Guidelines for Engineering Research Centers (1983)

Pages
33

Size
8.5 x 11

ISBN
030932632X

Panel on Engineering Research Centers; National Academy of Engineering

Guidelines for Engineering Research Centers

A REPORT FOR THE NATIONAL SCIENCE FOUNDATION BY THE NATIONAL ACADEMY OF ENGINEERING

National Academy of Engineering
Washington, D.C. 1983

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This report has been reviewed by members of the National Academy of Engineering other than the authors. The members of the committee responsible for the report are drawn predominantly from the National Academy of Engineering and were chosen for their special competences and with regard for appropriate balance. The work on which this publication is based was performed pursuant to Contract No. ENG-8405964 with the National Science Foundation.

Available from

National Academy of Engineering
2101 Constitution Avenue, NW
Washington, DC 20418

Printed in the United States of America

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

Office of the President

February 15, 1984

Dr. Edward A. Knapp
Director
National Science Foundation
1800 G Street, N.W.
Washington, D.C. 20550

Dear Dr. Knapp:

I am pleased to transmit to you the report on Engineering Research Centers by a panel of the National Academy of Engineering. This report responds to your request last December for the Academy's advice on the organization, mode of operation, funding, and other elements of such Centers. That the report was done so quickly is a tribute to the vigorous work of the members of the panel and to the very able leadership of the panel's chairman, W. Dale Compton. The report is brief and speaks for itself, but I would like to underline some of its findings and recommendations.

The panel agreed that the concept of Engineering Research Centers is an ambitious and innovative initiative of the Foundation. Done well, the Centers program will enhance significantly the future competitiveness of American industry through strengthened programs of engineering research and education. The panel was equally concerned, however, with the adequacy of support for the disciplinary bases of engineering research and education. Without a complementary move to provide such support, cross-disciplinary research would be sapped at its roots. Therefore, I urge the Foundation to ensure that its budget for engineering include adequate funding both for the Centers and for disciplinary activities.

The report envisions the Centers as having two related purposes: (1) to conduct cross-disciplinary research that would lead to the greater effectiveness and world competitiveness of U.S. industrial companies, and (2) to improve the education of engineers at all levels, and thereby increase the number of students who can contribute innovatively to U.S. industry and its productivity. While the Centers should emphasize engineering research, their educational impact must be a major consideration in their planning, organization, and operation. Specifically, the Centers' activities should affect the educational experience of a significant number of the students attending their home institutions.

Since the major thrust of the Engineering Research Centers is to improve the effectiveness and world competitiveness of U.S. industry, the industrial role in the Centers' activities must be prominent. The need for the engineering communities in both academia and industry to collaborate more closely is critical and overdue, and these Centers can be viewed as a significant step toward encouraging and enhancing such collaboration.

The panel further recognizes the need not only to establish such Centers at engineering research universities in the United States but also to provide the means for other institutions to affiliate with the Centers, thus broadening their reach and enabling smaller schools to participate in the work and the educational opportunities available at the Centers.

The panel examined the size to which the program should ultimately aspire and concluded that a target of 25 Engineering Research Centers at the end of five years is reasonable. The panel proposes that the program be initiated with the establishment of five to ten Centers during the first year.

While it is difficult to estimate the cost of each Center, the panel suggests a range of from $2.5 to $5 million each, excluding stipends, tuition, and overhead for students. Additional funds for student stipends and tuition will be required. Such funds may come from many sources including this program.

The panel set its recommendations in the context of some basic observations. Patience will be required in developing these Centers. It will take time for the Centers' results to manifest themselves. Expectations need to be realistic. Also, the panel believes that the problems of engineering education are so numerous that this program, while an important step, addresses only one part of the problem.

Sincerely,

Robert M. White
President

CONTENTS

PREFACE

In December 1983, the National Academy of Engineering was asked by the National Science Foundation to provide advice on developing Engineering Research Centers, which the Foundation described as "on-campus centers that would house cross-disciplinary experimental research activities." In addition to the conduct of such research, the principal purposes of the Centers are: (1) to provide a means for bringing together university and industrial people to improve the education of those who will undertake the practice of engineering, and (2) to expose a significant number of engineering students to the nature and problems of cross-disciplinary research on engineering systems.

The Academy was asked to suggest possible structures for such Centers, their level and nature of funding, their number and duration, the criteria for selecting Centers, and their modes of interaction with industry. (Appendix A excerpts the Foundation's request.)

