SCIENCE: THE END OF THE FRONTIER?

LEON M. LEDERMAN
PRESIDENT-ELECT TO THE BOARD DIRECTORS
AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

Once upon a time American science sheltered an Einstein, went to the moon, and gave to the world the laser, the electronic computer, nylon, television, the cure for polio, and observations of our planet's location in an expanding universe. Today we are in the process, albeit unwittingly, of abandoning this leadership role. It is up to the President, the Congress, and the American people to decide whether this is really the road we want this country to travel.

America has lived and grown great through science and technology. From the founding of land grant universities and the flowering of agricultural research in the 19th century to the boom in microelectronics and information technology in the last two decades, we have hitched our economy to the best scientific research system we could develop and have prospered as a result. In this long-running success story, American universities have played a special role. University researchers have produced new knowledge to drive the economy and at the same time have trained successive generations of scientists and engineers to staff American industry.

But now, at a time when problems of international economic competition, environmental degradation, and quality of life demand the very best from our research community, new information assembled by the American Association for the Advancement of Science (AAAS) documents a deeply troubled mood among university researchers, even those who have been successful in pursuing research careers in our most prestigious institutions. This troubled mood is so pervasive that it raises serious questions about the very future of science in the United States. From one institution to the next, across demographic categories, across disciplines of research, the nation's scientists are sending a warning. Academic research in the United States is in serious trouble.

While it is difficult to make accurate predictions as to possible outcomes of the current situation, a major decline in research capability is certainly within the range of plausible projections. Indeed, given the current economic situation and budget climate, such a worst case scenario might be considered probable. In view of the close coupling we believe to hod between a vigorous and dynamic science and the economic and cultural well-being of the nation, this becomes a national problem.

Ironically, there is, among policymakers and the informed public, a general sense that American science is strong and healthy. Every year, we do well in the Nobel prize sweepstakes. Over the past decade federal funding for basic research has fared rather well in the budget battles, at least as compared to other areas of government spending.

To understand the morale problems in the research community, it is necessary to look at the long-term picture, not just at how federal investment in R&D for

---

Excerpts from a January 1991 Supplement to *Science*. Printed with permission of the American Association for the Advancement of Science.

this fiscal year compares to last or how R&D funding compares to transportation, agriculture, or other "domestic discretionary" programs. In this perspective, it is not hard to see the source of the problem. Despite recent growth, the level of federal support for basic and applied research in the universities in 1990, after correcting for inflation, is only slightly larger than it was in 1968, over twenty years ago.

In 1968 this level of funding was adequate. Indeed, 1968 was the peak year of a period that is considered the "golden age" of American science. Today, however, there are twice as many doctoral scientists in universities competing for those funds. Furthermore, in all areas of research the last decade's "easy" problems have been solved, and the cost of creating new understanding of nature has increased considerably. Finally, new regulatory requirements have added to overhead costs and reduced the funds available for the direct costs of research. Is it any wonder that morale among academic scientists is low?

Academic science has not arrived at its present state through a conscious decision by the Administration or Congress. No political leader has advocated starving science -- indeed, most feel that they support it strongly. Presidents Reagan and Bush have both promised to double the size of the National Science Foundation's budget within five years, and Congress, almost every year, appropriates more for the National Institutes of Health than the Administration requests.

Scientists in the universities began to feel the pinch in the early 1970s, when the sustained growth of the previous decade came to an end and rapid inflation combined with constraints on the federal budget to produce a constant-dollar decline of more than 20 percent in federal funding for academic research. Warning signals arose at that time and eventually, to an extent, they were heeded. The trend in federal funding turned upward beginning in 1983. However, recent growth has been insufficient to compensate for the effects of the long drought that preceded it. Thus, in the view of those in the laboratories, there has been a gradual year-by-year erosion in the availability of funding and in the health of academic science over nearly two decades.

✦ The Increased Cost of Doing Research

The phenomenon of level funding and a growing community of researchers in itself would clearly cause considerable hardship in the scientific community. The problem is compounded, however, by a number of other factors that, taken together, further restrict the results that can be obtained from each research dollar.

1. Complexity

One factor is complexity--or what some observers have called "sophistication inflation." As our understanding of nature increases, the questions we need to answer become more complex. There is a corresponding increase in the sophistication (and cost) of the equipment needed to do research, both for small, "table top" experiments and large facilities such as telescopes and accelerators.

For example, a state-of-the-art dye laser cost about $19,000 in 1974. The corresponding state-of-the-art laser today costs $160,000. Even if we correct for inflation, a scientist who wishes to remain in the forefront of research in 1990 has to pay three times as much for this piece of equipment as he or she did fifteen years ago. Similarly, the cost of equipping a laboratory for a starting assistant professor in a university science department has increased by a factor of ten since 1968.

