Producing the Finest Scientists and Engineers for the 21st Century

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Science in the National Interest (1), the recent White House report on science policy, is receiving well-deserved praise for providing the vision needed to guide federal investments in basic science, mathematics, and engineering. The report in effect challenges the research and education enterprise to increase its contribution to improving the nation's health, economic prosperity, national security, environmental responsibility, and quality of life.

One of the central goals presented in the report is to "produce the finest scientists and engineers for the 21st Century." This goal reminds us that scientifically and technologically trained people are an invaluable national asset—a foundation of strength that enables the nation to pursue a great variety of opportunities. Professional scientists and engineers anchor the scientific and technological work force and are indispensable to promoting growth and innovation throughout our economy. As the report emphasizes, "Our principal resource for maintaining leadership in fundamental science and engineering and for capitalizing on its advances is our talent pool of well-educated scientists and engineers. . . . Because training scientists is a long process, we cannot quickly overcome shortfalls in trained personnel in some areas and should not react precipitously in allocating our training support" (2).

Therefore, to continue serving the nation in this way, the academic research and education enterprise faces one basic question: What is required to produce the finest scientists and engineers for the 21st century? The answer is far from obvious—for it depends entirely on the definition of the term "finest." On the one hand, many would say that we are already producing the finest scientists and engineers, provided "finest" is defined to mean superbly capable and highly specialized students prepared to carry on in the traditions of academic basic research. On the other hand, if one adopts a definition of "finest" that includes such attributes as versatility, a willingness to pursue a broad range of career options, an adequate reflection of the diversity of our society, and the ability to work in groups and integrate science and technology to meet the needs of industry and other sectors, then there is virtual consensus that the current system leaves room for improvement.

The challenge is to reconcile these two definitions of "finest"—preserving the qualities and capabilities instilled by the current system, while drawing upon all parts of society's talent base and readying students for the work force of the 21st century. This is a challenge that runs to the core of how best to secure a bright and sustainable future for the academic research and education enterprise—a future that preserves and enhances the tradition of excellence and achievement that has served the nation well for decades, and, at the same time, ensures continued strong public support for science and advanced education in the post–Cold War era.

Long-term success in this endeavor is not simply a matter of inventing a few new programs or selectively tinkering with the labor market. Rather, producing the finest scientists and engineers for the 21st century requires revisiting and reassessing many of the long-standing practices and traditions of research and graduate education in science and engineering.

Specifically, we recommend a policy framework that focuses on three key points: (i) Teaching and learning must be reinvigorated as the primary mission of academic institutions. (ii) Policies governing federal support for academic research must explicitly recognize the importance of such support to the education and training of scientists and engineers. (iii) Graduate education in science and engineering must better reflect the many profound changes in the economy generally and in the labor market for professional scientists and engineers specifically.

In this Policy Forum, we expand on these three points and outline ways that they can provide a cornerstone for future actions at the national level, within institutions, and by individual researchers and educators. The actions we recommend revolve around one basic principle: providing science and engineering graduate students, especially at the Ph.D. level, with a broad range of experiences that prepare them for rewarding careers both inside and outside of academe.

Furthermore, while these three points focus specifically on graduate education, they also apply to issues at the undergraduate and precollege level. Reaching the goal of producing the finest scientists and engineers for the 21st century requires improving education at all levels and cultivating the talents of all students in our society. We believe that the framework outlined here—by highlighting the natural connections between teaching and research—will improve linkages between graduate education and undergraduate teaching as well as position the academic enterprise to increase its contribution to mathematics and science education at the precollege level.

Academic Institutions: Refocusing on Teaching and Learning

The nation's colleges and universities are assuming (and being expected to assume) an ever-increasing set of roles and responsibilities. Even just a partial list of these new or expanded responsibilities would include serving as a think tank, a government and corporate research arm, a small business incubator, a technology-transfer mechanism, a promoter of economic development, and numerous other functions in addition to the core teaching responsibilities of the institution. These responsibilities reflect increased recognition for the contribution research universities can make to regional and national economic growth, as well as the value of linking research, education, and training to nonacademic settings.

What is most important, therefore, is that institutions pursue (and be allowed to pursue) these activities in ways that enhance learning experiences for students and further the teaching mission of higher education. This point was underscored by the Industrial Research Institute (IRI) in its 1993 Statement on Strengthening Industry-University Interactions: "The Institute endorses the premise that the top priority of universities should be to educate their students. Basic research in universities and interaction with the private sector can support and strengthen this educational priority" (3).

Academia's partners in these activities—notably government and industry—should adopt a holistic perspective of the academic enterprise that fosters the processes of teaching and learning. The IRI statement signals such a commitment on the part of industry. *Science in the National Interest* outlines a similar commitment on the part of the federal government. The report's primary thesis is that "Science is an endless and sustainable resource with extraordinary dividends" (4). Government policies and programs should view the academic enterprise as a whole and cultivate it as a national asset. This in turn would establish a framework for future partnerships that would allow teaching to flourish in conjunction with research and other activities.

