Perspective

Applied Research: Key to Innovation

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RESEARCH IN THE NATION'S UNIVERSITIES AND NATIONAL laboratories is facing strong new pressures: the huge federal budget deficits, which led to the Gramm-Rudman-Hollings legislation, and the widespread perception of a decline in U.S. industrial competitiveness, due in part to inadequate coupling of scientific research to technological innovation. These pressures may lead to significant changes in the institutional arrangements for research in the United States and the priorities assigned to research programs. The research community should seek to ensure that any changes in resource allocations are carried out in ways that advance both research and innovation.

These pressures on the research system have already called forth three proposals for change that could have major and unforeseen consequences:

1) The Packard-Bromley report on the state of health of the nation's universities recommends that the federal government make substantially greater investments in university research during the next decade and suggests that the most probable source of such funds is a reallocation of research and development appropriations (*1*). Erich Bloch, director of the National Science Foundation (NSF), has extended this idea by proposing that increased support for basic research should come from a reallocation of applied R&D funds and in particular those of the national laboratories (*2*). In asking for this shift, he argues that a White House Science Council panel "found that many laboratories have lost a clear sense of their mission and that the quality of their research has declined. The explicit ties between laboratory research programs and their sponsoring agencies have also built in a bias toward applied research and development, which may not result in the most productive use of the national laboratories" (*2*, p. 24). This statement seriously misinterprets the critical role of applied research in mission-oriented national laboratories such as Sandia and Los Alamos and industrial laboratories such as AT&T Bell Laboratories. It also disregards the synergism between basic and applied research on the one hand and development work on the other, in the purposeful environment of a mission-oriented laboratory.

2) In a complementary proposal, Frank Press, president of the National Academy of Sciences, has recommended that research in the federal intramural laboratories and federally funded R&D centers, including the national laboratories, be opened to a common peer-reviewed, national competition (*3*). Although it would apply to fundamental research and not "mission-oriented research," this proposal raises some serious concerns.

3) A second recommendation of the Packard-Bromley report is that the federal government support a major initiative to establish "university-based interdisciplinary, problem-oriented research and technology centers directed to problems of broad national needs and relevant to industrial technology" (*1*, p. 6). In a related set of actions the NSF has established six engineering research centers at universities, with more to come, and is considering a major effort to fund basic science and technology centers directed toward "creating the technology that the nation needs" (4, p. 598; *5*). The establishment of these centers, which would also be done on the basis of funds reallocated from other R&D programs, raises further serious concerns.

Such proposals for major changes in the U.S. research system demand a sophisticated understanding of a complex and fragile system that has served the country well but could easily be damaged in unexpected ways. However well intentioned, these proposed changes seem ad hoc and have a potential for harm that warrants careful consideration before implementation. Although the proposals would seriously affect the conduct of applied research at universities and national laboratories, they seem to reflect little explicit appreciation of the role played by applied research in advancing technological innovation in these institutions and in industry.

Why is applied research a matter of so much concern? The reason is that applied research is that part of the fundamental research spectrum (*6, 7*) where generic technology arises out of basic research. The prime example of our time is the transistor invented at Bell Telephone Laboratories in 1947. The transistor was in every respect the outcome of basic and applied research in semiconductor science. The exploratory and advanced development that made the transistor and integrated circuits such powerful engines of innovation came later. There is an endless list of other examples of basic technology flowing from applied research that have been or have a high potential to be important sources of innovation. A short list would include gaseous and solid-state lasers, very large-scale integrated circuits, optoelectronic integrated circuits, magnetically and inertially confined fusion, accelerator technology and the free-electron laser, nuclear magnetic resonance imaging, recombinant DNA technology, artificially layered materials, composite materials, and surface-modified materials. These are basic technologies, emerging from research, that generate diverse exploratory and advanced developments.

Applied research as defined by these examples is a vital, creative part of research in universities, national laboratories, and industry, and plays a key role in innovation as the end of the research spectrum that links research with subsequent development. Although it has been said that R&D is a continuum of activities leading to innovation, a more realistic view is that (i) basic and applied research comprise a continuum of research activities; (ii) basic and applied research are functionally distinct from exploratory and advanced development since the latter must be concerned with milestones, timetables, and specific goals in a way that research is not; and (iii) exploratory and advanced development are characteristically more expensive than basic and applied research.

A concomitant of the distinction between applied research and exploratory development is the fact that these two activities are often carried out in different organizations within the same R&D laboratory, or even in different institutions, as when a university applied research group interacts with industry. The interface between applied research and exploratory development can therefore be a serious barrier to technological innovation; overcoming this barrier requires dedicated and collaborative effort on both sides. The barrier has often been best overcome in the environment of a well-integrated R&D laboratory.

For a strongly mission-oriented national laboratory, basic and applied research provide an indispensable technology base for exploratory development. They also define the laboratory's technological future, and provide an important mechanism for coupling with university research. As a result, one cannot lightly consider redeploying resources from applied research in these laboratories

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without risking harm to U.S. leadership in technological innovation. It is important for a mission-oriented R&D laboratory to maintain a balanced program of work in basic and applied research, exploratory development, and advanced development. The fact that a mission-oriented laboratory engages in exploratory development does not make it less capable in basic science and technology. On the contrary, it provides a stimulating environment in which basic and applied research flourish. It is a major misrepresentation of the role of research in mission-oriented laboratories to imply that emphasis on exploratory and advanced development affects their research quality and productivity.

