately after World War II when they started the Joint Services Electronics Program. That program effectively created centers of strength in electronics in 9 or 10 universities throughout the country -- by using stable, long-term programmatic support, not project-by-project funding. As a result, the universities produced much knowledge and very talented graduates. This country has developed and maintained a very strong electronics capability.

It would be desirable if industrial consortia could be set up in some specific technical fields where companies recognize the need for new generic knowledge. If such consortia could focus support for those fields in a few universities, centers of strength could be developed. The subject fields could be relatively narrow. For example, nondestructive test techniques are important to many companies, but not usually highly proprietary. A few institutions with a strong capability in the area would be a source of strength both to the universities involved and to the industrial community as a whole. However, the development of a university center of strength requires support over a number of years, so that faculty strength and student interest can be developed. Appropriate laboratory facilities are also necessary.

One implication of this sort of approach is that more universities would develop specialized capabilities. I think that this development is desirable. At the undergraduate level, there is a need for breadth; at the graduate level, however, specialization is not only desirable but essential to attaining both depth and excellence.

I suggest that this possibility be carefully considered. Government policies, such as those mentioned earlier by George Low, could help; for instance, tax credits to companies for supporting university research (in Congressman Vanik's Research Revitalization Act) could supply a strong thrust in this direction.

There is a very real advantage to direct interplay between the universities and industry; I concur with George Low's recommendation that government should usually restrict itself to a facilitating role.

Finally, I would like to say that federal agency support since World War II to the colleges of engineering throughout the country has done a tremendous job of strengthening programs, raising standards of academic excellence, and increasing the schools' breadth and capabilities. I think industrial-sector support could have a similar effect.

Some of my academic colleagues may question whether industrial funding might interfere with academic procedures, threaten academic freedom, and so forth. My response is that our present faculty members are strongly influenced by federal program managers. I would like to see faculty members have the opportunity to be influenced both by federal program managers and industrial program managers. Diverse sources of external funding could lead to more, rather than fewer, choices for the individual faculty members.

DR. SALINE:

I am going to use a slightly different approach and focus primarily on the early, entry-level years of individuals going from engineering school into industry. My background will be General Electric, of course, so I'll tell you our perspective and rationale for doing what we do, without pretending that this method is something that should be generalized to other companies.

To get a feel for what we were aiming for in these entry-level years, we asked a large number of managers of technical people in engineering, manufacturing, technical marketing, and R&D what they wanted from their young (and by "young," let's say we mean 5 years beyond the bachelor's level) employees. They gave us many ideas, and we have distilled them into eight characteristics I would like to tell you about.

First, the young employees should have a desire for and momentum toward functional expertise, be it in engineering, manufacturing, marketing, or research.

Second, they should possess intrinsic high performance standards and self-esteem.

Third, they should have started to know their territory. By that, we mean the product or service with which they are involved, their industry, their customers, their professional societies, and the relevant literature.

Fourth, they should be developing and using their ability to recognize "right answers" and to ask "dumb" questions.

Fifth, they should be developing their ability to sense, identify, and solve unstructured problems that usually are multifunctional and certainly are multidisciplinary.

Sixth, they should know and feel that teamwork is GE's modus operandi.

Seventh, they should feel comfortable operating in the General Electric system and culture.

Eighth, they should feel secure in knowing what GE expects of them -- through the active support and encouragement of their colleagues and managers.

Obviously, new college graduates, whether they are at the bachelor's, master's, or doctoral level, don't have all of those attributes. But, by and large, we are quite well satisfied with the graduates we are hiring into GE. First of all, we find they are very well prepared in academic theory. They are first-rate, and we find they are getting even better. Second, they are quite familiar with systems concepts and with engineering tools and techniques. Third, their attitudes are exemplary. They have great skills, and they are goal-oriented.

Now, on the negative side, there are a couple of things important to us that the new graduates don't have. One of these is communication skills that meet GE standards, both in written and in spoken communications. We find these graduates are much more comfortable writing computer programs than writing technical reports. Second, the new graduates are quite weak in applying the knowledge and analytical skills they have acquired in their engineering college work.

Now, given those pluses and minuses, and keeping in mind what our engineering managers would like to have after 5 years, we have developed what we call the entry-level process. It is based on our professional development model, which includes a melding of work assignments, coaching and supervision, education, career planning, and other kinds of activities.

In our entry-level paths, we hire people into corporate programs, into component programs, and into direct placement jobs. At our corporate level, we have a program that I'm going to talk about in a little more detail, because it relates quite specifically to some rather major in-house education activities.

This entry-level program is called our Edison Engineering Program. It uses rotating work assignments, coaching and supervision, education, and career planning in a combination that we have found (over a period of 57 years) has served very well.

But I want to focus primarily on the educational portion of that program: our Advanced Course in Engineering. It is designed to increase graduates' abilities to analyze and evaluate the technical and economic significance of engineering problems; to effectively utilize and apply the principles of mathematics, physics, and engineering; and to communicate and present conclusions and recommendations concisely and clearly.

The course format includes 4 to 5 hours of lectures on company time and about 18 to 20 hours of homework per week. The full course runs for 3 years; it's divided into 1-year parts, the A Course, the B Course, and the C Course. Currently, this Advanced Course in Engineering is accredited at 17 universities. The A Course is good for about 6 graduate credits toward a master's or a doctorate; the B Course is worth 9 more; and the C Course yields an additional 12. We currently have more than 750 participants in A, B, and C courses.

This course is our way of doing something we feel we can do most effectively at GE, with our skills, experience, and work opportunities. We do not hold colleges responsible for making those kinds of transitions. Colleges play a very important role both in the design and the implementation of those courses, however. GE uses adjunct faculty from universities, and, interestingly enough, some of the GE employees are adjunct faculty to the universities as well.

In addition to this program, which focuses heavily on engineering design and development activities, we have similar kinds of programs in manufacturing and technical marketing. I'm not going to review those in detail, however.

I would like to take a last minute to suggest what we see as the primary challenges for engineering education as it helps meet our needs at General Electric. One of these is the necessity for more emphasis on manufacturing technologies and theory, in regard to processes, automation, and robotics. A second challenge is the growing computer-aided design, manufacturing, and testing area. I don't mean helping individuals learn which buttons to press on a particular machine, but, rather, making sure that our engineering graduates learn to think in terms of utilizing these great new devices and systems and processes as they go about attacking real-world engineering problems. A third challenge, an ongoing and continuing one, is the need to increase the number of minority and female engineers.

On the whole, then, our industry-university interactions at the entry level are embodied in the adjunct faculty who teach in our A, B, and C courses. We have also had an interesting experience in running a faculty workshop. Twenty young, engineering college faculty members spent 3 days with us, during which we exposed our approach to teaching engineering cases the way we do in the Advanced Course in Engineering. We also have made a large number of case problems of the kind we use in that course available to universities.

DR. PUCKETT:

I'll summarize some of the things we are doing at Hughes. The philosophies and purposes of our in-house program are very similar to much of what has already been discussed, so perhaps I don't need to say much about them.

We have a program we call our Advanced Technical Education program, which is, in effect, an in-house university. In any given year, we offer about 160 different courses. In the course of a year, about 3,500 students take these courses. (That is not necessarily 3,500 different students. Some students take two or more courses in a single year.)

Why do we have this fairly elaborate program? Well, for a combination of reasons, some of which you have heard already. Most of these courses are simply not available at any of the local universities. They are courses dealing with technologies that evolved from our own development work at the company. The remaining courses have some counterpart in the universities, but we still choose to teach them for several reasons. One reason is employee convenience. Another is to tailor the content more closely to our own particular programs and projects.

In addition to our in-house courses, we have an extensive program of cooperative education with universities in the Southern California area and across the country. We make considerable use of a master's degree cooperative program, similar to those you have heard about already. In any given year, we have about 400 students studying halftime toward master's degrees and working halftime. They are our employees, and of course we hope to keep them so.

Their nominal halftime work may turn out to be more than that, so with vacations, summer holidays, and so on, students can support themselves and still complete their master's degrees in 2 years. We have found this program to be one of the most valuable sources for employees with high degrees. Such students have an opportunity to learn about the company, and we have an opportunity to learn about them.

We also have other fellowship programs. For example, we have a doctoral fellowship program that is really an off-campus, generally fulltime, program. And beyond the purely technical programs mentioned earlier, we have extensive in-house courses in other aspects of our business -- management, project engineering, and so on.

I'd like to note that I agree with Lindy Saline's list of challenges to engineering education. We need more emphasis on manufacturing education, on the real disciplines required in modern manufacturing. I think it's worth underscoring the fact that manufacturing today is quite different from manufacturing as I knew it in our industry even 20 years ago. It's no longer simply a place where the mechanic or the tool-and-die maker works up the ladder to become the general manager of the plant. The dividing line between manufacturing and engineering, which used to be rather sharp, is gradually disappearing -- not so gradually, in fact, because of the computer-aided processes Lindy mentioned, CAD/CAM/CAT. Computer-aided systems tend to blur that dividing line, and we desperately need people who are trained in disciplines that cross those borders.

Last, of course, I agree with the comment that engineering needs more minorities and more women, which (at Hughes) we emphasize as best we can.

PANEL A OPEN DISCUSSION

ARTUR MAGER (The Aerospace Corporation):

I am rather dismayed by what I consider three significant omissions in the discussion. The first is the use of professional societies as a resource for continuing education. Their growing programs could be very useful in updating the education of engineers who are in danger of becoming obsolete.

A second omission is the question of supervisory training. I think many engineers would like to climb a supervisory, rather than a technical, ladder. Supervisory training is increasingly important in this era of equal employment opportunities, and few of you mentioned it.

Third, in this era of very complex systems, program management is becoming an important facet of engineering education. That too was not mentioned.

DR. SALINE:

I concur that professional societies are certainly a major element in ongoing continuing education. In our own case, we encourage our people to participate, both at the local level (in technical society workshops and seminars) and at the national level. There is no difference in opinion there.

With regard to supervisory training, GE may have a slightly different philosophy from that of some other companies. I would encourage engineering educators <u>not</u> to try to teach management at the undergraduate or even the graduate level. The curriculum is already crowded with subjects getting short shrift because of time. Most engineering graduates would not use management courses for a number of years.

I have a similar feeling about program management. It is certainly critical in carrying out large, complex projects, but I believe the appropriate skills and awareness can be developed much more effectively at the point in an engineer's career when the need is there. We call this the "needs theory of learning": Give it to people when they can use it, rather than have it tucked away in the skills inventory of numbers of people who may never need it.

JACOB RABINOW (National Bureau of Standards):

While we're talking about omissions, what bothers me is that nobody today has mentioned the fact that our high schools and elementary schools are doing an absolutely abysmal job of teaching mathematics, science and related subjects, or economics. Why talk about what our colleges do or don't do when students come in not knowing algebra? And I've heard that they don't even speak English so good.

The damage is done long before they get to college, let alone into industry. Unless society takes a very strong stance on high school teaching -- including such things as paying decent salaries to high school teachers -- we are going to have poor engineers, and you will have to do a great deal of corrective work. And I suspect that you can never entirely correct 18 years of neglect.

JACOB M. GEIST (Air Products and Chemicals):

I heard only one speaker mention one point I think is important. That was Mr. Haddad, who noted that, while universities would like to have adjunct professors from industry, many qualified people from industry hesitate to leave their jobs for any length of time.

A lot of the discussions I've heard today suggested that engineers are remarkably altruistic: They want to help industry, they want to help government, they want to help universities. But I think another question is implied: What can we do to motivate the engineers to do their jobs well?

MR. HADDAD:

My reason for raising the question of job responsibility was to suggest that the academic people join in a search for ways to accommodate both sets of needs. There are a lot of differences between industry and academe. Even the school and business years don't coincide. I think that course plans and semester timing and things like that could perhaps be modified to accommodate more readily the responsibilities of engineers in industry.

DR. PUCKETT:

I think the word "accommodation" is very important. It seems to me that, not long ago, it was hard to find compromises and accommodations between what industry could do in collaboration with a university, and how much the university was willing to modify its traditional patterns in order to utilize industry skills.

