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Introduction: The following article is based on a presentation at an invitational Conference on Basic Science in the Service of Public Objectives, November 28-29, 2000, Washington, D.C. It was the third such meeting, the previous two having been held at the offices of the OSTP and at the National Academy of Sciences, respectively. In the November 2000 meeting, the speakers included Mary Good, Lewis Branscomb, David Hamburg, D. Allan Bromley, Richard Klausner (of NCI), Rita Colwell, Shirley Malcom, Jim Duderstadt, Ralph Gomory, Paula Rayman (Radcliffe Institute), Sarah Harringan (OMB), Jack Gibbons, Walter Massey, Rep. Vernon Ehlers, David Guston, Leon Lederman, John Bransford, Rush Holt, Warren Washington, Mildred Dresselhaus, John Holdren, and several others. A full report is to be published.

"What is the Imperative for Basic Science that Serves National Needs?"

Gerald Holton

A major focus of discussion in Washington and in academe is how to strengthen the conduct and support of basic research in science and technology. It is a timely effort: the federal support for basic research has dropped precipitiately during the last decade (to about 0.6% of GNP, back to where it was in 1953), the U.S. population remains, to our shame, dangerously ignorant of the sciences (for example, 70% of the nation's colleges do not require even one hour of science or mathematics for graduation), and the true champions of basic research support in the House and Senate of Congress are still few in number. More ominously, the world has entered a new phase of history, with potential instabilities before us, including global change, energy, literacy and learning, the threats of wars, poverty and the spread of disease--among many possible examples. Many of these are relevant to scientific studies; but all, known or yet unsuspected, will greatly determine the life of our children and generations beyond. Just as our nation's civilization has been shaped in large part by the extraordinary powers of the sciences and technologies, the phase of history which we have entered will surely also be formed by the findings and tools to be developed by scientists and their near colleagues, by how their work is to be encouraged and conducted.

Thus a main point of the vision I wish to sketch is this: The scientific part within our total cultural spectrum can do, and now must do, far more to serve the needs of this nation and humankind, and needs a corresponding expansion in terms of human resources and financial support. True, the sciences as a whole have risen to glorious heights in the twentieth century, despite many shortcomings and persistent obstacles. In addition, economists have found that the social return on the federal investment in science and technology has been between 30% and 60%. In the darkest middle-part of World War II, the sciences and technologies even helped the Allied forces to rescue Western civilization itself. Now, in our battle for a more secure future, the sciences, more mature and numerous, are even more capable of great achievements for the public good.

How? Many of us believe the first step is to widen the common understanding of what the sciences now can do. It is imperative to cut the chains impeding some of today's sciences; to let them help more effectively with the public needs before us. By widening of the common understanding of science's powers, I mean specifically to encourage much more intensively *a style of basic research that locates itself in areas of ignorance of how to meet societal needs.* It is a mode of research that I have thought and written about for some time, using as convenient shorthand the term "Jeffersonian Research." That notion is neither radical nor untried. For example, much of the basic research now supported by the National Institutes of Health is chosen and pursued in this mode, with wide approval in Congress and among the public. The White House report on science in 1994, and Rep. Vernon Ehlers' report of 1998 contain similar proposals. A fascinating attempt to institutionalize this mode across all executive departments and agencies was made under the direction of Frank Press during the Carter administration. In the last decades there were also a few other federal initiatives along that line. But what many of the past attempts have lacked is an explicit verbalization of the overarching rationale and the institutional legitimating of Jeffersonian Research within science policy. This is what I shall consider here. A proper start is to summarize more precisely what characterizes the two current main research styles as commonly perceived, and how a third one I select for greater attention differs from the others.

Newtonian vs. Baconian mode of research

Among the familiar research styles are two modes of basic research, well established and utterly needed to be adequately supported in the total range of efforts. One mode is primarily curiosity-driven basic research, without the expectation of any but perhaps long-term social benefits, apart from the important one of increasing of scientific understanding itself. The other mode is that part of R&D pursued in the reasonable hope that a fairly early harvest would result, for use and practice beyond the originating laboratory. In popular parlance, the difference between the two is ivory tower versus quick payoff, or pure versus mission-oriented, or the craving for omniscience versus that for omnipotence, or, for shorthand use, the Newtonian mode versus the Baconian.

At first glance, those two modes seem antithetical, even antagonistic, and invite choosing one over the other. For example, as to the support of basic research, Senator Harry Reid warned in April 2000 that many people are now beginning "to see science as a luxury that can be reduced or abandoned." On the other hand, federal support for applied science research has been attacked as "corporate welfare"; and similarly, one still hears occasionally Vannevar Bush's remark, made in passing in his grand Report of July 1945, that "there is a perverse law governing research:...applied research invariably drives out pure."