In responding, a panel was assembled, its combined experience touching on essentially all of the issues related to industrial technology and engineering education. The panel met twice: on January 4 and 5, and on January 18, 1984. It heard elaborations of the rationale, purposes, and planning for fiscal year 1985 for the Engineering Research Centers from George A. Keyworth II, Director of the Office of Science and Technology Policy, and Richard S. Nicholson, Acting Deputy Director of the National Science Foundation. In addition, members of the panel described in detail several possible models for the Engineering Research Centers. Other perspectives were provided by the President of the National Academy of Engineering. The National Science Foundation provided support for the study.

Although the results of the panel's work are given in this report, several themes that recurred during the three days of intensive discussions should be emphasized: (1) the relationships with industry must be real and must be perceived by both sides, the faculty and students of the Centers and the engineers and management of the participating companies, as mutually beneficial and as dealing with problems which are industrially important and intellectually demanding; (2) the Centers are experimental, will take time to grow, and will inevitably require altering protocols and programs; (3) to have an impact, the program must be a significant one, meaning that it is better to have fewer Centers with sufficient funding rather than many with inadequate funding; and (4) the Centers must complement and not supplant, either in size or numbers, the Foundation's grants to individual investigators.

It also should be understood that funding for the Centers' programs will supplement, and must not be considered a replacement for, interactions that research universities have with state governments, national laboratories, professional societies, and other groups. Since this is a long-term program with results that will not be immediately demonstrable, all of the participants, including the government, must be patient and firm in maintaining sufficient funding for several years. If the Foundation embraces the concept with enthusiasm and supports it with zeal, the program could contribute well beyond expectations.

These themes are elaborated in the report. That this report was prepared in a very short time is due to the extraordinary response of the panel members. With already overcrowded calendars, they were willing to come to meetings on short notice and to participate actively in the development of the ideas contained in the report. We are all in their debt, as we are also to the panel's staff, in particular, Jesse H. Ausubel and Norman Metzger.

W. Dale Compton
Panel Chairman

I. INTRODUCTION

Two purposes underlie the Engineering Research Centers (ERC's). One is to enhance the capacities of engineering research universities to conduct cross-disciplinary research on problems of industrial importance. The other is to lessen one of several weaknesses in engineering education: an inadequate understanding by students of engineering practice; that is, the understanding of how engineering knowledge is converted by industry into societal goods and services.

These problems of engineering research and education have been articulated in several recent reports. For example, the National Science Foundation (NSF) has noted that:

- The rapid advances in technology are driving engineering toward cross-disciplinary interactions. Specialists are still needed, and continued development of high quality engineering subdisciplines is essential. But, in addition, there is a growing need for engineering education that cuts across the engineering subdisciplines and applied sciences.
- The technological advances are also leading toward integration among design, engineering, manufacturing, and marketing. There is a need for engineers with a broad understanding of the overall manufacturing system and of the interrelations among its components. (See Appendix B: National Science Foundation, The Quality of Engineering Education and Research.)

Further, the National Academy of Engineering, in its report entitled Strengthening Engineering in the National Science Foundation,[1] pointed out that: "cross-disciplinary activities in engineering...represent major areas of concern for government and industry. Examples abound, among them areas such as manufacturing systems; the systems aspects of megaconstruction projects, such as nuclear and hydroelectric power plants, and pipelines, and materials design and processing." The issue also was put in relief by a recent report of the Research Briefing Panel on Computers in Design and Manufacturing,[2] prepared for the Office of Science and Technology Policy and the NSF. That report noted, among other things, that progress in this field will depend on educating a new breed of engineers who thoroughly understand all aspects of computer-integrated manufacturing engineering in its broadest sense. This involves developing new engineering courses, programs, resources, attitudes, and other desiderata. In universities, research tends to be small scale in nature, where specific, well-formulated problems are studied in a formal manner. For a variety of reasons, including inadequate funding, universities have found it difficult to train people to grapple with the larger problems of integration.

Several other concerns have been noted which devolve from this particular weakness in engineering education: an overemphasis on analytical research, with less opportunity for "hands-on" experimental research; inadequate exposure of engineering students to engineering practice; a widening gap between academic engineering programs and industrial practice, and a lack of interaction between faculty and industrial practitioners of systems engineering.

As a partial response to these problems, the National Science Foundation has proposed the establishment of university-based Engineering Research Centers.