As Jerry says, we have found that it's unrealistic to expect one of our employees to go on an exchange arrangement or sabbatical for a year. That engineer essentially leaves the job. On the other hand, we find it's very practical for many of our senior engineers to teach evening or after-hours courses at local universities. About 200 of our senior staff members give lectures or courses at some of the local universities, without interfering with their career involvement. That may be a solution.

MR. CAPLAN:

I think the accommodation in this kind of situation has to take place on both sides. In other words, there is something wrong with industry management when the individual engineer's perception is that taking off a year to teach engineering jeopardizes a career because management considers it a waste of time. Management has to think it's a worthwhile, broadening experience for the engineer, as well as for the university.

SEYMOUR M. BOGDONOFF (Princeton University):

I think some appropriate comments can be made about the university side. Just as industry can't spare some of its best people for sabbaticals, the idea that professors can take the summer off and work for industry is a little unrealistic. Aside from considerations of promotion and tenure, the best professors are busy during the summer. Professors who have time to take summers off may have time for a good reason.

The idea of short-term interactions seems to me to be the only practical way to do it. There were several suggestions about case studies, an intensive 2 weeks at a university. Similarly, I think that there would be a better opportunity for people at universities to spend time in industry in that sort of short-term, intensive arrangement. These exchanges are critical in engineering education, perhaps moreso than in science education. I think this mode of interaction has real strength, and I hope it will be pursued.

SIDNEY A. BOWHILL (University of Illinois at Urbana-Champaign):

Since we have such a heavily industry-loaded panel here, I would like to express to them my concern about the fact that the industry recruiters who come to university campuses tend to suggest to the bachelor's degree candidates that they can pick up all the training they need in the industry -- that industry courses will teach them almost as much as graduate school, and that they'll be getting paid a lot more.

I remember, on the other hand, what happened when certain fields such as aeronautical engineering lost a large number of jobs. Engineers flooded the market, and couldn't find work. One reason for this was that their training was not broad enough. Is it not doing the new graduates a disservice to discourage them from undertaking, or at least not encouraging them to undertake, the broadening experience of graduate study at the university level, even though it may delay their arrival on the industrial scene?

DR. PUCKETT:

You are quite right, of course. We are always caught between the two requirements, one for graduates with at least master's degrees, and the other for engineers no matter what. Sometimes it's hard to reconcile those two needs.

PANEL B

ACADEME-INDUSTRY JOINT PROGRAM

<u>Panel Chairman</u>

Paul E. Gray, President, Massachusetts Institute of Technology, Cambridge, Massachusetts

<u>Panelists</u>

C. Gordon Bell, Vice President of Engineering, Digital Equipment Corporation, Maynard, Massachusetts
Earnest F. Gloyna, Dean, College of Engineering, and, Joe J. King Professor, University of Texas at Austin, Austin, Texas
John C. Hancock, Dean of Engineering, Schools of Engineering, Purdue University, West Lafayette, Indiana
Russell R. O'Neill, Professor and Dean, School of Engineering and Applied Science, University of California at Los Angeles, Los Angeles, California

DR. GRAY:

This panel is charged with examining areas in which there is substantial partnership between the academic community and industry through special agreements, academic initiatives, informal exchanges, internships, associateships, fellowships, or any other means.

Just 4 weeks ago, I spoke in the Boston area to a group from the American Electronics Association and the Massachusetts High-Technology Council. The subject was university-industry interaction, with a particular focus on the role of MIT in that interaction. As you might guess, that discussion generated quite a lot of heat. It may even have generated some light. In any case, it provided some background for the conversation today.

In the context of engineering education, it seems to me that university-industry collaboration is a natural, necessary, and mutually beneficial process. I believe that we should construe engineering education as a continuum, a process that begins in an undergraduate college of engineering, continues through graduate study, whether that graduate study be in a university or in an industrial setting, and includes the lifelong experience of engineering practice. If we do not communicate this process to the young people who enter the profession of engineering, I think we fail in a fundamental way.

It seems to me that there is also a continuum of activity in the advancement of the profession, and universities and industry are both participants. That continuum perhaps begins with engineering science, which has traditionally been heavily university-oriented but enjoyed major contributions from industry. It extends through design, manufacturing, and engineering practice and requires staying current with evolving technology. And it seems to me that this second continuum is another reason why this mutual dependence and interaction are entirely appropriate.

I am less sanguine than George Low seemed to be this morning about the projected supply of and demand for engineers at the bachelor's or master's level or about how well the normal processes of market adjustment can respond to any imbalances between supply and demand. I find it startling that the total production of bachelor's-level engineers over the last decade has increased by only about 25%, especially as one looks at the rates of growth of the industries depending on those engineers. And it strikes me that most of the conventional wisdom about demand for engineers at the bachelor's or master's level over the next decade fails to account for several forces that I believe change the dynamics of those markets in a fundamental way.

One of those forces is contained in the broad problem of energy. The accommodation to energy problems that must occur in the United States over the next 10 or 20 or 40 years is going to put tremendous demands on the market for engineers.

The second force that I think has not been reckoned with adequately in the estimates of demand is the revolution in information-processing capability. I believe that the increasing availability of inexpensive computer hardware and the growing application of computer-based technology have already generated, and will continue to generate, vast demands for engineers skilled in these areas. I think that these demand forces, coupled with the steady reduction over the next 20 years of the number of 18-year-olds and with growing scientific illiteracy, will make it almost impossible for universities to adapt quickly enough to the imbalances between supply of and demand for professional engineers in the decade ahead.

Perhaps the most useful kind of introduction to this topic would be a brief taxonomy of four or five possible modes of interaction between universities and industry.

One mode of interaction between industry and universities is the advisory mode. I start with this one because it seems to me to be very important, and it is often overlooked. By advisory mode, I mean the involvement of people from industry in determining university direction and agendas, through participation in visiting committees or service on boards of trustees or other advisory mechanisms, depending on the circumstances of particular institutions. I could give a long list of examples of ways in which the participation of industry in the governance of MIT has made fundamentally affected the directions we have taken and the choices we have made.

A second mode can be broadly defined as student-related. Summer employment was mentioned by the first panel. It is important for students in engineering programs to have the opportunity to hold jobs that are significant and productive in educational terms. In helping the individual engineering student, industry is also developing the talent pool from which it can draw graduate engineers.

Cooperative programs, another example of the student-related modes of interaction, are extremely important in the educational setting. I was brought up in a department at MIT in which cooperative education goes back to 1917, the VI-A electrical engineering co-op program. When I was a faculty advisor at MIT, it seemed to me that the most able students who came out of bachelor's-level programs at MIT in electrical engineering were those who had co-op experience. The chance to interweave work in the academic and industrial settings contributed enormously to both. Students were more motivated in the classroom because they could see the relevance of what they were learning to the industrial setting, and they made better graduate engineers because they had a set of practical experiences on which to build.

Still another student-related mode of interaction is, simply, support--through fellowships and scholarships.

A third mode of industry-university interaction is the set of activities that I will call "profession-related." One of these is consulting in the industry setting by university faculty. This enables faculties to stay abreast of the changing frontier of technology as it is defined in industry. Another is sabbatical leaves for university faculty to spend time in the industrial setting. Here, I might note that plucking someone out of a university setting and putting that person into industry for a period of 6 months or a year is as difficult as removing someone from the industry setting to the university. Most faculty members who would be involved in such exchanges have substantial ongoing research programs that require a great deal of maintenance effort. However difficult the process may be, though, it is nonetheless important. A third profession-related activity, the use of visiting and adjunct faculty, has already been discussed.

Finally, we come to research-related modes of industry-university interaction. Here, one might start with gifts of specialized equipment. George Low spoke earlier of the problems of equipment maintenance and of the rapid obsolescence of both teaching and research equipment. This problem is serious for universities, and it seems to me that the area is one in which industry could help a great deal.

One mode of research-related interaction is industry support of broad institutional activities, with improved access to research in progress as a quid pro quo for that support. The best example I know of this mode is the industrial liaison program at MIT. There are other associate programs, such as those at Stanford and Caltech, which follow the same pattern.

Another possibility is support of research in some general area of activity, where the industrial participants provide some general direction. Industry might also provide professionals in residence as participants in that program. Examples of this are the Center for Energy Policy Research and the Polymer Processing Program at MIT or the

Silicon Structures Program at Caltech. We are now endeavoring at MIT to develop such a program in very large-scale integrated systems, with broad industrial participation.

Another of the research-related modes is support of work on specific problems through flexible consortia. An example of that is the Electric Utility Workshop, which has existed now for 3 years in MIT's energy laboratory. It differs from the support of research programs just mentioned, in that groups of industry people come together, work for a short time (generally less than a year) on some specific problem of mutual interest, and then disband. They may come together in slightly different configurations to work on other problems at other times. Again, though, this mode of interaction involves participation in direction of the work as well as a sharing of professionals.

Finally, there is individual company support of specific work. For instance, General Motors supports work at MIT on particulates in diesel emissions. Another example is Exxon's support of combustion research, also at MIT. That program is unique, I believe, because it has a long time horizon. It's conceived as a 10-year program. Also, both parties understand that if there is a reason to terminate it, there will be a 2-year wind-down time. That long transition period is a recognition that the time constants in universities, where graduate students are involved, are rather long. The life of a graduate student in an institution is on a time scale of 2 to 4 years, not one of months.

I should also mention the participation of several of the computer companies in sponsored research at the Laboratory for Computer Science. These types of interaction require negotiations and development of specific contracts and probably come closest to federal sponsorship of research in their formalities.

Moving down this list of research-related modes of interaction, we find increasingly greater problems with respect to issues of patents, publications, protection of proprietary interests, and other sensitivities. The tension between the openness of the university and the protection of proprietary positions within the company grows as you proceed down the list.

I am persuaded that those problems do not represent truly intractable issues in the development of these sorts of relationships; they have been successfully worked out time and again.

One other possible mode of interaction has been in the papers this week. I am referring to the possibility that Harvard University will participate in the spinoff and joint-venture mode of a new enterprise in the area of applications of genetic engineering to technology. Of all the modes I have described, I think that one is the most difficult to bring off. It lays on the table -- right at the outset -- all of the complex questions related to proprietary interests, patents, publications, secrecy versus openness, and institutional and personal conflicts of interest. It is an exceedingly difficult mode to get started. It will be interesting to see how Harvard works this out over the next months, as it be a major management partner with industry.

MR. BELL:

I am happy to see Paul's taxonomy, because structure seems to be lacking in our discussion. I will describe our program at Digital and hope that some useful plan or conclusions can be drawn from it. It is mostly of Type 4, research-related programs, with some Type 3 and Type 2 interactions -- consultancies and students. All the interaction types seem to work together and are complementary.

Our current formal program has developed from rather random equipment grants that we started about 20 years ago -- new equipment was given away on the last day of our fiscal year when we happened to have the money. It's virtually impossible to do today, with our larger corporate bureaucracy, but I liked the old random program. Some of the best results came from the early program, mainly because of the element of surprise.

The random grants put unplanned, free resources in somebody's hands, and people became creative. We are beginning to understand the management of research better; one problem seems to be that it has become too predictable -- and then we wonder why we are less creative. For example, the computer program called Space War, which was written for a PDP-1 delivered to MIT on June 30, 1962, spawned all those space games you now play on your TV sets or in arcades. We can't say they are of any benefit to Digital, but the work started a new industry.

MIT also worked on one of the first time-sharing systems with that same computer. We had similarly good results from a machine placed at Carnegie-Mellon on June 30, 1971. Therefore, I recommend that industry look around at the close of the fiscal year -- not to dump unsold inventory, but to find places for some creative accounting.

Our current grant program results are highly variable. The program covers a range from manufacturing engineering science to basic research in computer science. We try to couple it to our needs. We would like to support more of the manufacturing-related work that George Low spoke of: the more we dig into that field, the more we find deep scientific areas, particularly in artificial intelligence, where we need help. In fact, I think computer science would do well to focus more on these areas. (I also think business schools should get more involved with manufacturing and less with marketing.)

