Letters

How Perceptive Is Hindsight?

Project Hindsight (*1*) is a retrospective study of the origins of the innovative contributions of recent science and technology to certain weapons systems. An important conclusion of the first interim report is that undirected basic scientific research of the kind performed in universities is a very poor contributor to these systems. This conclusion was quoted, without critical commentary, in a recent editorial by Abelson (2 Dec., p. 1123). Greenberg's review of the same report (News and Comment, 18 Nov., p. 872), while somewhat better balanced than Abelson's editorial, still does not mention a most important disclaimer included by the authors of Project Hindsight early in their summary. The following paragraph, which appears at the end of section 2, is important because it shows how the stringent conditions placed on Hindsight by its authors severely limit its relevance to academic research.

> It is important to note that this technique is selective in identifying the contributions from recent science and technology. The many important contributions which predate the World War II period are not included; *nor are the countless results of research that, although indistinguishable in themselves, contribute to the pool of general knowledge of scientists and engineers from which ideas are drawn.*

I have used italics in the above quotation to emphasize one of the most important kinds of contribution that undirected basic research can make to any technological activity, military or otherwise. Many of these post-1945 research results have been transmuted into routine techniques, without which commonplace experimental and computational procedures would be performed as they were 20 years ago, not as they are today. A few examples are nuclear magnetic resonance, electron paramagnetic resonance, measurement of intervals less than a nanosecond, precise frequency standards, coherent electromagnetic wave generation, computer logic, and new methods in statistical and mathematical analysis. All of these, and many others, were either primary results of undirected research, or were developed by the scientists themselves in order to make such research possible. Further, a great deal of this work was supported in universities by the Department of Defense, and might never have come to pass if the DOD had opted out of this support in 1945, 1950, or 1955. The end is by no means in sight. To take one example, current cryogenic developments inspired by "useless" research in superconductivity, general relativity, and high energy physics, give promise of order-of-magnitude improvement in the performance of magnetometers and gyroscopes.

A second major kind of contribution of university research to military and other technology is hinted at in the first conclusion of the Project Hindsight report (section 6), which reads in part:

> A utilized innovation can occur only when there is a conjunction of three elements: (1) a recognized need; (2) *competent people with relevant scientific or technological ideas*; and (3) financial support.

As before, I have used italics to stress a point at which academic research enters in an essential and unique way. Competent people with relevant ideas acquire their competence through graduate study and postdoctoral work with active university scientists, who are for the most part engaged in undirected research. Again, it is fair to say that many of these people would not have received their training were it not for DOD-sponsored research in the universities during the post-1945 period.

The third kind of academic contribution is more subtle, and falls outside the terms of reference of Project Hindsight. Nevertheless, it is one that follows most directly from DOD support as contrasted with, say, NSF support of university research. It is important for military in-house laboratory personnel and industrial contractors to maintain communication with the scientific community. It is generally easier and more satisfactory to accomplish this through personal contact than through perusal of journals. Such contacts with academic scientists supported by DOD grants or contracts are among the highly valued by-products of the military basic research program. A current example of this contact is provided by the annual series of scientific seminars sponsored by the Air Force Office of Scientific Research. The audience consists of Air Force and industrial scientists and engineers, both civilian and military. The speakers are among the most distinguished and active of academic scientists; in 1965 two-thirds of them were AFOSR grantees (*2*).

The foregoing comments on the Project Hindsight report are not intended as a criticism of the procedures used in gathering and analyzing the information presented there. My purpose is rather to make explicit the limitations inherent in the Project, insofar as the relevance of academic research to military technology is concerned. In a study of this kind, what is found does not extend much beyond what is looked for. It is possible to be as myopic in hindsight as in foresight.

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References

1. First Interim Report on Project Hindsight (Summary), by C. W. Sherwin and R. S. Isenson, 13 October 1966.
2. The June 1965 Seminar has been published as *Science in the Sixties*, D. L. Arm, Ed. (University of New Mexico Press, Albuquerque, 1966).

The immediate inference that one draws from Project Hindsight is that the needs of the Department of Defense are not very well served by expenditures for undirected research at universities.