Peer review of university research is an important strength of science in this country but could lead to serious problems if applied to research in those federal laboratories that have strong mission orientation. First, a terminology problem should be clarified. Frank Press's proposal includes a stipulation that peer review of research in the federal laboratories would apply to fundamental research and not "mission-oriented research." Mission-oriented research, as used by Press, means something closer to exploratory development than to applied research and would usually be considered sensitive at a mission-oriented national or industrial laboratory, and therefore inappropriate for peer review. The real concern then arises from the proposal that fundamental research, meaning basic and applied research, should be open to peer review. R&D laboratories with well-developed missions conduct basic and applied research in fields relevant to their laboratory's mission because this research is expected to have an impact on the laboratory's programmatic work and because they are essential to ensuring the laboratory's technological future. It is not at all obvious that it is possible to replace such research with similar research done outside the laboratory, even with committed efforts at liaison. The research-development interface is a difficult enough barrier to surmount, even within a highly integrated R&D laboratory, and it is more difficult to import research, even with the best will on both sides. The best way to import university research into an R&D laboratory is through active in-house basic and applied research groups, a channel that would be closed if the laboratory relied too much on external research.

As Frank Press noted (*3*), all federal laboratories use some form of evaluation to review their internal research. Sometimes this review is performed by external visiting committees, but more often it is and should be an integral part of research management in a well-integrated R&D laboratory with a strong sense of purpose and mission. The effectiveness of internal quality control is evident from the leading role played in basic and applied research by large industrial laboratories such as IBM and AT&T Bell Laboratories, which have maintained a pattern of excellence without relying on external competition and peer review.

Applied research is an important part of academic research in the United States and is explicitly recognized as such by major research universities (*8*). This reflects the fact that basic and applied research are characterized by similar intellectual values and scientific approach, both serve as the basis for research activity in graduate education, and both share the intent of open communication and publication in refereed journals. An important aspect of university applied research is that it has usually been carried out by individuals or small research groups and has not been subject to the mission orientation and time constraints typical of exploratory development. Instead, it has often had strong ties with applied research in industry and national laboratories and has been a prime source of manpower for these laboratories. These central characteristics of university research must be preserved.

Applied research at universities is expensive and is in danger of lagging behind research in national laboratories and industry because of the high cost of equipment in fields such as molecular beam epitaxy, nuclear magnetic resonance, ion implantation, and electron microscopy. It must therefore be a matter of real concern whether the establishment of organized science and technology centers on university campuses may divert funds needed for new equipment for small research groups and at the same time introduce a foreign element of mission orientation. James Williams, dean of the Carnegie Institute of Technology, has expressed the serious concerns of university research administrators regarding such a proposal: "The bottom line is that we must maintain a research climate on our campuses that permits the full intellectual talent of our faculty to be invested in the creation of knowledge . . . . A highly structured, short-term payoff climate tends to stifle the creativity which has been the hallmark of academic research and which has been so valuable both in absolute terms and in terms of the type of students it produces" (*9*, p. 5).

I have noted that the interface between applied research and exploratory development is a barrier to technological innovation. This barrier has been surmounted in well-integrated R&D laboratories having strong applied research programs by close collaboration between research and development. A more formidable task is to introduce new science into industries that have not traditionally been research-oriented. Therefore, a valid concern is whether organized basic science and technology centers on campus will meet expectations for interaction with industries that do not already interact well with universities through their own in-house research programs.

To the extent that these organized university research centers bring more funds to applied research, encourage interdisciplinary research, support individual investigators, and encourage interactions with industry and the national laboratories, they will be of great benefit. To the extent that they enlarge the research bureaucracy, compete with individual investigators, and move toward mission-oriented research or exploratory development in an effort to address problems of genuine economic consequence, they can constitute a serious diversion of resources.

The U.S. research system has traditionally excelled at converting science into high technology. An important factor in this success has been high-quality applied research in universities, industry, and mission-oriented national laboratories. If the predicted tight budgets for research materialize, support for basic research must be maintained; at the same time, if research is to continue to be a prime source of new technology, it will be essential to support strong programs of applied research in the universities and mission-oriented national laboratories and to take no unconsidered actions that might affect their vitality.

REFERENCES AND NOTES

1. "A renewed partnership" (Office of Science and Technology Policy, Executive Office of the President, Washington, DC, 1986).
2. E. Bloch, *Issues Sci. Technol.* **2**, 20 (winter 1986).
3. F. Press, *Science* **231**, 1351 (1986).
4. E. Block, *ibid.* **232**, 595 (1986).
5. E. Clark, "Passing the buck in R&D financing," *Business Week* (2 December 1985), p. 34.
6. The President's National Security Decision Directive 189, *National Policy on the Transfer of Scientific, Technical, and Engineering Information*, says that "Fundamental research" means basic and applied research in science and engineering, the results of which ordinarily are published and shared broadly within the scientific community, as distinguished from proprietary research and from industrial development, design, production, and product utilization, the results of which ordinarily are restricted for proprietary or national security reasons.
7. Applied research as used in this article and defined in (*6*) departs from the NSF definition, according to which applied research is research directed toward gaining "knowledge or understanding necessary for determining the means by which a recognized and specific need may be met" [*Science Indicators: The 1985 Report* (National Science Board, Washington, DC, 1986)]. Such a definition spans applied research and exploratory development and is not very useful in discussions of the interface between research and development.
8. For example, the Department of Applied Physics at Stanford University, the Division of Applied Science at Harvard University, and the Division of Engineering and Applied Science at the California Institute of Technology.
9. J. C. Williams, *Carnegie Inst. Technol. Eng. News* **5**, 5 (1985).