Our current program provides equipment grants that internal groups can use as a free budget to sponsor specific work outside. In addition, a group may directly fund research. The sponsoring group is responsible for monitoring the results and interfacing with the university.

There is an implicit involvement with the government in these programs because, in many of these institutions, our grant supplements a government program. This has a certain benefit in that all sides view it as something of a free lunch. Also, we strongly support NSF's industry-university grants program.

Our "internal research buyers" are now concerned because we have begun to ask them to report on the work going on outside in the universities, just as though they were responsible for that work internally. Hence, they have to invest to get any benefit. For example, the very successful Silicon Structures Program requires not only money, but a key person at Caltech every year <u>and</u> the equivalent at the company of a fulltime person inside to work with Caltech and understand what's going on there. We are, in fact, spending twice as much money inside as we spend at Caltech. It is important that industry -- and government research sponsors -- realize that, to get really good results from these programs, they have to put at least an equal effort into them. There has to be impedance matching to transfer information.

Another important thing with these programs is that the interaction is usually with a set of individuals, rather than with an institution. One of the biggest problems is that engineering-type projects are apparently not the normal mode within universities, because NSF seems to have supported the single researcher. Larger programs are difficult to run, because they require both technical and administrative skills.

Despite the contracts, joint programs also have the predictable problems of confidentiality. Untenured faculty members are particularly tempted to use the information they get from being inside industry to get points in the academic world for being knowledgeable.

In a well-coupled industry-university program, there is also the predictable danger of control. We try not to interfere in basic research projects. In fact, we occasionally have to replicate the research inside before we can proceed with advanced development. Alternatively, we get highly developed breadboards or even products from universities, but don't realize that they are good enough to make producible right then.

One thing the universities like in these programs is the change from the government funding requirements. The proposals are short (sometimes oral), and we can turn them around quickly. I notice that the agreements are starting to run six pages long, but the proposals can be as little as one page. We discourage the government-length proposals, because you usually can't find out what people really want to do.

Industry could become an alternate source of funding for universities for the ideas that don't have 3-year lead times, the length of time it takes to get a proposal accepted. We can also negotiate without the reviewers and other red tape involved in government research grants. Researchers find themselves becoming proposal writers rather than researchers. I also think that the focus on getting results has been lost in much of the sponsored research. Therefore, when universities find out that we really expect results, this aspect, i.e., the focus on getting results, will probably be welcome too.

DEAN GLOYNA:

Being a university professor, I have broken down my well-honed 50-minute talk into two little quiz questions. Question No. 1: Do professional schools such as those in engineering have a particular challenge in helping to develop the personnel we can use for the next decade and provide a better quality of life for succeeding years? Question No. 2: Is it abundantly clear that all the interests of academe and business are inextricably intertwined? If the answer is yes to both questions, then we can proceed.

Let me tell you why my comments are going to be biased. I represent a university with a faculty of 230 fulltime-equivalent people, of whom 30 or 40 are visiting professors from industry. They teach in various modes: Some give a course, some come on board for only 2 or 3 hours during the semester. Our budget is roughly divided as follows: 40% from state-appropriated funds, 40 to 50% from earned research and contract dollars, and 10 to 15% from endowments. So this gives you a basis for evaluating my comments.

Realistically speaking, I suspect that even the fullest spirit of cooperation will not satisfy all of industry's and academe's needs. For instance, Petroleum Engineering was our largest engineering department on campus in 1952; in 1958, it was the smallest. We were doing a pretty good job of training OPEC students at that time. In 1980, it was back up there again: The number of students, plotted against time, follows the count of oil rigs in operation in the U.S. (The pressures are similar too.)

The fact is that our enrollments have increased 100% in many of the engineering schools in just a few years. We have not had the type of interaction with industry during that time that we might have wished. As everyone knows, sponsored research provides the present funds to carry on a lot of a university's activities. Everyone also knows that the source of most of this money is the government. The charges that such esteemed organizations as the National Science Foundation neglect engineering are not altogether incorrect. The blizzard of paperwork associated with anything from Washington, including the new OMB circular on allocation of faculty time, makes it even more difficult to concentrate on industry-university-government relations.

The principal means by which industry can stimulate professional education continue to be two: money and exchange of professional personnel. Industrial support of an engineering school in a particular locality permits educational specialization that will yield a more skilled pool of possible employees. Of course, the obvious questions for industry are who receives and for what purpose.

It is probably impossible to determine the precise extent of industrial contributions to universities. But some of the numbers I have seen suggest an average figure of roughly $52 million per year. In 1979, business and industry contributed about $20 million to 15 engineering schools in the country; this amount supported about 10% of the separately budgeted engineering research performed by these colleges.

Let me tell you a little about the actual cost of educating an engineer, at least at a state-supported university such as mine. The gross cost -- including overhead, buildings, research equipment, and so on -- for a student in a baccalaureate program in engineering is roughly $19,000. For an master's student, it is $34,000; and for a doctoral candidate, it is $138,000. That is one of the reasons why graduate enrollment is down.

However, the main reason enrollment has declined is the difference between the starting salaries of bachelor's graduates and the research assistantships. When I was a graduate student, my research assistantship was probably about half the salary I could have expected on the open market. Today, the research assistantship in most schools is running about 15 to 20% of open-market salary. Furthermore, one company represented here today offered one of my young assistant professors twice what I was paying him, plus a $10,000 moving grant. No university can compete with that kind of money.

Let's take a look at some of the areas where industry can and does help very effectively in carrying out the three missions -- education, research, and public service -- of an engineering college. Some of these areas were mentioned earlier. The traditional modes are contract research grants, specified grants, professorships, cooperative undergraduate and graduate education, continuing education, and equipment. Equipment is particularly beneficial, provided the end-of-the-fiscal-year donation isn't just making industry's inventory problem our inventory problem. Assistance in selected problem areas, such as senior design classes, is a great help. The visiting committee concept is very important. It has taken us about a decade to learn how to work effectively with a visiting committee, but it is now a significant mechanism in the operation of our college of engineering.

One non-traditional scheme of interaction might be for industry to provide senior engineers to help teach while enrollments are high. We have found that, in an effectively designed course led by a fulltime professor, we can bring in five or six people from industry to talk about a particular subject and stimulate intense interest.

Another possibility is the assignment of young engineers, with pay, to pursue graduate studies. We found that the mechanism of engineering student loans, perhaps with a forgivable clause for those who go into teaching, is very important.

Finally, I think it would be well if at least some of the industrial research brought to the campus could be directed over a much longer lead time. With a few exceptions, nearly all of this research has a lead time almost as short as the year-to-year government contracts.

DEAN HANCOCK:

Over the last several years, we at Purdue have strenuously tried to strengthen our ties with industry. In the research areas, we have obtained additional support from industry, both to finance research and to educate graduate students. In spite of these efforts, only about 5% of our $18 to $20 million of research support (not counting fellowships or minority-program support) comes from "industry."

The major category, direct contract support from industry, constitutes about 80% of the total. This kind of support ranges from $12,000 to $60,000 per year, with a professor to work on a specific project. Each contract must be individually negotiated, a process that can take from several months to a year. Like many other universities, Purdue is very careful when it comes to negotiating rights to patents and copyright material. The rather firm position that the University retains all rights may work with the government, but with industry it's an entirely different matter. Approximately 30 to 40% of initial basic research contracts with industry are stymied because of disagreements on ownership or other sensitive issues.

It is probably for this reason that most of our industry sponsors have been our supporters for a number of years. Once we have worked out an agreement with an industry, that industry will usually stay with us, year in and year out. We normally have complete publication rights, although often the papers will be reviewed by the industry to make sure that no critical numbers are included. The technology transfer associated with these programs tends to take place through the master's and the doctoral graduates. Almost 80% of the students in industry-supported programs end up working for the companies involved, taking with them the technology they have developed.

Another category of industry support, a little different from the one at MIT that Paul mentioned, is the consortium approach. A number of Midwestern utilities are supporting us in the energy area, at a little over $100,000 a year. This unrestricted money is used to stimulate the education of students in the power and energy fields. Because few of our utilities are involved in a high degree of research, they are primarily interested in students at the baccalaureate level. Consequently, much of the money goes to support undergraduate students. Some companies support master's candidates and some master's theses. Many of the master's theses are directly derived from problems occurring in the utilities.

More important, however, is that we use this money for leverage. It provides a most effective means of attracting more funding from government agencies. Every dollar given by the utilities is multiplied 5 or 10 times by the government agencies, because of the good interaction we have with industry and because of the cross-fertilization with utility people throughout the Midwest. This industry support has greatly benefited us at Purdue and has attracted many students into the power and energy industries. We are now in our thirteenth year and committed 5 years ahead, which we consider a most successful long-term program.

Another program that has been established in the last several months is a major CAD/CAM effort with Control Data Corporation. CDC gave Purdue a grant for approximately $1 million a year for the first 3 years, including one of their professionals fulltime on campus -- something new for us -- and another of their senior people soon to be in residence. That 5% industry-supported research is going to 10 to 12% this year, thanks to efforts like CDC's.

We were very excited when CDC approached us about a program in the CAD/CAM area, because it gave us an opportunity to purchase equipment that we could not have otherwise afforded. It also provided a means for us to bring together professors from a number of engineering disciplines in a team effort and then to feed the technology back into many of our academic areas.

CDC came to us with this proposition -- and we were immediately confronted with the university's policy on patent and copyright ownership issues. The university started to negotiate the contract from the position of complete ownership. Purdue did agree to give CDC an exclusive license, but CDC would have to pay for it, and the price would have to be negotiated. Of course, CDC said those terms were unacceptable because they expected the primary result of this 10-year effort to be software for the next generation of CAD/CAM. One simply cannot determine the value of software. When CDC sells a system, the software is often an integral part of the package, and the company was not willing to get itself into the position of having to negotiate with the university for software. The answer was no.

Being convinced that the program was certainly in the best interests of Purdue, and that the long-term benefits to us in this important area of CAD/CAM were enormous, the university did something uncharacteristic: It turned the tables. In essence, it went back to CDC and agreed to enter into a long-term arrangement with the following stipulations: All results could be published by the professors and the students. Everything that came from the supported effort would be on the open market; nothing could be company-confidential. The university would also be free to attract other industries into the program in order to increase the support base.

As for patents, Purdue entered into an arrangement in which CDC annually evaluates the contribution made by the Purdue program and determines what royalties if any are to be paid. Purdue accepts that evaluation.

One other point I want to make is that we at Purdue have seen a number of industry propositions that are largely self-serving. Often a company wants to provide speakers for regularly scheduled classes or to donate equipment that is obsolete and does not meet our needs. They want their names on fellowships with stipends that would hardly support a freshman. Yet we have made some progress. A few industries are getting serious. We have persuaded some companies to give us $10,000 fellowships for graduate students. (Here I disagree with George Low; $8,000 is not going to do much good at Purdue. We need $10,000 or $12,000 to attract top students into our graduate school.) Industries are beginning to interact with us in other ways too, and as long as we can sit down together to discuss and understand each other's problems, I think we can indeed make headway.

DEAN O'NEILL:

I find that I spend a very large part of my time working at the industry-academe interface. In view of the brief time available, I shall limit my remarks to one very specific example of an industry-academe joint program at UCLA. This case, although smaller in scope than the RPI Manufacturing Productivity Center, does illustrate some of the general issues that have been raised.

UCLA's School of Engineering is only 35 years old. During its short history, it has developed both strength and breadth. However, the ceiling on faculty (135 permanent and 10 temporary) and the usual limitations of dollars and space with which all deans are familiar force us to exercise considerable restraint when thinking about new programs.