If one looks at these two modes in turn, and arrays historic examples of scientific results in two opposite columns, deep differences seem to persist. In the column on the left, that of curiosity-driven achievements, we would find for example Galileo's telescopic discovery of the moons of Jupiter; Newton's Principia; Faraday's discovery of generating electricity by moving conductors in magnetic fields; Johann Gregor Mendel's report of his experimental results of artificial plant hybridization and Thomas H. Morgan's research on fruit flies; Roentgen's discovery of xrays; Einstein's brief paper of November 1905, ending with the speculation that "The mass of a body is a measure of its energy content," and the vaguely expressed hope that "It is not beyond possibility that this theory may be tested." The story continues in the latest, astonishing reports in journals such as Science and Nature.

The second, right-hand column, presenting mission-oriented or Baconian-mode results, would be equally long. It might start with the casting of a monstrous canon of new design at the command of Sultan Mechmed II in the 14th century, which breached the walls of Byzantium; in our century it would feature the inevitable transistor, antibiotics, the Genome project, or the discovery by Müller and Bednorz of high-temperature superconductivity found in a substance nobody else thought worth investigating.

A closer look at these apparently divergent listings, left and right, reveals that they have four important commonalties. First of all, each has its own charisma. I need only say that the fascination of the public with, say, astronomy on one hand and mechanical and electronic devices on the other are reminders of those ancient, benign enchantments with science and technology that are built into most souls from the beginning.

Second, both modes are part of a whole seamless web or eco-system. Galileo's telescope depended on the practical results of ancient glass-making technology; Newton's calculations required data supplied by map-making expeditions; and so forth. Conversely, Müller and Bednorz's work rested crucially on basic results in thermodynamics, crystallography, quantum mechanics, as well as the applications of low-temperature technology, and of some thermometry first developed in the 19th century. There is much borrowing of ideas and sharing of instruments. Thus, both these research modes are essential for each other's well being.

Third: Basic research done without an explicit mission does of course sometimes result in unforeseen, extraordinarily useful applications, although usually with considerable time delay. Faraday's discoveries were the basis of electric generators and motors built decades later. Mendel's and Morgan's labors eventually became part of the intellectual ancestry of brilliant biotechnology industries. One of Einstein's papers of 1916 was to be the basis for the ubiquitous laser. NMR was morphed and transformed into MRI. The roots of the computer and the Internet can be traced similarly.

The possibility of such eventual, but not foreseeable, spin-offs from basic research has undergirded the public's affection with basic science so far. These were explicit in Vannevar Bush's Report when he wrote to President Roosevelt, without committing to a timetable of achievements: "Scientific progress is one essential key to our security as a nation, to our better health, to more jobs, to a higher standard of living, and to our cultural progress."

A last, fourth kind of similarity between the Newtonian and Baconian modes of research is both exciting and troublesome. An advance in either one can undermine an old worldview, and help in the ascent of a new one. Galileo's finding of the moons of Jupiter presaged the final acceptance of the Copernican view of the universe, and of our place in it; and similar tectonic shifts began with Darwin's lonely studies of finch beaks. The whole pseudo-scientific alibi for racism had to be abandoned, thanks to the findings of anthropologists and geneticists. In each case where a new worldview and new rights asserted themselves, vigorous resistance had to be overcome, and

may, to some degree, exist to this day. It explains why science and technology are now feared or derogated by some parts of academe, and why the public may be quietly troubled by the possibility of another such revolutionary earthquake. Therefore I see part of the imperative for an expanded vision of science policy that it may put the needed respect of the populace and policy makers on a sounder basis.

The Jeffersonian mode of research

The Baconian mode generally applies known science to a known need; the Newtonians pursue science regardless of needs. Both must of course continue to flourish, not least because all modes interact. But research in the Jeffersonian mode, by contrast, places itself on an uncharted area on the map of science, which, if the expedition succeeds, may reasonably soon have a bearing on a persistent national or global problem. It is in a sense a combined mode, and the label I chose for it reflects the fact that Thomas Jefferson himself saw two intertwined goals for science--not only the full understanding of nature, which he treasured, but in addition what he called simply "the freedom and happiness of mankind."