While the panel supports strongly the establishment of the proposed Centers, it wishes to emphasize two points. First, if the Centers are to represent a bold and ambitious response to these needs, significant industrial involvement in them is essential. Second, not only must they be thoughtfully designed and staffed with first-class faculty and students but they also must be of sufficient scale to make a noticeable impact on the overall content of engineering education. Accordingly, it is concluded that a target of 25 Centers should be established for the overall program and that the commitment and funding level for each Center must be adequate to affect directly at least 10 percent of all of the graduate engineering students in the Centers' home institutions.

This report gives the panel's views on the fundamental mission of such Centers, the level and duration of their funding, and the criteria for judging the initial proposals and the success of the working programs.

II. MISSION

The goal of the Centers is to improve engineering research so that U.S. engineers will be better prepared to contribute to engineering practice and to assist U.S. industry in becoming more competitive in world markets. Thus, engineering research and education must be firmly linked in these Centers, and they must be judged by their success in achieving this linkage. While the Centers will differ from one another, reflecting their home institutions, people, and programs, their mission must have some common traits. First, specific working ties with industry must provide a continual interaction of academic researchers, students, and faculty with their peers, namely, the engineers and scientists in industry, to assure that these programs remain relevant to the needs of the engineering practitioner and that they facilitate and promote the flow of knowledge between the academic and industrial sectors. Second, the programs of each Center must emphasize the synthesis of engineering knowledge; that is, the programs should seek to integrate different disciplines in order to bring together the requisite knowledge, methodologies, and tools to solve problems important to engineering practitioners. Third, the programs must contribute to the increased effectiveness of all levels of engineering education.

Against these common traits, the panel sees the mission of the ERC's as conducting cross-disciplinary research which will:

- o lead to greater effectiveness and world competitiveness of U.S.industrial companies. The Centers should be concerned with both technologically strong and weak U.S. industries;
- o contribute to the education of engineers at all levels, with particular emphasis on engineering practice; and
- o increase the number of graduating engineering students who can contribute innovatively to U.S. industry and its productivity. Achieving this mission will require a substantial intellectual interaction among participants in universities and industry to:
- o define significant problems for the engineering community in a rapidly changing world;
- o improve or establish core competency in fields of engineering research directed toward these significant problems;
- o participate jointly in engineering research directed toward a solution of these problems;
- o increase the proportion of engineering faculty committed to cross-disciplinary programs;
- o search for and develop new methods for the timely and successful transfer of newly developed knowledge to industrial users; and
- o generalize and codify the newly generated knowledge.

III. SCOPE

There are possible models for the proposed Centers, and the panel heard detailed presentations on several, including: the Materials Research Laboratories, the Joint Services Electronics Program, the Massachusetts Institute of Technology Laboratory for Manufacturing and Productivity, the Stanford Center for Integrated Systems, and the Cornell Center for Submicron Structures. While there are highly desirable features in each of these programs and in various emerging industry-university partnerships including the NSF university-industry cooperative program, the panel concluded that none was wholly suitable as a model for the Engineering Research Centers. The Centers are unique.

IMPACT ON ENGINEERING RESEARCH

The panel concluded that the primary emphasis at the Centers must be on engineering research, especially group or team research, aimed at improving engineering practice. In this context, "engineering research" is regarded as the process of augmenting the body of knowledge generic to producing societal goods and services. Defining the knowledge required and creating it are joint responsibilities of academia and industry. Thus, industry must assist the faculties of the Centers in identifying those needs which it cannot meet effectively because it lacks the fundamental engineering knowledge. Academia's responsibilities are to help provide not only the missing knowledge but also to understand intimately the mechanisms for--including economic and other constraints on--the conversion by industry of that knowledge into societal utility.

Indeed, industrial participation will depend in large part on the Centers' potential for producing usable knowledge and for enhancing the careers of industrial engineers who are already sophisticated practitioners. However, research at the Centers should be attractive to capable students and responsive to their interests, and not be driven only by faculty or industry interests.

The cluster of disciplines around which the ERC's will be built will vary. In most cases, good representation from the traditional engineering disciplines, supplemented by expertise as needed in computer science, management science, economics, and so forth, should be provided. The character of each Center should be defined by the participating faculties. These faculties are not envisioned as separate from the rest of the university but, rather, as sharing a disciplinary and departmental base. However, the Centers must have full-time leadership.