However, when we held our faculty retreat for the entire school 3 years ago, we did identify one area of interest to almost everyone, not just to those in one or two of our seven departments. It was the consensus that manufacturing engineering should be developed as a schoolwide program. We recognized a demand for graduates in manufacturing engineering and visualized instruction and research that would complement our existing strengths. We could not develop such a program by ourselves on even a modest scale, so we set up a small steering committee comprising representatives from a handful of major companies in Southern California and a few faculty members with specialties in related fields. The companies were those that were long on know-how in manufacturing engineering, but short on the personnel they needed to maintain their position. If we could provide the companies with motivated, well-prepared engineering graduates, it would be worth the investment of their senior staff's time. The companies had a stake in the outcome and were willing to provide us with individuals of the caliber of our colleague, Dr. Morris Steinberg.

Each side had something to gain, and it was a hardworking group. Meeting once a month, the members outlined undergraduate and graduate programs, developed a few new courses, and planned both a seminar series and a conference. These accomplishments probably took the steering committee longer than originally expected, because the members first had to recognize and appreciate each other's approach and concerns. Although our faculty members were generally familiar with the analysis and synthesis that go into a design, they had no expertise in carrying the design into profitable production. On the other hand, the industry representatives had to become inured to the diversity, redundancy, and bureaucracy that flourish at all large universities. It took 2 years, but I believe that we have now reached an accommodation and have a solid foundation for our joint purposes.

There was also the matter of luck. We were fortunate enough to acquire terminals, controls, and cables for a computer-aided design capability from one of our partners and the license to use the software from another. Again there was a mutual benefit: This equipment that fitted our needs was something that the company wanted to give away for its own purposes. This situation is not always the case. In addition, a member of our faculty was willing to redirect his own activities into a channel slightly different from the one in which he had already made a career. Not many professors will do this. With such a fortunate combination, we were able to launch a CAD/CAM course last spring. Again industry shared its expertise with us; it provided the equivalent of 4 work-months to get the system up, develop a course plan, and create specific assignments for the students. The course was an immediate success.

But even more important, the industry-university relationship that has been developed has also led to joint research, summer jobs for students, consultancies for faculty, and fellowships. Obstacles still remain; for example, industry is reluctant to sponsor research that is likely to benefit foreign competition via the many foreign students studying engineering in the United States. However, thanks to industrial support, we are well on our way to meeting a specific local and national need. We could not have done it alone.

PANEL B OPEN DISCUSSION

PHILIP BARKAN (Stanford University):

I am somewhat concerned about the danger of fads. Obviously, many aspects of the production area need more attention in universities. The software aspect I understand. But was the result of all that effort at UCLA a single CAD/CAM course? How much does that do for the students? It seems to me that this subject should involve many disciplines.

DEAN O'NEILL:

Well, the CAD/CAM program was a starting point -- the first thing we were able to realize after a long effort. We now have research underway in this area. And introducing students to the use of the equipment will make them more productive on summer jobs or after they graduate. I think it's a good start.

DANIEL C. DRUCKER (University of Illinois at Urbana-Champaign):

I wondered why my distinguished colleagues in public universities on the panel didn't mention another area of industry-academe cooperation that would also affect private education. One of the major services that industry could perform for academe would be to tell governments which areas of research they would like to see supported. As John Hancock has pointed out, support in the normal mode is, in his case and mine, at present 95 percent government-provided. We have great difficulty in getting support in areas of importance to industry, both at the federal level, which applies to all of us, and at the state level, which applies to the state-supported schools. For instance, we have tremendous equipment needs. Industry indeed gives us equipment support, but the total amount that we can get is negligible by comparison with our needs. I'm sure this is true of every college of engineering in the country.

The same is true for large fellowship programs. Industry can't provide all the money needed; it has to be a national federal program. So I think joint activity on the parts of industry and academe to bring these needs to the attention of those who fund us would be of inestimable value -- perhaps in the long run of even greater value to industry than are the results of direct support.

DEAN GLOYNA:

You are quite correct; but, unless the federal government changes its policies, it is going to drive most of the schools receiving that support into bankruptcy.

DEAN HANCOCK:

Our experience with trying to involve the government in the industry-academe interface has been twofold. When it comes to supporting research, industry has indicated to us it doesn't want anything to do with the federal government. If the problem is important to the companies, they will take care of it themselves.

We have had one major success in getting the government involved in an industry program. We had several industries supporting us in the acoustics area. A couple of years ago, those industries got together and supported us in our proposal to the National Science Foundation for a special acoustics lab. We got $350,000. It was a big percentage of that year's NSF engineering research equipment budget, so we were convinced we would never have gotten that laboratory if industry had not supported us and applied pressure through its own avenues.

Other than that, though, we haven't had much encouraging experience with getting industries, the university, and the federal government together.

MR. BELL:

I served on the Feldman Panel, which wrote a report last year to NSF arguing for computer equipment for experimental computer science. It takes several million dollars to start up a semiconductor lab, too. The only straightforward way to do that is to get an industry consortium to underwrite the facility, because the government process takes a very long time and is unpredictable. The Feldman Report apparently did help, though.

I say that if a university has something it really feels needs doing, then it should put together a program that one or several industries can support. A group of competitors -- IBM, Hewlett-Packard, Digital -- are involved in the Caltech Silicon Structures Program. I think that if a university takes the initiative and puts together the deal, industry will buy it. We need the work, and we need the interaction.

ROBERT C. McMASTER (Ohio State):

I would like to warn you of two hazards that haven't been mentioned. During the 1960's, our small department went out and, by personal effort, brought in $1-2 million worth of end-of-fiscal-year hardware. But the university failed to support us in two vital areas: they gave us nothing for maintenance, and they did not provide amortization funds to replace the equipment.

One of the reasons I retired was that I could no longer hand-make the spare parts we needed, and I could not safely teach in the laboratories with the equipment in such a dangerous state. Universities must recognize the need for amortization and maintenance and make sure that both are funded when the million-dollar gift is made.

Now, the second hazard: Over the last 20 years I have observed with great concern the change in the makeup of graduate school classes in our university. From 80 or 90% U.S. students, they have become 80 to 90% foreign students. I have often seen classes with only one or two American students. Now we have transferred technology very effectively -- they practice what we preach. Our industries did not practice what we preach so, in certain areas -- shipbuilding, automobiles, and so on -- we now are at a considerable national disadvantage. I sincerely hope that American industry's attitude toward graduate studies in the university changes before we find Japan and other countries outrunning us in all technologies.

FLOYD L. CULLER, JR. (Electric Power Research Institute):

Thus far, the discussion has been concerned principally with how to acquire funds to build equipment and experimental systems within the universities. Given the problems of equipment maintenance and acquisition and the rate at which equipment loses its usefulness as a teaching tool, keeping a laboratory like Draper modern becomes an exercise in futility.

Could universities assign their graduate students and instructors to industries where the appropriate equipment already exists, more or less in an expansion of the MIT Practice School idea? Individual relationships with various companies could then allow graduate programs on manufacturing equipment to be conducted within oil refineries, or the coal conversion systems, or the electrical distribution systems of TVA, for example. In fact, many industries, in the course of training graduates beyond the undergraduate level, have developed training programs of graduate-level quality in a particular technology. For instance, I suggest that no university offers anything like the training available in the Tennessee Valley Authority or the American Electric Power for power engineers.

It seems to me that a sort of reverse lend-lease might work; you lend your professors and students for graduate-level work to the industry. Would it not be preferable to learn on equipment that is currently in production, rather than trying to get semi-outmoded equipment installed within the university confines?

MR. BELL:

We support the cooperative programs, particularly where large laboratories are involved. For instance, in the semiconductor area, we are all concerned with the problem of laying out very large-scale integrated circuits. The universities hadn't been able to afford the production facilities, so they couldn't work on the problem at first. Now Hewlett-Packard manufactures parts that are designed in several universities, and we have made similar offers to let universities use our production facilities to manufacture semiconductors.

DEAN GLOYNA:

I think everyone recognizes that there are very fine facilities outside the campus, and that we in academe need to be more flexible. I believe that before long we will have such programs, not only for the graduate interns but also for our faculty. Education is a process of motivation. If you don't have fulltime, experienced, competent faculty who are the leaders in the field, there will not be much motivation.

PANEL C

THE SUPPORT ROLE OF GOVERNMENT

Panel Chairman

Robert A. Frosch, Administrator, National Aeronautics and Space Administration, Washington, D.C.

Panelists

Henry C. Bourne, Jr., Deputy Assistant Director for Engineering and Applied Science, National Science Foundation, Washington, D.C.
Albert Bowker, Assistant Secretary for Postsecondary Education, U.S. Department of Education, Washington, D.C.
P. L. Thibaut Brian, Vice President, Engineering, Air Products and Chemicals, Inc., Allentown, Pennsylvania
Antionette G. Joseph, Associate Director for Field Operations Management, Office of Energy Research, U.S. Department of Energy, Washington, D.C.
Harold Liebowitz, Dean and Professor, School of Engineering and Applied Science, The George Washington University, Washington, D.C.
Richard Meserve, Senior Policy Analyst, Office of Science and Technology Policy, The Executive Office of the President, Washington, D.C.

DR. FROSCH:

I fear I must begin by reporting to you a most sinister circumstance: The Foucault pendulum in the Great Hall has stopped. We may be in for some terrible cataclysm.

Ignoring that, let me say that I think I heard two attitudes toward the government's role in engineering education expressed today, one of them in passing and one of them repeatedly. The one expressed in passing essentially was that the government has been doing a good job in supporting the universities and should keep it up. The one repeatedly referred to was that the government should stay out of the industry-academe interface. In summary, don't bother us, stay out of the interaction, and send money.

It sounds to me, however, as though there may indeed be a larger role that government can play in this interaction. The time line of industry research has generally been getting shorter and shorter. Although the time line of the universities continues to be long, there is considerable pressure on them to be more and more responsive to short-term things. It may be up to the government to take the long-term view on behalf of the country and to try to arrange a compromise between the short-term industry requirements and the long-term need to build knowledge bases. The government might also be able to help with transferring the long-term knowledge base into use in the industry, while using the short-term problem solving motivations of industry to stimulate the kinds of long-term research that universities might be interested in.

It is conventional to view university research and long-term science as the basis for engineering applications and industrial practice. It is less conventional, but I think equally true, to think of the history of science and basic knowledge generation as frequently being stimulated by immediate industrial and engineering problems. For example, I think one can make an excellent case that the development in the 19th century of what started as applied mathematics and turned out to be the mathematical base for modern engineering and science occurred in response to engineering problems of the day. Bessel did not invent differential equations and Bessel functions because he was a pure mathematician, but because he was trying to solve engineering problems. I think government may have more of a role to fill in stimulating the feedback between industry and university, and vice versa, than has heretofore been mentioned today.

My agency is different from the other government agencies you will hear from this afternoon in that we are both a producer and a consumer; that is to say, we actually do large-scale engineering work directly in the government. We are thus more analogous to a company than are most government agencies. We have had to solve some of the same kinds of problems the industry representatives were talking about -- the continuing education of our engineers and scientists and how to help universities keep up-to-date in the academic subjects we are interested in when they can't afford the necessary facilities like wind tunnels and test stands. We have work schemes whereby both industrial and academic people use government facilities in ways that I suspect industrial firms and academic departments could arrange -- both by moving people back and forth to do particular jobs or by opening a facility to these personnel. We also have some rather special arrangements with particular universities and departments.

In addition to these roles, I believe the government can also play an important part in ensuring that long-term problems of national significance receive attention. There is a class of such problems -- for example, those related to energy. The whole question of how to solve industrial, environmental, and societal problems in a better way than we have succeeded in doing so far is well worth exploring.

The real difficulty, of course, is what mechanisms one can construct to provide this support, yet not interfere with the normal flow of events. Because government mechanisms are so public, they become very cumbersome. Anything public must be defended continuously, so an elaborate system of "just-in-case defenses" tends to build up. We need to find some way out of this defense-system maze if government is to play the kind of role I envision.

DR. BOURNE:

Many of the problems we have been discussing today have been around for a while, although maybe at varying intensities. Consequently, federally funded programs related to some of these concerns have come into existence. Let me briefly describe a few of these programs and discuss their rationale; you may then want to comment on their appropriateness or adequacy.