It is not difficult to imagine intentionally targeted basic science research projects where, with less uncertainty and less time delay than from Newtonian research, one can reasonably hope to find a key to alleviate specific, well recognized societal dysfunctions. For example, much remains to be done in cognitive psychology; the biophysics and biochemistry involved in the process of conception; the neurophysiology of hearing and sight; molecular transport across membranes; or the physics of nanodimensional structures, to name a few. The results of such basic work may plausibly be expected, on a reasonable timetable, to give us a better grasp of complex social tasks such as, respectively, childhood education, family planning, improved quality of life for handicapped people, the design of food plants that can use brackish water, and improved communication devices. Other examples with plausible societal significance, many now in progress, could include marine biology resources and related environmental and ecological goals; further research on imaging of the brain; studies situated between understanding behavior and mental illness on the one hand, and neurophysiology on the other; and research on the remaining social and psychological obstacles that still stand in the way of greater participation and diversity, not least in careers in science and technology.

I am not saying that this terminology, Jeffersonian research, is the only acceptable one. Of course not. It is merely a convenient shorthand term, analogous to the widely accepted one using the names of Newton and Bacon. "Basic Research in the Service of Public Objectives," although longer, is one of many equally good terms. But Jefferson himself pointed to the existence of this third mode, when he announced the twin aims for the support of the Lewis and Clark exploration. He wrote that its purpose was "to extend the boundaries of science, and to present to [the citizens of this nation] their knowledge of this vast and fertile country which their [children] are destined to fill...."

Jefferson, who declared himself most happy when engaged in some scientific pursuit, was delighted to receive from the explorers the samples of new fauna and flora, the notes on Indian languages, the geographical maps, and the like. But he also knew that such scientific information would help to prepare America's future on its vast new territory. Out beyond the frontier, there had to be, as Jefferson put it, "room enough for our descendants to the hundredth and thousandth generation." In just this way do I see the need for some portion of our sciences to be dedicated explicitly to the preparation, beyond our own time horizon, of the fortunes of our descendants.

In the Louisiana Purchase and the Lewis and Clark expedition, we see also examples grasped initially by only a few visionaries, to change the opportunities latent in history, as if by a quantum jump. The institutionalization of the Jeffersonian mode of research in all fields, as part of a new mandate for science, parallel to that for National Security, would again take a brave act of political will, expressed not least in enlarging the whole pie of federally-funded support for the entire spectrum of science and technology--just at a time when we may afford it.

In one of the meetings arranged on this topic, Dr. Harold Varmus, then of NIH, noted that it would be important to get active public support through the kind of council-of-citizens group he used at NIH, and also that the delivery of outcomes is now of concern to every sponsoring agency as a result of the Government Performance and Results Act (GPRA). Dr. Rita Colwell reminded us that the National Science Foundation has recently developed increasing constituency support, for example, by forming the NSF Council for Public Research. Other participants thought that the availability of explicitly Jeffersonian research might greatly appeal to potential science researchers now not sufficiently attracted to the other, more visible current modes. As Dr. Walter E. Massey remarked: "I am

particularly attracted to the argument that tying research to broad and meaningful national goals may make science more attractive to women and minorities.... I think that showing how scientific research can be related to visible societal goals can be a strong attraction to many students who might otherwise not consider scientific careers."

Finally, there is a need to face the rarely asked question, "In what consists the moral authority for the pursuit of science and technology in the first place?" In my view the answer consists of several interlocking components: the imperative to excellence of the enterprise; internal accountability, which centers on the ethical imperatives in the conduct and use of research; external accountability, including explaining to the lay public and funding authorities what is being achieved and how; identity preservation, including identifying what is science and what is not, where the limits are, and fighting against unjustified external attacks or misrepresentation, as well as internal enemies such as arrogance and scientism. The most important component of the moral authority of science is the last component on such a list, obligation to the larger community, or, in short, coupling science and technology to the wider interests and needs of the country and the world. As Representative George E. Brown once said: "We must have a research system that arches, bends, and devolves with society's goals...I consider it a moral imperative to enlist science and technology in a campaign for a more productive and humane society." Representative Brown did not need to evoke Jefferson explicitly, but there was an echo in his words.

I know it will not be easy to make this vision a functioning imperative, alongside, and with the same power as, the existing imperatives for lively curiosity-driven and mission-oriented research. Like the latter two, basic research in the service of urgent public objectives will need administrative help and funding through various administrative agencies, although no single "home," any more than, say, applied research is the captive of only one agency. However, the enlarging of basic research in the nation's interest will need, at least in its early stages, a congenial institution that agrees to serve as champion, teacher, information center, facilitator.

A search for that will not be easy. But this should not dissuade us. Jefferson himself gives us courage. In 1812, a dark period in the nation's history, he writes to John Adams: "I have given up newspapers in exchange for Tacitus and Thucydides, for Newton and Euclid; and I find myself much the happier." But Jefferson's native optimism prevails all the same, an optimism we can share as we gather allies. He tells John Adams: "I do believe we shall continue to grow, to multiply and prosper, until we exhibit an association, powerful, wise and happy, beyond what has yet been seen by men."

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