While the activities of a Center will vary, they should include:

- o a small number of research projects focusing on common areas or problems, with significant collaboration by faculties of different disciplines and by industrial partners. Examples of such problems might include the design, manufacture, or operation of systems for data and communications, computer-integrated manufacturing, computer graphic design, biotechnology processing, materials processing, and transportation.
- o team projects or other mechanisms designed to stimulate an understanding of the roles of human factors, organizational structure, logistics, management, marketing and vendor characteristics, finance, technology, and computer-based integration in engineering practice; and
- o seminars in which students and faculty from various academic disciplines and departments, together with professionals, examine how decisions in one part of a system can influence the performance, schedule, quality, and economics of the whole system.

While the ERC's should be encouraged to emphasize the systems aspects of engineering and to help train people in synthesizing, integrating, and managing engineering systems, they should be careful to avoid focusing too rigidly on any particular engineering problem. They must retain flexibility in their program orientation if they are to remain current in their approaches to engineering practice.

IMPACT ON ENGINEERING EDUCATION

As noted above, each Center must assume a broad role in engineering education. In this context, "education" is regarded as meaning engineering education at all levels--from undergraduate to post-doctoral to all aspects of continuing education. It also means explicit efforts to extend the educational impact of the work done within the Centers through codification of the new knowledge to introduce it into the classroom and possibly through affiliations with other centers of engineering education, notably smaller universities and colleges without their own research programs. Because these efforts are believed critical to extending the impact of the Centers, they are discussed separately below.

Undergraduate Education

There are many ways of involving undergraduates in the ERC's: through seminars, lecture series, and other modes. Opportunities for "hands-on" experience through participation in research projects is especially valuable and should be strongly encouraged. Further, as noted earlier, many, if not all, of the problems that will concern the Centers may not, by virtue of their newness, be found in textbooks and similar materials. Therefore, to satisfy the educational purposes of the Centers, their faculties must be continuously engaged in codifying the knowledge and methodologies which emerge from their work. Codification is important for continuing as well as for undergraduate education. Thus, the Centers can be especially effective in amplifying their impact on undergraduate engineering students by developing educational materials such as textbooks and laboratory experiments.

Academic Affiliates

An engineering school that is unable to develop and house its own ERC could participate in the ERC at another institution by becoming an "academic affiliate." Thus, the affiliates program could increase substantially the regional impact of a Center.

Affiliated schools could participate in a number of ways. They might share faculty members or send them on sabbatical leave to work at a Center; they might establish computer and video links, or have student exchanges or cooperative projects. While some schools might make proposals when ERC's are first established, it is anticipated that academic affiliates will become a larger factor in later years of the program.

Affiliates are a desirable, although certainly not an essential, feature for an ERC. More than two or three affiliate schools per Center would probably be awkward, and funding for each affiliate probably should not exceed about 10 percent of a Center's overall budget. It would be desirable for funding to flow directly to an affiliate school, with the Center's real costs being reimbursed by the affiliate. Where affiliations are formed, a Center and its affiliates should be reviewed as a package, with the expectation that the combined entity would be strengthened by the association.

IV. SIZE, FUNDING, STRUCTURE, AND RESULTS

Discussion of overall character, activities, and possible accomplishments of the ERC's now turns to more pragmatic considerations.

a. What broad impacts should be expected of each Center?

These should include several or all of the following:

- enhanced institutional innovation and creativity--between university and industry, as well as between educational institutions and nonprofit organizations, governmental entities and professional societies;
- an environment that fosters the development of new cross-disciplinary research initiatives;
- experience in the synthesis of knowledge to augment the classroom teaching of analysis and design; and
- central experimental facilities, developed, operated, and maintained to facilitate ERC research projects, but also available to other researchers on the campus.

b. What specific impacts should be expected of each Center?

These should include several or all of the following:

- demonstrable results of joint university-industry research programs;
- new educational materials resulting from the codification of new knowledge generated by the research programs;
- a regional impact on engineering education; and
- identifiable efforts to promote the transfer of knowledge to engineering practitioners.

c. Who selects ERC projects?

The Foundation is responsible for approving and improving the overall direction and broad objectives of all of the ERC's and their programs and for monitoring and reviewing progress. Each ERC should be allowed to select the particular projects to be undertaken. The flexibility that this procedure allows should be exercised by a committee of university and industry representatives that is sensitive to both university and industry needs and the capabilities for productive cross-disciplinary research.

d. How large should each ERC be?