I would like to concentrate on the support of graduate education and university research in engineering, particularly those programs which involve university-industry-government interaction, and the role of NSF. Incidentally, I do not attempt to separate support for education from support for research, because at the graduate level I do not believe they are separable.

First, let's look at the overall support of engineering research in our universities:

Federal support (non-mission-oriented)	$180 M
(supplied by NSF: $70 M)	
Federal support (mission-oriented)	260 M
Industry	60 M
Other	120 M
	$620 M

As you can see, industry is supplying less than 10% of the engineering research support in our colleges and universities.

Now, I believe that university engineering research needs the independence associated with having a significant portion of federal research support that is based on non-mission-oriented, peer-reviewed proposals. But it also needs the relevance associated with receiving support from industry to do research in areas important to particular companies or industries. At the moment, the two kinds of support are far from balanced. The balance between knowledge-driven and problem-driven research, if we can distinguish between these two categories in university engineering, appears to be better. However, I think these two balances should be the subject of further discussion and study.

Let me highlight a few specific programs that illustrate some kinds of government involvement in this three-way relationship.

First is the NSF Industry/University Cooperative Grant Program. It encourages cooperation by reserving a special source of money for funding joint research teams working on common problems. It's just seed money so far -- $6.2 million this year, with $15 million planned for next year -- but we hope it will build up the amount of interaction. By the way, it's an NSF-wide program, but engineering gets the lion's share: 10.8% goes to civil and mechanical enginering (8 awards); 16.2% to chemical and process engineering (12 awards); and another 16.2% to electrical, computer, and systems engineering (12 awards also). The only other large division -- 27%, 20 awards -- is materials research, which of course involves many engineers.

A second approach is our grants for starting up university-industry cooperative research centers. The idea here is that government gives the front-end funding, but the university must involve industry from the start. Over the course of 5 years, it is hoped, industry will take over the program funding, and government will phase itself out of the picture. That has happened just as planned at the Polymer Processing Center at MIT, which got $500,000 over the 5 years, and the Research Center in Computer-Aided Design at RPI ($1.3 million) is coming along well. We also have two brand-new $1 million centers, welding research at Ohio State and industrial polymer research at U. Mass. Of course, if a center can't attract industry support, it just gets phased out.

We also make planning grants for cooperative research centers. Our five current grants are to Catholic U. for vitreous materials, to Kent State for coating research, to Case Western Reserve for an industry cooperative program in polymers, to the University of Kansas for microprocessor-based systems, and to Arizona State for ferrous material research.

Another kind of thing NSF does is help bring together different groups of people in hopes of encouraging cross-fertilization and innovation. One of those meetings, which actually was mandated in our congressional instructions, will bring together the deans of engineering schools and the deans of business schools in St. Louis in early December. We are hoping this session will result in improved curricula, particularly in the areas of technology management and entrepreneurship.

Still another type of NSF involvement in the university-industry interface is the funding of what we call innovation centers. These centers have a dual purpose: to educate and train technological entrepreneurs and inventors and to facilitate the commercialization of university-developed technology. Again, the idea is that NSF will provide startup money, maybe $500,000, and then fade out of the picture as the center becomes self-supporting from patents or proprietary information. We have five innovation centers operating right now -- MIT, Carnegie-Mellon, Oregon, Utah, and Worcester Polytechnic -- and each one has a slightly different emphasis. For example, one evaluates inventions or idea commercialization potential for anyone who walks in. Another offers courses in managing high-technology enterprises, entrepreneurship, and innovation.

I do want to mention a couple of NSF programs that don't involve industry. There is a graduate fellowship and traineeship program, though I have my doubts as to how far the 70 awards granted to engineers last year will go toward getting the number of engineering doctorates back up to where it should be. The postdoctoral fellowships are not bad at $15,000, but we had only three takers in 1980. No engineer wants to stay around for postdoctoral training. And then we have the science faculty professional development awards, of which six went to engineers last year.

Last, but not least, are the engineering research initiation grants. These attempt, in a small way, to address the problem of keeping young engineering faculty in our engineering schools. Last year, we awarded

90 grants to 58 universities for a total of $3.6 million. We feel that the awards make the universities a little more attractive, in that young faculty members can compete for research support with their own peer group.

Of course, all of these programs represent only a small fraction of NSF's engineering research support.

Let me close with the thought that the real questions concern the appropriateness of these programs, the adequacy of their funding levels, and the need for other programs. I think I'll leave those to discussion.

DR. BOWKER:

The activities of the Department of Education in engineering education will occur primarily in the future -- if we have one. We do have a few things going on now, like the cooperative education programs that we fund in a large number of universities. In these programs, we give a number of small grants to help colleges and universities pay some of the administrative and implementation expenses for initiating and sustaining cooperative education ventures. The programs have been pretty successful to date. We have some similar activities in vocational education.

The Department of Education's largest involvement in postsecondary education has been the federal student aid program, which includes grants, loans, and work-study money. The main purpose of this huge program is to remove financial barriers for students who wish to pursue undergraduate degrees. Indeed, the federal student assistance programs have been the principal instruments by which the Department has attempted to put into practice the national commitment of access to educational opportunity.

Curiously, a great many of the student aid programs (which were originally designed for undergraduates) have become vehicles for supporting graduate students. Perhaps as a result of this, Congress has recently instructed the Department of Education to study the financing of graduate education. Our preliminary analyses indicate that, of the two principal areas of support for graduate students (work-study and the guaranteed student loan program), hundreds of millions of dollars are being spent to support graduate students. (Paradoxically, work-study funds are need-based, and getting a GSL depends on finding a bank that will lend the money.)

In addition, we have a whole grab bag of fellowship programs: one for mining; one for public service; one for international education and languages; and the Graduate Professional Opportunity Program, which is aimed at increasing graduate support for minorities and women. At present, these programs are not very well coordinated. However, with new Title IX legislation and some internal restructuring within the Office of Postsecondary Education, I believe that over the next few years we will be able to organize our financing of graduate education more systematically.

Now, I want to talk a little about a report that the Secretary of Education, Shirley M. Hufstedler, and the Acting Director of the National Science Foundation, Donald N. Langenberg, prepared for the

President this summer. It is entitled "Science and Engineering Education for the 1980's and Beyond." (This report has been released and should be available in about a month.)

The report focuses on two areas. First, it takes a broad look at science education in elementary and secondary schools. It documents the well-known story of declining student ability and decreasing emphasis on science. The report recommends to the President something analogous to a post-Sputnik effort, involving teacher training, new curriculum material, and a national commitment to excellence in science. Such a commitment would have to include far more than just the federal government, of course; it must also involve state departments of education, which in turn would look to industry for support. The report outlines a very comprehensive program for turning around the whole science-education picture at the elementary, secondary, and even collegiate levels. For example, many liberal arts students today learn almost nothing about technology or what it can mean to them. The recommended programs would correct this lack of exposure.

The second subject this report looks at is the areas in which there are shortages of scientists -- computer science, chemical engineering, et cetera. It suggests some things that might be done to improve graduate training in these areas; for instance, it recommends that the NSF Research Initiation Program be substantially expanded, to encourage more scientific research.

One thing that has become clear to me from reading about and discussing this matter of engineering education is that, if we want to raise the number of graduate students in engineering, we will have to provide somthing like $8,000 to $12,000 a year for students to live on. I, for one, wonder whether the federal government will want to underwrite that kind of stipend to encourage a student to prepare further for what is already a fairly well-paying profession. Even beyond the economic considerations, however, it seems to me that the worst problem is that of teacher shortage -- and a fellowship program would not guarantee that doctoral students would go into teaching.

To encourage Ph.D.'s to teach, we should consider a program like the one used by the Public Health Service to recruit medical doctors. They pay for medical school, and students serve for as many years as they were subsidized in a Public Health hospital or in a designated area of physician shortage. About 12,000 people have gone through this program, and I understand that there are many more applicants for it than the Public Health Service can handle. Thus, it might be possible for us to encourage more students to commit themselves to this area. We might combine an NSF-level fellowship with a loan of $5,000 (or whatever would be needed to get the proper income) and make a year of the loan forgivable for each year the student spends teaching in an engineering school or in an area where a particular shortage has been identified.

We have had some experience with similar programs in recruiting teachers to serve in low-income schools. Although I dislike equating research and teaching in our major universities to providing medical service in deprived areas, I believe some kind of incentive is needed. I suspect a lot of people would stay in graduate school if they could move up from real poverty to genteel poverty.

DR. BRIAN:

If I've counted correctly, I am the eighteenth person to address you today on the subject of engineering education. I don't think I can offer any completely new insights into the problems or completely new suggestions for their solution. So I am just going to emphasize a couple of aspects that I consider particularly important.

Like many other people, I have observed over the last 20 years that, as the funding of university research in engineering has been assumed by the federal government rather than by industry, the faculties of engineering departments have tended to take on the perspectives of government -- despite the fact that most of the students who graduate from those departments will make their careers in industry. Obviously professorial research is important not only to a career path, but to the attitudes and perceptions brought to teaching, both graduate and undergraduate. I don't see any solution to that problem except for industry to reassume a significant role in the funding of engineering research.

Probably many of you know of the conferences in Midland a year ago and in Allentown-Bethlehem a month ago, at which the chemical industry attempted to reconsider its relationship to chemical engineering and chemistry departments. The heads of the chemistry and chemical engineering departments of about 75 or 80 major universities, and the senior technology officers of about 70 major companies in the chemical industry, came to Allentown to talk about the problem. What impressed me the most about this conference was that I got the feeling that something more than proceedings would come out of it. The formation of a Chemical Research Council to help the chemical industry fund research in universities seemed at least likely.

To be sure, there were still some problems, such as the method of allocating the funds. I think everybody at the conference, on both sides of the industry-academe interface, agreed that a procedure like NSF's formal peer review was to be avoided. However, there were those who felt that industries that wished to participate should contribute to a general fund, and allocating the money should be entrusted to an all-wise and all-powerful committee. Others -- like me -- felt that industries that wished to participate should pledge a certain amount of money and decide for themselves which centers of excellence to support, and maybe even why.

All that actually happened at that second annual conference was that a committee was established to found this chemical research fund and institute, but I felt that we got closer to being able to predict a significant action than ever before.

As for the role of government in the industry-university interface, I think that the best role government could play would be to offer incentives to encourage industry involvement. The Vanik bill, which would give tax advantages to industries participating in such programs, would be a significant inducement.

The funding discussed at the conference was on the order of $10 million a year after the third year of operation. I suggest that a participating company allocate a certain percentage, perhaps 1 or 2%, of its R&D budget to funding research in American universities. The board of directors or management committee would then charge the vice president for research with choosing the centers of excellence to be supported. This process would involve senior corporation technology officers and their key lieutenants in evaluating the research. Then, perhaps, engineering professors would once more begin to ask themselves whether what they are doing is important to the industry they are training people for, rather than important to the federal government.

The other problem I want to focus on is even more significant in the short term: the dearth of graduate, especially doctoral, students in engineering, and the small number of those going into faculty posts. Certainly, the principal reason for this shortage is that graduate students' stipends and faculty salaries have not kept pace with inflation, whereas engineering salaries in industry have. How to solve the problem is a big question. One solution proposed at the Allentown-Bethlehem conference was a program such that General Motors had been running. The concept was that industry would contribute fellowships to selected university departments, for outstanding students who might wish to pursue doctorates with the thought that they might go into teaching. If they were sufficiently interested in an academic career to agree to try it for at least 3 years, the company would fund them on a "Cadillac" fellowship, $10,000 to $12,000. In addition, during the 3 years of teaching, the company would make up the difference between the likely industry salary and the academic salary. The students would be encouraged to take summer jobs with the company so they could get to know each other.

One thing that wasn't mentioned in discussing the General Motors program, but perhaps should be, is that the university department would have to have some voice in selecting the recipients of such scholarships or fellowships, because the faculty posts the students commit themselves to fill are the university's.

I don't know what role government could play in this sort of relationship. I think a program like the proposed GM one has a very high return on investment, and the government might help support it. If it didn't, tax incentives of the Vanik type would again be useful.