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Support for Fundamental Research: Importance to Education and Training

Our next point also requires taking a new look at the relationship between the federal government and academic institutions. The federal government's reasons for supporting basic research at academic institutions have long included both ensuring a continuous flow of new knowledge and educating future scientists and engineers through participation in research at the frontiers of knowledge.

Today, research funding serves as the predominant means of federal support for graduate students in science and engineering. In fact, the mechanisms used by the federal government to support science and engineering graduate students have shifted markedly toward research assistantships over the past two decades. In 1975 graduate students at doctoral institutions who received their primary support from the federal government were almost as likely to have fellowships or traineeships as research assistantships (41% compared with 49%). Today they are more than twice as likely to receive support through research assistantships: in 1992, 65% of students enrolled in doctorate programs who received federal support relied on research assistantships for their primary support, compared with 27% who relied primarily on fellowships or traineeships (*5*).

The dominance of the research assistantship as a form of student support certainly has its pluses and minuses. There can be no doubt as to the intrinsic value of participation in research as a teaching tool. By working on first-rate, merit-reviewed projects, students receive the ideal form of on-the-job training with the latest research methods and instruments. The downside, however, is that, when compared with fellowships and traineeships, research assistantships are a very imprecise instrument for producing human resources for science and engineering. First, because students are in effect bound to their faculty mentors for financial support, they have less flexibility to pursue innovative learning experiences, such as participating in collaborative research with private corporations. In addition, research funding could play a larger strategic role in developing human resources for science and technology, particularly in attracting and cultivating more students from groups in the U.S. population that have traditionally been underrepresented in science and engineering. This has taken on added importance now that the majority of new entrants to the workforce are women and minorities.

A key policy recommendation presented in *Science in the National Interest* directly addresses this issue. The report directs the National Science and Technology Council to "produce a human resources development policy for sustaining excellence and promoting diversity in the science and technology work force" (*6*). It almost goes without saying that a key tenet of this policy must be to recognize the vital link between research and graduate education—the defining strength of our academic research and education enterprise.

Other positive steps are already in the works, thanks to the current priorities in science and technology policy. First, the emphasis on connecting fundamental research to national priorities gives graduate students more opportunities to participate in interdisciplinary research that is relevant to pressing societal concerns. Students thereby gain increased experience working in multidisciplinary and often multisectoral groups on projects designed to highlight connections between new knowledge and the health and well-being of society. In this same way, industry-university cooperative activities are also vital. These activities yield multiple benefits. By working directly with scientists and engineers from industry, students gain new awareness of needs and opportunities in the private sector. At the same time, the companies are given a window on leading edge research and emerging technologies as well as the abilities of possible future employees.

Graduate Education and Changing Realities

The first two points we have made in this commentary require increased leadership principally on the part of academic institutions, the federal government, and research-intensive industries. This third point focuses more directly on individual faculty members and the guidance they provide to science and engineering graduate students. Our message is a simple one: Everyone who teaches and counsels future scientists and engineers must give careful consideration to the many profound changes in career paths in these fields and in the economy and work force generally.

Contrary to what is often reported on the issue, the changes in the academic job market have been under way for some time. While the nation will always need outstanding scientists and engineers to teach in colleges and universities, the share of Ph.D.-level scientists and engineers employed at academic institutions has been steadily declining for over two decades, and today roughly half of all doctorate level scientists and engineers work outside academe (*7*). This in itself necessitates some rethinking of the purposes of doctoral training.

More sudden changes have occurred in the sectors of the economy that traditionally have employed large numbers of Ph.D.-level scientists and engineers. These changes have been widely reported and discussed. As the National Science Board's most recent version of Science and Engineering Indicators puts it: ". . . in the early 1990s, the recession, defense-related spending cutbacks, reduced research and development budgets, and industry downsizing all took their toll on [science and engineering] employment" (*8*). With national laboratories being refocused and industry's research and development laboratories being restructured and often attached to corporate business units, newly minted Ph.D.'s more and more are facing the prospect of exploring nontraditional career paths.

This places a new set of responsibilities on faculty to help students prepare for and seek a wider variety of career opportunities, and the reward system at academic institutions should take these responsibilities into account. In the end, it falls to individual faculty members to help their students recognize the diverse set of rewarding careers available to professional scientists and engineers.

Consider, for example, two areas where young scientists and engineers could make an immense contribution to the nation, yet all indications are that these areas remain largely unexplored. Teaching is one area where people who can communicate the excitement of science and engineering can make a major contribution. National Academy of Sciences President Bruce Alberts among others has sounded this call (while also noting that graduate students expressing such interests receive little support from their faculty advisers) (*9*).