An Engineering Research Center should be of sufficient size to involve at least 10 percent of its home institution's graduate engineering students at both master's and doctoral levels. Further, the Center's program should have a substantial impact on undergraduate engineering students and on continuing education.

The faculty required to attend to the needs of 10 percent of the graduate engineering students will depend on the size of the institution. A minimum faculty commitment of three full-time equivalent (FTE) positions is believed essential to operating a Center with a significant program. It is anticipated that faculty staffing will be supplemented by engineers provided by industry.

e. How long should an ERC be supported?

A five-year initial commitment is suggested, with a detailed site review after the third year. Following a favorable review, a three-year extension on the initial five-year commitment would be awarded, with a recurring cycle thereafter of three-year reviews. Flexibility in planning and funding the Centers is vital, given the uncertainty associated with any five-year plan.

f. What will each Center cost?

Stating precise amounts is impossible, given that both the operating costs and the number of FTE faculty will vary with each Center and its program. However, an estimate of between $2.5 and $5.0 million per Center can be developed based upon faculty salaries, other operating costs, and an annual equipment and supply expenditure of $1 to $2 million. If student stipends and partial tuition are to be provided by the ERC program, costs will be accordingly higher. Estimating a yearly cost of $25,000 per doctoral or master's student, including overhead, and assuming that all students are supported, such costs would add $1.7 to $2.7 million per Center per year. However, it is expected that many students will obtain full or partial support from other sources. While the initial funding for staff and operations is likely to be somewhat less than this average, some Centers may experience large preliminary costs.

The need for a visible, distinct locus for an ERC may be crucial for establishing the fresh kind of identity described above, and space may be a key limitation on some campuses. Funding arrangements should allow accelerated recovery of the costs associated with space.

g. How many ERC's should be maintained?

A small number of well-funded Centers, outstanding in quality and located in institutions that can directly affect graduate engineering education, is recommended. While the NSF may wish to consider developing the program in steps, with the establishment of about 5 to 10 Centers during the first year, the panel believes that a prestigious, competitive, and high-quality program could be maintained with as many as 25 ERC's. That latter figure is the panel's best judgment of the number of schools that can provide the disciplinary breadth and can absorb the level of funding envisaged without distortion of their overall research programs. A total of 25 Centers could affect a large number of graduate engineering students. Further, affiliation by other schools with the Centers could increase this number substantially.

h. What will the overall program cost?

Based upon the above projections for a program influencing about a tenth of the graduate students in the participating engineering schools, the ERC program target should be about $100 million per year in core NSF funding, with additional funds required for student stipends, tuition, and related overhead. While substantial subventions from other federal and nonfederal sources are anticipated, it is unlikely that the Centers can become self-sustaining on non-NSF funds alone. The panel believes that the viability of the Centers will depend on a long-term commitment of support by the NSF.

Uncertainties about the costs of equipment, where needs change rapidly, may be especially great. It may be prudent to create a fund, which would be available competitively to all of the Centers, for unanticipated requirements for additional equipment, facilities, and instrumentation. Such a fund would enhance further the flexibility of the ERC's, an essential feature of the program.

i. What should be industry's role?

Industry must be a substantial and continuous contributor to the program. Whether that is translated into direct funding, sharing of equipment and other facilities, provision of personnel, or detailed interchanges at an intellectual level through teaching and research will depend on the needs and goals of the particular ERC and on the capabilities and resources of the participating industries and institutions. Since the responsibility for an effective relationship lies with both the ERC's and industry, it is essential that each ERC and its industrial partner(s) develop intellectual involvements that will contribute to the exchange of ideas and the transfer of technology.

V. SPECIAL REQUIREMENTS FOR REVIEW AND EVALUATION

CRITERIA FOR REVIEW

The Centers' proposed mission leads to the following criteria for evaluating proposals. These are that:

a. each ERC must be associated with one or more industrial or other organizations involved in engineering research and practice.

b. the problems to be addressed by the ERC, in concert with industry or other organizations, should display certain characteristics, such as:

- o being part of a technical area that relates strongly to the global competitiveness of U.S. industry;
- o providing a mechanism for integrating the various disciplines essential to making substantial progress on the problem; and
- o addressing economic, social, and human constraints associated with a specified technical goal.

c. each ERC must present a credible proposal for assembling the internal (university) and external skills, facilities, and resources to pursue the Center's mission according to its proposed schedule. Such a proposal should include:

- o an assurance that the program will have or develop the highest quality people and research; and
- o a description of mechanisms for selecting projects, allocating funds, recruiting personnel, and periodic reporting.

d. identification of modes for integrating the Center's work into engineering education:

- o for both graduate and undergraduate students;
- o by the preparation of educational materials (textbooks, audiovisual and other curricular materials); and
- o by opportunities for continuing education for practicing engineers.

e. a clear statement is offered of why core support, rather than individual or multi-investigator project support, is required.