DR. JOSEPH:

Let me start off by giving you a few statistics on DOE's overall budget, to put what I'll talk about later into some perspective and for comparison to the magnitude of NSF's effort.

DOE's total R&D budget for 1980 is $5 billion. About one-third of that is in basic and applied research and about two-thirds in development; $522 million is in basic research and $750 million in applied. Some $200 million of that is spent in our basic energy sciences program; about $100 million of it goes to materials research; about $20 million of it goes to a new program called engineering, mathematics, and geosciences research. This last area includes a materials center at the University of Minnesota and a combustion research center activity at Lawrence Livermore. The total DOE funding to universities for research is $350 million a year. As you know, most of the support goes to individual researchers, through the same peer-review process talked about earlier.

DOE also has a very small effort underway to fund a variety of programs to help support university-industry interaction in research. And because of some of our past successes, we are proposing some other activities to strengthen these programs. I think we are not so pessimistic about the government's playing some role in this area as were some of the earlier speakers.

We do fund a very few joint energy research projects in which university researchers collaborate directly with industry, and faculty and industry exchange personnel. And we have some in which industry serves in only an advisory role to the university researchers.

DOE's institutional awards program, which is less than $3 million, specifically requires the universities to develop mechanisms to ensure that there is long-term industrial participation. We also support activities that involve the national laboratories, universities, and industry, especially when the laboratory has unique facilities or equipment. But it also covers the technology transfer activities at the laboratories, one example of which is an $0.5-million program at Lawrence Livermore Laboratory in microcomputer processing. It functions as a training course to keep the industry and universities up-to-date on the advances, which come almost monthly, in that area.

The Department has sponsored several university-industry research workshops, designed to enable each group to appreciate the other's energy research perspective. The laboratories, on their own initiative, have undertaken the same kinds of discussions with universities and industries. Also, we have recently proposed a targeted traineeship program in specific energy-related engineering and science disciplines. Trainees in this program would be required to interact with the energy industries for a specified period of time.

In summary, DOE is encouraging universities and industry to understand and use each other's complementary talents and interests to advance energy technology, and we are trying to promote such efforts through several types of mechanisms that we hope will be beneficial to both groups.

DEAN LIEBOWITZ:

I feel that universities must find new ways and outside resources to educate their engineering students in the future, especially at the graduate level. Universities must link themselves with institutions that can enhance the training of engineers.

We must remember that whatever consensus is reached at this conference, it may not be applicable to all universities. Each university, whether private or public, has its own objectives in the areas of training, research, and public service.

There are a number of novel ways in which universities can interact with private industry or the government. Look, for example, at the program NASA has instituted at the Langley Research Center, the Joint Institute for Advanced Flight Sciences. In this case, a university went to a government laboratory and made commitments on tenured faculty -- three positions at present and a fourth in process -- at about $1 million apiece. It committed itself to a long-range program offering master's and doctoral programs off-campus at the Langley Research

Center. In addition to the 60 or so researchers and faculty at Langley, there are openings for visiting scholars, honor students from other academic institutions, and people from private industry.

It is interesting to note that Stanford University's Aeronautical Engineering Department was rejuvenated in the 1950's with the cooperation of Lockheed. The Navy and the Air Force encouraged Professor Hoff to join Stanford University; Lockheed offered to contribute toward his salary. The Navy and the Air Force awarded him research contracts, which made it possible for the university to attract very good people and to develop an outstanding Aeronautical Engineering Department. It was an excellent example of cooperation between Lockheed and Stanford -- in the exchange of people, use of equipment at the university, and utilization of the Lockheed laboratories. (I have no stock in Lockheed, by the way.)

We have seen that the National Advisory Committee for Aeronautics (NACA), the predecessor to NASA, has been an excellent model for today's proposals to develop generic technologies through cooperation among government, industry, and academe. The Route 128 and Silicon Valley experiences illustrate how government-funded university research can stimulate commercial activity, which, in turn, causes unprecedented growth in industry.

In England, the Finniston report, Engineering Our Future, recommended that industry plan to perform some of its basic research at the universities and make long-term commitments to support such work and the necessary facilities. Perhaps programs could be developed in which a company would not necessarily give money, but would locate itself near and cooperate with universities. The government could encourage such programs without being directly involved.

The government might look at the independent research and development programs in industry, which I think now amount to about $1.8 billion, and suggest some applications that would help provide the long-term programs that are really required at the universities. A portion of industry IR&D money could be earmarked for such coupled university-industry programs. The government could also help in coupling academe and industry by recognizing IR&D as an allowable cost in university grants and contracts. Such relatively free money would provide for the exploration of new ideas, support younger people, and smooth out the discontinuity inherent in project funding.

Last week, the President signed into law the Stevenson-Wydler Technology Innovation Act of 1980, which has many important implications for engineering. The act seeks to enhance technological innovation by means of a strong national policy supporting domestic technology transfer and utilization. It establishes a new Office of Industrial Technology in the Department of Commerce. This Department, with assistance from NSF, will establish technology-transfer centers affiliated with universities or non-profit institutions. This program will foster an exchange of scientific and technological people among academe, industry, and federal laboratories. Each federal laboratory will establish a resource and technology applications office. Each agency will make available 0.5% of its R&D budget for technology-transfer activities. The act authorizes the expenditure of $285 million over the next 5 years.

I believe this act can be an effective means of strengthening relationships among the government, industry, and academe in engineering education. Each sector contributes to the process of technological innovation and utilization. The government can play a very important role in facilitating their communication and cooperation.

DR. MESERVE:

At this time of the day, and after 20 other speakers, I fear that much of what I will say will sound like a stuck record. I must apologize for that.

There is one main theme that I would like to hammer home -- a theme that is implicit in much of what you have heard today. The support role of the federal government in engineering education is changing very rapidly -- and I think it is growing.

Let me explain why I think this is happening. It is not primarily because of federal interest in education per se, important as education is. Rather, we perceive many national issues to which science and engineering are particularly relevant -- economic difficulties, military challenges, energy problems. And, as a consequence, some bolstering of engineering education is an appropriate part of the national response.

I am going to focus on the area that is undergoing the most dynamic change -- the economic area. We are all very much aware of lagging growth of productivity in the United States, increasing international competitiveness, the trends in innovation in the United States as compared with those of some of our foreign competitors, and the great debate throughout the country as to what we should do to change the situation.

One common element in the discussion is the use of our scientific and technological capacity to deal with these problems. And I think that that emphasis will inevitably result in much greater attention to engineering education, both by the federal government and by industry. I think there will be direct and indirect impacts. Let me discuss some of the changes that I see under way now.

At the very end of August, the President announced his economic message. The part that understandably got the most attention was the variety of tax proposals, particularly those involving billions of dollars of tax revenues that industry would be allowed to retain to encourage the construction of new capital plants and equipment.

One element of the President's program that has received less attention, but which is particularly relevant to our discussion today, was the announcement that the budgets for scientific and engineering research and development would be supplemented by $600 million over the planning levels for fiscal years 1981 and 1982. The money will be used in part to sustain a real growth of 3% in the support of basic research in each of these years.

We have engaged in rather extensive discussions with universities, industry, and engineering and scientific professional societies to determine how the funds could best be applied. One recurrent theme in these discussions has been the equipment problem, particularly as it relates to engineering education. Professional shortages in engineering are a prime concern as well, and, of course, these funds will also be used in part for actual engineering research. So this direct federal effort to increase available funds for scientific and engineering R&D is very likely to have a significant effect on engineering education.

Let me turn to some of the indirect federal involvement in the interaction between industry and universities. I think that the federal role here is chiefly that of catalyst. We have heard about quite a few programs today, several of them recent, that are designed to improve the links between industry and universities and to regenerate some that withered during the Vietnam era.

NSF's industry-university program builds those links at the bench-scientist level. The Stevenson-Wydler bill, which is the congressional enactment of a program resulting from the President's innovation review, is intended to establish some generic technology centers of importance to industry at universities or other non-profit organizations. (Jordan Baruch has been very active in designing that program.) I think that engineering may have a prominent role in the establishment of such centers, since it's a logical point for couplings with industry.

Our office, the Department of Transportation, and the National Science Foundation have been very active in trying to design some sector-specific initiatives. The government is feeling its way very tentatively, as it tries to design appropriate research programs for sectors in which the federal research involvement is new. In some sectors, like defense, we have a long and extended history. The federal government pays for the research and development and the production costs through the entire cycle, from original idea to purchase of equipment, because the federal government is the user. In other areas, such as energy, the government has tried direct stimulation to meet a national goal.

But where the aim is general economic advance, we are still feeling our way. One area of a sector-specific program on which our office has spent a great deal of time is a jointly funded cooperative program with the automotive industry. This program is designed to improve the fundamental research base that will underlie automotive advance. Greater fuel efficiency or improved cars over the next year or two will not result; the program looks toward advances in automotive technology in the 1990's and beyond. It will start at modest levels; the federal government's investment in the coming fiscal year will be around $12 million. If all goes well, it will eventually increase to about $50 million, with a matching $50 million coming from the five domestic automotive manufacturers. Again, I think that engineering education is likely to benefit considerably from such a program, because the engineering areas are in many cases the easiest places to forge links between universities and industry.

PANEL C OPEN DISCUSSION

DR. FROSCH:

I think it is clear from today's discussion that there is a great deal of diverse and experimental interaction between government and academe in engineering and technology research and education and also between industry and academe. However, I think this very diversity raises some questions: whether there is enough activity; whether the existing activities are spread too thin; whether some of these experiments -- government-academe or industry-academe -- ought to be turned into larger programs and others dropped; whether there is some kind of shakeout of programs coming. Diversity, although a good thing, can lead to a great dispersion of capabilities and funds, and thus may be less likely to get results than would a few more concentrated efforts. We have no direct mechanism for examining and consolidating programs, but it's something we might want to give some thought to.

JULIUS J. HARWOOD (Ford Motor Company):

I find it interesting that in all today's discussions of government-industry-university interaction, the role of industrial research was hardly mentioned.

Mr. Chairman, you called attention to the concern that industry's research goals are too short-range, that academe is being pressured to adopt the same perspective, and that government support is all that allows the university to maintain the long-range focus it should have.

But it seems to me that, when we look at all the components and at the role of the national research effort in promoting productivity, innovation, et cetera, we find that one of the strong links in the equation is the role of long-range research in the industrial sector. I would like to hear some discussion of how clever the government might be in encouraging industry to protect its long-range research. As long as industry looks at the short range and universities at the long range, the mismatch and incompatibility of these two sectors can only increase. Indeed, if industry is to use the long-range research of the universities, industry must be able to understand it, interpret it, and run parallel activities.

The cooperative automotive research program that Dr. Meserve discussed may prod the industrial sector into adding its own long-range research activities over the next 5 years.

Anyway, it seems to me that we must look at both sides of the equation, if we are to address the problem in its entirety.

DR. FROSCH:

One of the long-term aspects of the NACA and now the NASA programs, particularly in aeronautics, has been for the government to do both long-term research in-house and to fund cooperative research of various kinds with industry. The effort was an attempt to bring along technology that was anywhere from 5 to 15 years away from industrial production technology. We tried to structure the research so that the most basic things were done in-house or with universities; but, as the technology developed, there was more and more cooperative work with industry. Then the government would drop out when the technology became mature enough to turn into aeronautical products.

I think this has been one of the successful aspects of the development of the U.S. aeronautical industry. I have to say, though, that the intermediate step -- in which the government, together with industry, sponsors the technology to the point at which it is ripe to become an industry research project -- is probably the area of our research coupling that has been most under attack during the past few years. There seems to be general agreement that NASA should not be in the let's-design-an-airplane end of it, and also that NASA should be in the basic research end with the universities. When we meddle in the middle, one school of economic thought begins to talk about subsidies and markets and how industry should do all this by itself. Myself, I think that this attitude reflects a misuse of the market economics idea and a misperception of what industries can do by themselves, but it is a very strong ideological problem that we keep running up against when we try to splice basic research and actual application.