One might argue that there are countervailing trends. As the cost of certain technologies decreases, the cost of doing science should go down as well. Ordinary hand calculators, for example, once cost several hundred dollars, but now cost only a fraction of that sum. While this cost reduction is real, in practice it is completely swamped by the increased demands for computation. although the cost per arithmetic operation has gone down dramatically since 1968, the increased need for computing power has made computer costs a major portion of today's science budget. Similarly, the unit cost of building an accelerator has dropped from $1,000 per MeV at Fermilab (in 1970) to $100 per MeV at the SSC, but the energy required to do meaningful research in high energy physics has gone up so much that the total cost of the required accelerator is much higher today than it was in 1968.

These are not just examples of researchers trying to keep un with the Joneses--one can no more do 1990s research with 1974 equipment than one can build a modern superhighway with pick-and-shovel labor. The complexity factor is a direct cost imposed on research by increasing sophistication in science.

2. Increasing Costs of Regulation

The cost of regulation is a second factor. In many fields, particularly in the life sciences, increased regulation absorbs significant funds and research time. Requiring researchers to comply with guidelines such as those concerning animal care, human subjects, low level radioactive waste, and hazardous substances isimportant and certainly justifiable, but it must be recognized that the costs of complying with these regulations reduce the amount of research that can be done for a given amount of money.

3. Increased Overhead

A third factor is institutional overhead. According to the National Science Foundation, indirect costs at universities (including administration, maintenance of buildings, utilities, etc.) have risen from 16 percent of the national academic R&D budget in 1966 to about 28 percent in 1986. Charges equivalent to 70 percent of salaries are not unusual today. In the minds of many faculty members, overhead amounts to a tax on research. Obviously, it is a legitimate component of the cost of doing research and its recovery in research grants is essential to the survival of the universities. But, as is the case with increased regulation, the absorption of a growing share of research money by overhead means that less money is available to the laboratory scientist for the direct costs of the research.

✦ Conclusions and Recommendations

The depressed state of the academic scientific community is attributed to a failure of our system of science funding to recognize and maintain the essential needs of a healthy infrastructure.

Science funding has increased steadily in the past several years, yet it is apparent that current levels are far below what is required for healthy, even lean, science. Perhaps this may give some policymakers a sense of frustration at the "ungrateful and insatiable scientists." Yet we are not alone in seeing this problem. Warnings have been creeping up everywhere. Almost five years ago, the Packard-Bromley report documented an obsolescence of university research equipment and evaluated the cost of renovation at $10 billion. Since becoming the President's Science Advisor in 1989, Allan Bromley has continued to speak out about underinvestment in research, as has Frank Press, the President of the National Academy of Sciences. There is an emerging consensus among science policy leaders that we are not making the long-term investment in research required to restore our economic and scientific leadership.

The United States today finds itself slipping in its ability to compete with dynamic societies abroad. The new Europe, Japan and the Pacific Rim nations are increasing their investment in research, having already surpassed us in the various activities needed to convert research results to economic benefit. It is up to us as a nation to decide whether the U.S. will remain a major player in world science and science-based technology or whether we will continue to slide.

The implications of the loss of such leadership are immense. Just as the "brain drain" drew talented scientists from Europe and the Third World to the United States in the 1950s and 1960s, so too will some American scientists (and potential immigrants) follow the frontiers of their fields to Europe, the Pacific Rim, or wherever they might be in the future. The pipeline of new research that has nourished our high-tech industry will dry up, crippling our ability to compete in a world where science and technology play an ever more important role.

We can already see ominous signs in economic trends. In 1986, for the first time in history, the United States imported more high-tech manufactured products than it exported. Residents of foreign countries now receive almost half of the patents granted by the U.S. Patent Office. And the three corporations registering the most U.S. patents last year were Canon, Toshiba and Hitachi.

Finally, we should not neglect to mention the more subtle, less quantifiable but nonetheless profound influence that science has upon society. We are a great nation which must value the culture that the success of science engenders. This success permeates society, generates self-confidence, inspires our youth, creates a sense of endless frontiers of the human mind and of human aspirations which would otherwise become increasingly confined in an ever-shrinking world. The loss of this scientific and technological exuberance would be another heavy price to pay, perhaps even the greatest penalty in the long run, for the decline of the research system.

The full effects of the impoverishment of basic research will not be felt next year or the year after. We have been living on our accumulated scientific capital for a while, and we will probably be able to do so for a while longer. But if we persist on this course, we can expect to see America's position in the world gradually weaken. We will watch as our technology-based products become less and less competitive in world markets. By then, of course, it will be too late.

It is the long-term nature of the enterprise that makes the issue so dangerous. Once we begin to weaken, there are many feedback forces that tend to accelerate the decline. The best people move on to other activities. Students are no longer attracted. The stream of immigrants diminishes. The essential influx of young investigators dries up. Within the range of possible outcomes are both acceptable and unacceptable consequences. Yet to wait rather than take action now is to invite a situation that will be difficult and very time-consuming to reverse.