Proposals also should discuss, as appropriate, the potential for affiliating with other colleges and universities without major research programs but engaged in teaching engineering.

As each Center will mirror unique combinations of local interests and capabilities, the detailed form of the proposal must be fitted to the nature of the proposed Center. No formal requirements are deemed advisable other than those generally requested by the NSF. However, it is recommended that proposals contain the following:

- a description of what the most significant undertakings and accomplishments of the Center are likely to be;
- a general but inclusive description and a timetable of proposed engineering and technical thrusts for the first two to three years, with emphasis on the thematic and cross-disciplinary content of the program;
- an engineering research plan for the next three to five years, based on unique local interest and expertise, potential areas to be explored, views on important new directions in the engineering enterprise, and likely areas for significant progress;
- a description of the available facilities and programs expected to be closely allied to the ERC, indicating corresponding faculty and what their relationship to the Center may be;
- a description of proposed industrial links, strategies for arranging and maintaining them, and past experience in working with industry;
- a realistic description of future central facilities needs, distinguishing clearly between major needs for the first year and requirements anticipated for subsequent years;
- a clear description of the administrative structure of the ERC, both internally and in relation to the total university structure;
- a mechanism for transferring results to industry; and
- a nomination of a director for the proposed Center, and a description of his or her qualifications for that position.

REVIEW AND EVALUATION PROCEDURES

While traditional peer review works well for identifying quality in proposals by individual investigators, it is less apt for the type of cross-disciplinary, highly experimental program proposed here. Proposals for the ERC's and their programs will pose challenges for effective review and evaluation because of the broad scope and variety of work covered and the various institutions involved. It will be difficult to select the grantees and to review their subsequent progress. Furthermore, an assessment of the contribution and the impact of the overall program should be made.

Foreseeing these problems, it is proposed that review and evaluation be made by a single panel composed of individuals having:

- a broad knowledge of engineering practice and its constraints;
- a broad view of the needs and practices of engineering education; and
- proven competence in engineering research.

The panel should contain a substantial representation of individuals currently active in industry. The panel also might use substantive expert technical review by consultants whom they choose.

The panel should be responsible both for recommending initial awards and for reviewing the Centers and affiliated programs three years after they are established. This latter review should be an in-depth, comprehensive one.

VI. CONCLUDING OBSERVATIONS

After discussing the overall mission and structure of the Centers, their size, and procedures for their review and evaluation, the focus of the report turns to some general observations which the panel believes are pertinent to increasing the chances of successful operation of the Centers.

1. The fact that this is a new program, that it is pioneering, and that its goals are ambitious will demand more than the usual patience in awaiting and appraising results. For the program to work, the NSF must make a significant commitment not only in funds and in program duration, as indicated above, but it also must give this endeavor its wholehearted and enthusiastic support. Further, as with any new program, there may be a tendency to overpromise. The resultant damage can be considerable--to the program itself and to other initiatives. The Foundation--and the ERC leaders--are cautioned to be demanding, but realistic, in their expectations. The program's charge to integrate the work of different disciplines and to build working relationships with industry and other centers of engineering practice is a difficult one, and needs to be so recognized.

2. Support for the disciplinary bases of engineering research by federal, state, and private sectors must continue. One cannot look at engineering systems overall without a sound appreciation of their parts. The goal in engineering education and research must be a proper balance between specialization and breadth. Schools that are not strong in research on and teaching of components of systems are unlikely to be good at synthesis.

3. The problems of engineering education are numerous and severe, and this program is an important step toward solving some of them. While it is a commendable effort and sorely needed, the program will not eliminate such long-standing problems of engineering education as inadequate funding for facilities, equipment, and a variety of research areas--problems compounded by the difficulties of attracting American graduate students and retaining high-quality faculty.

The ERC program should be viewed as only one of several urgently needed initiatives to address the problems besetting engineering education and research. These include incentives for outstanding young engineers to enter university careers, substantial increases in the size of the NSF's grants to individual principal investigators (especially grants for experimental work), and support for instrumentation, facilities, and the development of improved curricular materials.