DR. BOURNE:

I should have emphasized that one of the main goals of the industry-university cooperative research program is to encourage industry to do long-range research in collaboration with university researchers. NSF supports the research in both places.

THOMAS F. JONES (MIT):

For 25 years the subjects under discussion today have been very near to my heart. Some 25 years ago, the level of industrial support of research in universities was 3% or so (although the federal support was also rather low at the time). It has grown to somewhere between 5 and 10%.

But it has all been slow incremental change, and I think most of the measures we have talked about today would merely speed up the change. We need something much more dramatic than that. And I think tax-credit legislation, like the Vanik bill, is the one measure that might make such a dramatic change. Just how much industrial support for research should there be in the universities, relative to government support? We can probably safely say somewhere between 30-70 and 70-30, and I think most of us feel 50-50 wouldn't be a bad balance. But whatever the number, it's likely to be a long way from where we are.

So I would very much like to hear how some of the industrial people here feel about the tax-credit approach. If they could get the research at 25 cents on the dollar instead of at 50 cents on the dollar, would there be much greater participation? I realize that there are some trade-offs involved, like publication requirements, and various other questions to be addressed. But I think we have a good forum here for discussion of this question.

DR. MESERVE:

I think that this is a very interesting proposal. It is one with which I think most people here would agree philosophically, and, of course, there have been discussions with the Treasury Department concerning such tax incentives. The chief problems are the practical issues of how such tax credits might be appropriately enforced and policed. The IRS auditors or examiners are not scientists or engineers; they cannot distinguish R&D expenditures from other kinds. Thus, it is difficult for the Treasury to satisfy itself that there is no "leakage." Tax credits might be claimed for funds used for proprietary work, quality control, or any one of a variety of things that, to an uninitiated eye, might look a great deal like R&D.

Now, it has been argued that, under the Vanik bill, there would be two parties, and each might be responsible for policing the other to some degree. That helps somewhat, as far as the Treasury is concerned, although it doesn't solve the problem completely. But another complication is that at least some proponents of the Vanik bill see it as supporting basic research. This means that the companies, the universities, and the IRS have to agree where to draw the line between what is basic research and what is not.

I think that the problems associated with some of the tax proposals can indeed be solved, but they are going to need some work.

DR. BRIAN:

With or without the tax incentives, I think that there will be more industry funding of academic research if a collective movement gets going. It's like a revival meeting -- if all my competitors will do it, I'll do it too. I feel the chemical industry research council can play a major role here. I suspect a company like mine will find it a lot easier to increase their support if they know most of the other companies in the industry are going to do it also.

FLOYD L. CULLER, Jr.:

As most of you know, the Electric Power Research Institute is a conglomerate of the electric utilities of the United States, supporting both basic and applied research in energy. It has been in existence for 6 years and is one of the very few examples of a voluntary industry-wide research and development activity. The funds available for R&D from the utilities are substantial. Some 85% of the privately owned and most of the publicly owned utilities are members; there are approximately 600 members.

Based on this cooperative experience, I have several observations that might be worth passing along. First of all, the cost of doing R&D, either long- or short-range, is so great that those who participate in it must be able to see the end result. Joint industry-university programs certainly can include long-range research, but they must also produce visible results, enough to justify the $50,000 to $100,000 per staff-year that R&D costs.

Second, because of this high cost and the consequent interest in having a visible output within a short time frame, industry tends to regard the university research as a primary end rather than as a teaching aid. Thus, in truth, the price of supporting research for educational purposes is extremely high.

Another point I wish to make is that if companies within an industry are going to pool funds for basic research, their commitments should be significant. Small contributions tend to be managed by an assistant, along with a hundred other small grants. This situation does not usually provide fertile ground for either great inspiration or new directions. I suggest that such research pools be larger than $10 million, so that top executive talent will be participating. For example, the Electric Power Research Institute has a 450-person advisory structure that meets once a quarter to provide guidance and learn the results of some of the 1,600 projects going on within the Institute.

With this background, let me make another comment. I think that the government-industry-academe interaction in R&D support could be likened to a three-legged stool, with the legs awkwardly placed at three corners of a square. It can very easily be tilted out of balance when the interests of the three supporting members are not mutual, compatible, and agreed on. There is still something of an adversarial relationship between the government and the private sector in the United States that other societies have solved in part, as witness the Japanese trading company and the French combined effort. Somehow, we have to be able to show that it is in the common interest to spend government money for good research and demonstration, even in the applied sector, to make sure that the industry can financially take the bigger risk of investing in a new or updated production complex.

This leads to a final comment I have concerning where the investment for the R&D and demonstration might come from. EPRI now participates in about $1.5 billion worth of demonstration plants -- coal gasifiers, coal liquefaction facilities, super-conducting generators, and the like. About 25% or so of the money for these is provided by us (the utility-EPRI program); the remainder comes from others -- the architect-engineers, the manufacturers, the utilities themselves, and the government. The risk is not these demonstration plants; rather, it is the cost of the manufacturing facilities that result from these successful demonstrations. These end costs must be met by the industrial sector.

Let me illustrate. The probability of having successful fuel cells within 3 or 4 years seems relatively high. EPRI, the government, and the private sector will have invested many millions in several development plants by then. The major investment, however, will have to come from United Technology Corporation, Westinghouse, and possibly others, who must set up production lines with careful quality control. Their investment will certainly reach 5 to 10 times the cost of demonstration plants.

RUSTUM ROY (Pennsylvania State University):

I want to second Julius Harwood's point that, if the industrial fundamental research base is not strengthened, there will be nothing for university work to couple to. Also, I think that the experience of industry associations over many decades has been neglected in all the flurry of rediscovering a good thing. The American Petroleum Institute has supported work at universities at a very substantial level for long periods. At Penn State, for example, API supported work on clays for 10 years and in lubrication for 20 years. There are a great many trade associations and, if their funds were matched by government, they could accomplish a lot that would be useful to their industries.

By far the largest provider of funds for university-industry work has been neglected today; it is the Department of Defense -- especially, for example, Defense Advanced Research Projects Agency (DARPA) and Office of Naval Research (ONR). DOD uses a "strong manager," coupling the best groups at universities and industries into effective teams.

At all the industry-university meetings held during the last year, I have been elaborating on the distinction between the roles of government as stimulator or catalyst and government as intermediary. In polls of the researchers on both sides, nearly everyone says that the government should not be involved in the middle of the university-industry interface. Everyone agrees that the Vanik bill or the Baruch Commission recommendation on matching funds would stimulate industry support most effectively. What we haven't heard about today is the obvious strategy of government action, mainly stimulating via matching grants. From the university viewpoint, that would be by far the most effective and the simplest means government could use to encourage industry support. If a company gave $40,000 for a specific piece of work to Prof. X in Dept. A, then NSF would match it with a grant to the professor and the department, not to the project specifically. Then NSF could get out of the double-proposal business, with multiple-level reviews and so on.

A related option I haven't heard much about is the possibility of requiring every federal agency to put a certain percentage of its targeted or applied research money into joint programs involving both academe and industry. The government money is our money, and I don't see why we -- the academic and industrial research leaders -- shouldn't guide them on the most effective way to use it. I think strong managers in government who know what they want would find the best teams if they had to. In any case, it would be less wasteful of scarce personnel than the "proposalitis" we have now. Incidentally, I recently calculated, using the Mitre figures published in Science, how much it costs us to get funded money -- the running to Washington, writing proposals, et cetera. To raise the $4 million for our laboratory last year, if we used the average Mitre figures, we would have used 110% of our personnel for the fund-raising! So I would like to see government not excluded, but included as a stimulator and catalyst, but not as an intermediary.

DR. FROSCH:

There is one difficulty with what you have proposed. One thing government managers are not allowed to do, or even to look as though they are doing, is to be arbitrary. That is a serious problem, because when government managers are faced with the question of who gets money, they must deal with all the interested corporations and universities so that it at least seems to be an absolutely equitable process, in which everybody has a chance. The proposal and peer-review systems are attempts to be even-handed.

Of course, it's not much more even-handed, simply because of the numbers involved. Nobody can handle 500 or 1,000 proposals in an equitable manner; you can't give them enough attention. It probably would be much better, probably even more equitable, to make a reasonable but partly arbitrary choice. But it would be politically impossible to do it and survive for more than a year.

PROF. ROY:

Is the matching grant any less equitable? It is guaranteed to be more equitable than peer review. Moreover, in the area of university-industry work -- which is, after all, a tiny portion of the whole -- it is more effective.

DR. FROSCH:

It would be more equitable if there were enough money that you could match all proposals at a significant level of funding. When there is a limitation on the pot, you have to choose only a few proposals to match; otherwise, the amount of money would be too small to be really useful. And then you are back to the problem of who gets what, why.

DR. BRIAN:

The tax credit is really a matching gift, even if some people in Congress think it's a tax.

DR. FROSCH:

Yes. Unfortunately, one of the virtues of a tax credit -- its flexibility -- is also one of its difficulties. It's like an uncontrollable in the budget; the amount given depends on the amount put up to be matched. That's exactly what makes it hard to get through both the Treasury and the Congress.

MR. BELL:

I think Mr. Culler made the final argument for this problem's being too large to have a single solution. I regard the electric utilities as essentially non-competitive, government-regulated geographic monopolies. Electric Power Research Institute funding is essentially government funding, only through your electric bill instead of your tax bill. I don't think the same conclusions apply to, say, two companies that compete to develop fibers (e.g., nylon).

I would like to comment on the tax bill. I was initially very strongly for tax relief, but I am beginning to be concerned with the side effects. Industries run on constant-percentage R&D budgets, and we don't know any better way of managing. So a tax credit will probably reduce internal spending for research. It will put more money in the universities, but decrease the number of industry people available to work with the university programs. For example, it seems to me that the research going on at U.S. universities moves into the Japanese computer industry more easily than it does into the American computer industry. A reduction in research within a company is not going to help us be more productive and more competitive.

As far as science goes, I think we may be winning enough Nobel Prizes now. But when it comes to engineering, the people who are absolutely at the bottom of the industry pecking order in most companies are manufacturing engineers. Depending on where the company is in the business cycle, manufacturing is run to suit lawyers, or accountants, or marketing people, or occasionally engineers in high-technology areas. Only as a last resort do manufacturing engineers worry much about actually trying to build something in a competitive way.

I think a lot of what we have been talking about doesn't address this fundamental problem. The United States is not competitive, because we are not giving enough attention to manufacturing. People say our science isn't good enough or our engineering isn't good enough; actually they are both just fine. There are plenty of new ideas; there is more patentable stuff around than we can get through the Patent Office. We just aren't working on the right problems. And if we don't do better in where we put our money, we'll be in even worse shape to compete in a couple of years.

And one last comment on industry involvement in graduate education. As a university professor, I love universities too much to have them a part of my industrial bureaucracy. They have got to be independent.

DR. BRIAN:

To return to Floyd Culler's comments, I would just like to reiterate that I am not convinced that the research results themselves are our pressing need, at least from our industry's point of view. I firmly believe that the reason industry must fund academic research is to revitalize the educational process. The research results are valuable, but they are secondary. What we must have are faculties and graduate students and undergraduate students, in increasing quantity and quality, to nourish our industry.

DR. FROSCH:

I'd like to add a note of political caution, for those of you not familiar with all aspects of the government business. Of the people on this panel, Henry, Albert, and Toni can support education. I am not allowed to support education: I must buy research. It is important to keep that in mind. Some portions of the government cannot engage in this game, no matter how desirable and proper its end. They must provide their assistance through programs aimed, negotiated, and operated in a different way. Of course, this changes whenever Congress has a new idea about who ought to do what.

MORRIS A. STEINBERG (Lockheed Corporation):

I've heard only peripheral comments today about minority engineering education. But I think one research program NASA has, which we have just begun to participate in, is worthy of note in this connection. The idea first came from the Rockwell Center, which decided to support research at Howard University, and got Cornell to help. It was a magnificent program, and NASA picked up the rest of it.