A second set of promising and largely unexplored opportunities may reside in the small business sector. The National Research Council (NRC) recently surveyed the small manufacturers that have sought advice from Manufacturing Extension Centers operated by the National Institute of Standards and Technology. The NRC found that one of the principal barriers to the competitiveness of these firms is their lack of awareness of "best manufacturing practices, innovative application of new technologies, and fresh approaches to improved production efficiency" (*10*). This suggests that with improved training in areas such as the management of technology and the business environment, recent science and engineering graduates would bring experience needed to help make these firms more competitive in the global marketplace. This adds up to a win-win situation for the individual students and the firms, as well as for the academic enterprise and the nation as a whole.

Conclusion

It has been said that the greatest teachers always point beyond themselves. This is what separates teaching from other professions—the hope and expectation that our students will surpass our own achievements. This standard might be best exemplified by J. J. Thomson, the Nobel Prize–winning physicist credited with discovering the electron. Eighty years ago, the model of the atom he developed (commonly known as the "plum pudding" model) was displaced by the nuclear model developed by his former student, Ernest Rutherford. (In total, seven of Thomson's students, including Rutherford, received the Nobel Prize—an amazing legacy by any criterion.)

Today's science and engineering graduates face a challenge of a different dimension—pursuing intellectual and professional horizons that surpass the conventions known for generations. For the individuals, institutions, and government agencies that shape policies for graduate education and research, this requires changing and updating many long-standing practices. The three points we outlined—reinvigorating the teaching and learning mission of higher education, fostering a more strategic link between research funding and graduate education, and recognizing the changed career paths awaiting future scientists and engineers—provide touchstones for progress in this time of change. By embracing these new directions while preserving its fundamental strengths, the academic enterprise, working in partnership with government and industry, should have no trouble producing the finest scientists and engineers for the 21st century.

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European Union: Fresh Tracks for Academic Exchanges

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Cooperation in higher education and training among the member countries of the European Union (EU) (*1*) is to be restructured. Since the mid-1980s, it has been typified by several international mobility programs. These are now to be consolidated in two new programs, SOCRATES and LEONARDO DA VINCI, corresponding broadly to education and vocational training, respectively. The move seeks to rationalize and develop EU activity in both areas. SOCRATES, additionally, will put education at all levels onto the Community map with, for the first time, substantial scope for cooperation among schools. Both programs are currently scheduled for adoption by early 1995 and will cover the European Economic Area (EEA) including Austria, Finland, Iceland, Norway, and Sweden, in addition to the present 12 EU member countries.

The various current programs are administered by the European Commission in Brussels. But their real visibility and impact are at the grass-roots where EU money is used by many thousands across the Community to breathe life into the notion of European union through cooperation within multilateral transnational networks. Three of the programs, ERASMUS (the European Community Action Scheme for the Mobility of University Students), COMETT (the Community Action Programme for Education and Training for Technology) and LINGUA [the European Community (EC) program to promote knowledge of foreign languages in the Community] all involve higher education, and ERASMUS exclusively so (*2*). Several others address different aspects of vocational training.

Roots of Exchange

Historically, the present programs are the by-product of a perceptible shift in the bearings of the European Economic Community set up by the 1957 Treaty of Rome. From within its economic focus has grown a political awareness that a closer union among the peoples of Europe can be interpreted broadly. However, this interpretation is circumscribed, not least of all in education and training, where cooperation, not harmonization or uniformity, has been the keynote. The present cooperation programs have only a modest budget, which has never reached 1% of overall EC spending.

It was recognized that if the EC were to consolidate its credibility as an international trading partner, it needed to be competitive and display cohesion, generating the benefits of healthy economic peformance across all regions and sectors. This policy vision pointed to the need for advanced training of Community students in more than one EC country, together with the transnational pooling of the intellectual resources in higher education and the skills of business and industry. Cohesion called for balanced cooperation, sectorally as well as geographically. Above all, mobility had to be on a scale sufficient for its effects to have an impact.

Launched in 1987 to pursue cooperation within higher education, ERASMUS was (retrospectively) the culmination of many years of discussion, political negotiation, and testing. It was built initially on a small Community-wide network of almost 600 university student and staff exchanges as part of a program initiated by member country education ministers in 1976.

Current Levels of Exchange

Estimates of student mobility in Europe are still far from standardized, with several countries including part-time students. In 1986 the European Commission concluded that fewer than 1 Community student in 100 was enrolled at a university in another EC member state (*3*). Often these included the children of EC citizens living abroad, or students on nationally funded exchange schemes. The Commission sought to boost this small proportion to around 10% of the total EC student population from 1992 onward. In 1987, this amounted to 150,000 students annually, out of a total EC student population of some 6 million for whom university studies lasted around 4 years on average. But in adopting ERASMUS, the Council of Ministers cut the Commission's

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