Therefore, the panel strongly supports the NSF's reported intention of complementing its initiative in establishing the Engineering Research Centers by expanding the size of its grants to individual investigators and by increasing the number of its grants to individuals.

4. Those administering the program must allow the Centers considerable latitude in attaining their goals. Flexibility is vital. The ERC structures within different universities should be expected to differ. Moreover, ERC's should be sufficiently protean to respond to new ideas, techniques, and relationships, inside and outside the university. The diversity of universities should be regarded as an asset in building a program that, taken in its entirety, will meet national needs.

A final observation concludes this report. The practice of engineering is a key to the industrial competitiveness of this nation. For too long, the engineering communities of academia and industry have coexisted with an "arm's-length" attitude. In recent years, this has been changing. Establishment of the Engineering Research Centers should be viewed as another important step in encouraging and enhancing the association between academia and the practitioners of engineering. When viewed in the context of the total annual expenditures for on-campus engineering education and research, the proposed target of $100 million for the ERC's represents only about 2 percent. If they can achieve their projected impact on 10 percent of the graduate engineering students at up to 25 institutions, as well as on undergraduates and on students at affiliated schools, the Centers will represent a highly worthwhile investment in the future.

REFERENCES

1. National Academy of Engineering. Strengthening Engineering in the National Science Foundation. Washington, D.C.: National Academy of Engineering, 1983, p. 5. See as well "Statement on the Engineering Mission of the NSF Over the Next Decade," as adopted by the National Science Board at its 246th meeting on August 18-19, 1983, NSB-83-250. Washington, D.C.:National Science Foundation.

2. Committee on Science, Engineering, and Public Policy (National Academy of Sciences, National Academy of Engineering, Institute of Medicine). Research Briefings 1983. Washington, D.C.: National Academy Press, 1983, p. 62.

APPENDIX A

Excerpts from a letter from the Director of the National Science Foundation, Edward A. Knapp, to the President of the National Academy of Engineering, Robert M. White.

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> The NSF is now developing...what might be called "engineering centers." The general idea is to develop on-campus centers that would house cross-disciplinary, experimental research activities. These activities would provide undergraduates with an opportunity for hands-on engineering experience, and graduate students and faculty with a focus for their research.
>
> The purpose of this letter is to request the help of NAE in developing these engineering centers. We are particularly interested in NAE's views on the following issues:
>
> - What is the appropriate organizational structure for the centers? Are the Materials Research Labs a good model? Are there other approaches that might serve as better models?
> - How should funding for the center be structured? Should NSF provide block grants to the centers, and leave the actual selection of projects to the centers themselves?
> - How large should the grants for each center be, how long should they last, and how many centers should be established each year and in total?
> - How should the basis for these centers be established at schools with little history of cross-disciplinary work? Would grants for multi-investigator, cross-disciplinary projects be a useful first step?

- Is it realistic to expect these centers to make a serious impact on undergraduate education? How large will they have to be in order to do so?
- How should relations with industry be factored into the program? Should special efforts be made to draw "smoke stack" firms and small manufacturers into affiliations with the centers?

We would greatly appreciate NAE's views on these and any other questions that would help us to structure these centers into truly effective mechanisms for engineering education and research.

APPENDIX B

A Working Paper prepared by
the Directorate for Engineering of
the National Science Foundation
December, 1983

THE QUALITY OF ENGINEERING EDUCATION AND RESEARCH

During the past several years, intense concern has been expressed over the state of our engineering education system. Much of the concern has focused on the sheer numbers--will we have enough high quality engineering faculty to train enough new engineers to satisfy industry's manpower needs? By now, a general consensus about how to approach the problem has emerged. Promising young Ph.D's must be lured into academia, and promising young BS's and MS's must be lured into doctoral programs. Fellowships, stipends and grants must be made available, salaries increased, facilities improved, incentives for teaching enhanced, and interactions with industry expanded. Industry, professional societies, colleges and universities, and state and Federal Government all have important roles to play. The problem is by no means solved, but the general solutions have been identified and many of the necessary mechanisms are now in place.

But a related problem still has not been adequately addressed. It is a problem not of numbers, but of substance. Is our engineering education system producing the kind of education and research needed by industry of the future? The growing use of computers in industry, coupled with the rapidly increasing power and distributed nature of computing, is fundamentally altering the processes of design, engineering, manufacturing and marketing, and with them, the manpower and research needs of industry.