A couple of years ago, your office showed us a letter that Jimmy Carter wrote to all the mission agencies, saying that one thing he wanted to do before he left office was to upgrade the quality of education at black colleges. Those of us working with your office found that there were only six black engineering colleges in the United States that really needed help.

We just signed our second contract on this program, at Atlanta University. We are contributing people and equipment, which are even more important than money. But, as you said, the program had to be research-oriented, and we had a terrible time trying to figure out a research program that would be both educational and acceptable to NASA. But I don't know of any other agency that has this kind of program. I think it is already supporting three of the black engineering schools.

DR. FROSCH:

There is also NSF participation in this; it's a three-way operation. I think NSF is both buying research and supporting education. We are only buying research, so the proposal must be for something we need. This does have some virtues, incidentally, because it means you cannot evade the responsibility for seeking excellence. Industry has been supplying guidance and participation in addition to equipment. The universities have been educating students and giving faculty research opportunities. We feel the program has worked very well so far. Real research is being done, and new educational opportunities are now available in those schools. Although the program was structured around improved minority educational opportunities and research capabilities, it may turn out to be generally applicable.

GENERAL DISCUSSION

With Panel Chairmen and Keynote Speaker

MERRIL EISENBUD (NYU Medical Center):

I would like to bring up an area of research involving industry, government, and academe that I don't believe has been covered yet. That's the enormous expenditures in the development area being made to meet environmental standards that are based on some pretty sketchy research.

About 10 years ago, Nelson Rockefeller asked a few of us in New York to see how we could accumulate enough information regarding management of the Hudson River Basin for optimum economic and demographic development, while preserving the ecology of the river. The conclusion that we came to seemed strange then, but I think time has proven us right. We concluded that the cost of the research required to make decisions regarding the siting of power plants, the location of intakes for water supplies, cooling towers, the way the water should be treated, the design of sewage treatment plants, the design of highways, and anything else in the Basin that would affect the quality of the Hudson River would be utterly beyond the reach of any existing institution.

Actually, we underestimated the amount of money required. We thought it would cost $20 million a year to understand how to manage the Hudson River. I suspect modern estimates might be a factor of 5 higher.

We concluded that any adverse impacts on the Hudson River over the next half-century or century would be the result of economic development, and that somehow this economic development should be taxed to provide a pool of money for environmental research.

At the time, the development the public was concerned about was power plants and whether or not there was a thermal pollution problem. The utilities seized on the idea of a development tax, and in New York state, so many cents per thousand kilowatt-hours went to an industry pool for research on the river. (Later, of course, the Electric Power Research Institute was developed.) However, the industries behind the other large capital expenditures -- highways and sewage treatment plants and water supply systems -- being proposed for the Basin by either the state or federal government were not interested in this type of plan.

Anyway, we are spending billions of dollars a year trying to meet design criteria and pollution standards that are based on very scanty research. We might as well recognize that environmental impact analysis is going to be with us for a long time, and a small tax -- at the time, we thought perhaps .01% of the costs of new economic development -- for doing the research would provide a pool of money for doing the research properly. Granted, it might be difficult to administer, but I think it would give us the means to obtain the information we need to approach the problem of environmental protection in a rational way.

MR. CAPLAN:

I just wanted to mention that the cooperative automotive research program is not yet a fait accompli. One of its problems is that some of its supporters, like the Department of Transportation, did not want any of the money to go toward environmental or biological basic research, necessary underpinnings to design programs. So some of us remain a little puzzled.

DONALD G. FINK (Director Emeritus of the Institute of Electrical and Electronics Engineers):

It is always interesting, toward the end of a meeting, to consider where we would be if the fondest hopes we have discussed today were fulfilled.

I think we should remember that, if we get more industry money, perfect our engineering teaching, and increase our industry-related on-campus research, but 80% of our engineering graduate students are not American, we are educating our competition. I see no problem in educating non-Americans as such, but until we learn how to compete in the international market -- certainly an area that needs some new ideas -- the problem is going to get worse.

DR. GRAY:

Fortunately, I don't think that 80% is an average. I think that across the country foreign graduate enrollment is a good deal lower; it runs about 30% at MIT. At the undergraduate level, I think that foreign enrollments in American engineering schools are considerably less than 10%.

We are concerned, though, because it is getting harder and harder to fill entry-level positions in engineering faculties with American citizens. In spite of the difficulty of getting work permits for foreign nationals, we are appointing an increasing number of assistant professors who are not U.S. citizens, simply because not enough Americans willing to begin academic careers are coming out of graduate programs. Will this practice have, in the long run, a destabilizing effect on engineering faculties?

DR. PERKINS:

I think Princeton also has about 30% foreigners. But I was quite startled today to discover just how many graduate students are being educated in industry. No wonder the universities seem to be all foreign students. I would be very much interested to know how many individual courses are being taken in the industrial graduate-education complex. If you count those, of course, the proportion of foreign students drops considerably.

PROF. BOGDONOFF:

The problem of inadequate high school preparation was mentioned earlier. But I also think that we don't get students involved in engineering early enough. Even when the math and physics and chemistry teachers were good, the students never saw an engineer and had no idea what engineering could do for them. And this problem will only get worse as the number of 18-year-olds declines.

I feel strongly that "newspaper language" statements of industrial and governmental policies and attitudes are very important drivers for these young people. They affect the students' parents and teachers, who advise them about what they ought to do. Remember all those studies, about 7 years ago, that said that the U.S. really didn't need many more engineers, and academic slots were full, and there was no point in getting a doctoral degree because there weren't going to be any jobs? We are still feeling the effects of that set of statements.

So one thing I think is crucial to the future of engineering is some sort of commitment by industry, government, and academe to make sure that this country knows that its future depends on getting more of our best people involved in engineering and technology.

Industry does a great job in educating engineers, once they get to industry. When people don't even get to the university, though, they aren't going to get to industry. Industry would like to have master's candidates. But we first have to get bachelor's recipients. We are seeing a continual decline in both the quality and the number of people coming out of high schools -- and they are the feedstock for engineering. No matter what wonderful things industry, government, and academe do for engineering education, we are not going to be any better off 10 years from now unless we have students to work with.

DR. LOW:

I think your concern focuses on one of the most important issues that has come out of today's discussions. I started out this morning by saying that I felt that the pull of the market would take care of the supply of bachelor's level engineers over the next 10 years. Paul Gray disagreed with me, and I believe he may well be right. He pointed out that I had not considered the sudden, major changes in the marketplace caused by problems such as the energy crunch or the information explosion.

I have here an advance copy of the study "Science and Engineering Education for the 1980's and Beyond," prepared by NSF and the Department of Education. The results of this study do not clearly indicate whether there will or will not be a shortage of engineers 10 years from now. I think this is an area in which the National Academy of Engineering could do an enormous service by coming up with some definitive answers. I think it can be done. And that information is going to be very important if the various constituencies represented here and the media are to publicize our country's need for engineers.

DR. FROSCH:

I don't think the question is simply one of analyzing how many people we need, or even one of education. I think engineering suffers from an image problem. I am the head of a fairly large engineering organization, but I have found that it is the general impression that everything NASA does is science. We have not found a way to make it clear to or through the media that most of the professional people in NASA are engineers. Even that work which is aimed at pure science is based on a substructure of major engineering.

In addition, technology has been bad-mouthed for 10 or 15 years, largely by people who know nothing about it. I rather think this tendency comes from a one-sided education; engineers may be shortchanged on liberal arts, especially English and communication, but many liberal arts people have almost no idea what science and engineering are about.

So I think we have to attack the image problem, even at the risk of being accused of self-interest. Perhaps the current reindustrialization fuss will show the importance of the role engineers play in our society, and improve our image.

MR. CAPLAN:

I think we have to be more pragmatic than that. I still have a lot of confidence in the ability of young people in high school and college to look at the marketplace, the demand, the rewards system, and the values of our society, and then make judgments as to what they want to do about careers. Image is a minor factor compared to the realities of the marketplace. If you want engineers, you pay for engineers. If you want Ph.D. engineers, you keep the salary ratio of Ph.D.'s to bachelor's at the levels they used to be, not what they are today. Unless we change the marketplace, I don't think the rest is going to make much difference.

ROBERT M. FANO (MIT):

It was quite clear from this morning's discussion that industry puts a lot of money into engineering education for their own employees. It made me wonder how much money goes into the whole engineering education system -- in industry, academe, and anywhere else. Where does that money come from? And who benefits from the education that results? I think we all could use a clearer picture of that.

Somebody has to pay for good engineering education. The last issue of the <u>Journal of the American Association of University Professors</u> contained an article on faculty salaries. Granted, the pay in different fields for the same position may vary by a factor of 2. But one statistician had projected that, by the year 2000, the salaries of the average assistant and associate professor would be below the level of poverty. Now, at that point, 5% more support is not enough incentive to keep someone teaching -- especially if competing as a researcher with fulltime industry people. We're going to need more like a factor of 2 increase in the support of engineering education in universities to do a good job in the long run.

DR. PERKINS:

I think the Academy might indeed try to find out where the students are. There is certainly a lot more graduate education in this country than what goes on in the universities, and I think it is important that we try to measure it.

Now, the point you raised about faculty salaries is certainly true -- though the good engineering professors, at least, can become consultants and nearly double their salaries. The problem with raising engineering teachers' salaries is that you then have to raise the salaries of all the faculty in the university.

MR. CAPLAN:

I'd just like to point out that this morning's panel represented five very large companies. I think most of the graduate education of engineers in medium-size and small companies is carried out in universities, not by industry.

DR. BRIAN:

Companies somehow cope with the fact that they have to meet the outside market when they hire a person in a given discipline. If there is going to be a shortage of engineers, I just don't see how engineering schools are going to keep their faculty unless the universities are willing to pay them more than, say, the classics faculties.

DR. GRAY:

I agree with Thibaut on this question. Bob Fano's comments on academic salaries are all too true, and I think the problem will only get worse as student numbers decline over the next two decades. As the system shakes out, salaries in higher education will generally lag behind salaries in the economy, just as in the 1950's and 1960's, when higher education was expanding, academic salaries led salaries in society generally. I think that is inevitable.

So unless we are going tolerate a decline in the quality of the institutions of engineering education, we are going to have to deal with salaries in engineering schools separately from those in other disciplines. Universities have long faced this problem with respect to medical schools and law schools. It's going to cause a great deal of heartburn, but I think they'll have to face it with respect to engineering schools.

DR. PERKINS:

One way in which some universities cope with the problem is to offer much earlier promotion in the engineering schools than in, say, the Department of English.

BETSY ANCKER-JOHNSON (General Motors Corporation):

At the end of this long day of fruitful discussion, I can't resist offering some comments from the viewpoint of someone who came from the private sector, spent 4 years in government, and then went back to industry.

All of us overachievers are just as anxious to dream up programs while we're in government as we are when we're in the private sector. Everything I heard today related to government programs has been suggested before, some of it even by my office. But I am very grateful that inertia prevented some of those suggestions from coming to pass, because I discovered when I got back into the private sector that a lot of the things that the government would like to do for you don't make any sense at all. For instance, generic technology centers were something we talked about for months while I was in the government. I have never seen anything that had so much cold water poured on it by those for whose benefit it was supposed to be. I think the same could probably be said for the cooperative automotive research program.

I would like to bring up another issue on a more positive note. As I have been deeply concerned about environmental matters recently, I haven't been able to avoid making an unpleasant comparison. The government funding toward achieving a goal with which both industry and university are involved has been far more successful in those areas where the government is also the user. The research and development related to what comes out of DOD or out of NASA is almost certainly going to be more successful, because whatever comes of it is going to be used.

The same is not true at all in the area of environmental research. As a result, unfortunately, I think we are seeing a very unrealistic attitude toward the research, resulting in a very thin base for our environmental regulations. I think the area offers the opportunity for some very fruitful collaboration between industry, government, and academe. The fundamental issues of environmental research are an engineering area that is just crying for more work, and I think the universities in particular could make a large contribution to them. I hope that our NAE will see environmental research as an engineering problem, which indeed it is, and give it a greater emphasis.

LIST OF PARTICIPANTS

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