Engineering Education: In a number of respects, these changes are placing new demands on our engineering education system:

- The rapid advances in technology are driving engineering toward cross-disciplinary interactions. Specialists are still needed, and continued development of high quality engineering subdisciplines is essential. But, in addition, there is a growing need for engineering education that cuts across the engineering subdisciplines and applied sciences.

- The technological advances are also leading toward integration among design, engineering, manufacturing, and marketing. There is a need for engineers with a broad understanding of the overall manufacturing system and of the interrelations among its components.
- Simultaneously, the advances in design and manufacturing technology are creating a growing gap between industrial technology and university facilities and capabilities. Engineering education must provide at least a working understanding of computer-aided design, manufacturing automation and control, and communication technologies. It must also provide an understanding of new materials and materials processing technologies.
- A closely related issue is the need for exposure to engineering practice. Engineering education must provide opportunities for "hands-on" experience with real (although scaled down) design and manufacturing problems.
- It must also provide exposure to industrial environments. The need here is for working interactions with industry engineers and problems, not just increased industry funding.
- Finally, engineering education must reflect the team nature of engineering as well as prepare young engineers for the problems of developing and managing a productive work force.

Engineering Research: The COSEPUP study, "Research Agenda for Increasing the Use of Computers in Design and Manufacturing," well summarizes the problem in engineering research:

> America's future growth in industrial productivity depends vitally on the health of the Nation's research in computers for design and manufacturing. In spite of the impressive apparent growth,...the central issue in this field is a pervasive lack of scientific knowledge.

The report identifies a serious need for research in five areas of generic importance to the use of computers in design and manufacturing--geometric and analytic modeling, human-computer interfaces, expert systems, information and data base management, and intelligent components and devices (such as robot sensors).

The underlying problem is that industrial applications have outstripped the fundamental knowledge generally developed at universities. The solution proposed by the COSEPUP study is the establishment of a genuine classical research community. In part, this can be established through government funding of basic research. But, along with government funds, the solution will require cross-disciplinary research, rather than research within the traditional engineering subdisciplines; extensive interactions with industry, since this is a case in which the applications in industry will drive the research at universities; and again, access to modern computing environments, and design and manufacturing technology.

A Proposed Solution: One solution is for NSF to support the development of on-campus "engineering centers" that would address the dual problem of the development of the underlying engineering sciences in new fields (such as the use of computers in design and manufacturing) and the education and training of young engineers to work on applications in these new fields. These "centers" might take a number of forms, and it would be up to each individual university to bid on how it could best contribute to the general problem.

One possibility might be to adopt the organizational approach used by the NSF's Materials Research Laboratories. Such Centers would be funded by long term "core" grants, which would be supplemented by more specific project grants. The core grants would provide in part for facilities, maintenance and associated infrastructure. The Centers would serve as the locus for cross-disciplinary projects in design, engineering and manufacturing. Undergraduates, graduate students and faculty would all participate. Undergraduates would gain training and hands-on experience in an actual engineering project. Faculty and graduate students would use the projects to pursue associated underlying research.

Adopting the organizational approach of the Materials Research Laboratories is only one of many possibilities. Different universities might respond in different ways. Some proposals might not involve project work at all. The actual form of these Centers would be constrained only by the following general criteria or "performance spec":

- Each Center would enlist industrial partners, who would participate in the selection, review, and perhaps performance of the work.
- The work would be directed at industrial problems, though at a much smaller scale.
- The work would be multidisciplinary.
- It would involve undergraduates, graduate students and faculty.
- It would address fundamentals as well as the practical.
- It would address all aspects of the management of engineering projects (the management of people, resources, inventory, quality control, manufacturing, etc.)
- An environment of teamwork would be created.

Of course, a good deal more will be required to meet the new demands on engineering research and education than just these Centers. Co-op programs, in which students spend their summers or a semester in industry, should be expanded; more emphasis should be placed on advanced education as part of the career pattern of engineers; the use of industry engineers as adjunct professors should be encouraged; university-industry programs for continuing education of engineers should be devised; NSF should seek more advice from industry on its engineering research priorities, and place greater emphasis in its grant programs on instrumentation, interactions with industry, and the training of undergraduates. But, along with these and other steps, the engineering centers--if properly devised--could play a major part in the effort to match engineering education and research to industry's needs.