As in all analyses of human endeavors, it is necessary to interpret the results in terms of the questions asked at the outset. In Project Hindsight, the procedure used was to start with an end item and then trace the path that led to its development. The question of whether the end item was the best attainable, given current knowledge in the pertinent sciences, or whether it

was merely the best attained, to meet a prescribed need, has not been asked for obvious reasons. Therein lies an important flaw in the "obvious" inference drawn above; namely, could a better result have been attained had a better scientific base been available? What role was played by a lack of awareness of scientific advances accomplished elsewhere? How much would have been accomplished without the underpinnings that undirected investigations tend to provide? There is no end to such speculation; yet it goes to the very heart of the matter. Fundamental investigations in science are the fertilizers that enrich the soil in which the more utilitarian crops can grow. Without them, the soil would soon become depleted—with familiar consequences. Whether DOD should provide its own foundations or rely on those built by others should be debated on grounds different from those based on percentage estimates of the direct benefit DOD derives from its sponsorship of undirected investigations in science.

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The main emphasis of the Hindsight study was on identifying and analyzing "events" which almost by definition proceed from applied research or development. An advance is not considered an "event" unless it makes a rather direct contribution to the weapons system under study. Essentially no scientific contributions to weapons systems were emphasized which did not have an applied motivation.

To show fully the contributions of scientific research through a Hindsight-type study, one must give major consideration to such factors as defining and analyzing the sources of knowledge available to the principal investigator given credit for the "event." For example, in the case of the titanium-aluminum-vanadium alloy, one should trace the origin of the information concerning the effects of structure on mechanical properties and of composition on corrosion properties, of the data from binary and ternary phase-diagrams, and of all the other information used either implicitly or explicitly by the principal investigator.

Studies such as that being conducted by the Air Force Office of Scientific Research (see "Relating the Accomplishments of AFOSR to the Needs of the Air Force," available from the Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151) reveal other important parts of the picture. We find that our phenomena-oriented research, for which AFOSR program managers provide the appropriate degree of military orientation, has resulted in many important contributions to weapons systems. Our program has (i) helped pioneer numerous fields of demonstrated utility, such as hypersonics, nonlinear mathematics, and quantum electrodynamics, and has (ii) also provided numerous effective means for coupling a wide variety of scientific research activities (including a great deal not DOD supported) to DOD technological programs. Among contributions accruing from DOD research sponsorship, but not generally identified with Hindsight "events," are the increased scientific knowledge required for attacking difficult practical problems, the education of people essential to technology, and the large consultation activity of scientists who maintain their expertise through research.

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The conclusions Abelson cites are more than a little misleading, and are typical of hardware oriented cost consciousness.

To be sure, direct contributions to systems from recent (post-1945) undirected science have been small, but was it ever really expected to be otherwise? The major contributions expected and abundantly received from the university contracts were and are a tremendous reservoir of trained scientists who would otherwise never have been able to afford graduate school, and large, modern laboratories in a great many universities—laboratories that would never have existed without government contracts. . . . I suggest that as hardware developments have been traced from inception to inventory, so too should the key people who developed these 20 proven weapon systems be traced in terms of their education and training. It would surprise me very much if most of them had not received their graduate school education supported, at least in part, by their employment on a DOD research contract.

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An aspect which seems to have been forgotten by the DOD in its recent foray into the "science of science" is that it was retrospective in a sense additional to the sense intended: the propositi were "weapons systems," followed back to research "events." Thus an apparent conclusion of the report, that mission-oriented research was more productive of weapons systems than non-mission-oriented research, seems to lead to only one of the two proper deductions—that in producing new weapons systems, a greater proportion of support to mission-oriented research would have been more efficient. A different deduction might have been implied if the investigation had also included a "prospective" part, in which significant scientific events of earlier years had been identified, and their results followed forward. The tritest example of this sort of thing is the eventual military application of the pure physics of nuclear fission; but let us note that an unsolicited letter from a nongovernmental scientist direct to the President was the adequate stimulus for the previously unenvisioned development effort which followed. Thus deductions which might be suggested by such a *prospective* study might include, in planning for the ability to identify new and novel weapons systems, greater awareness of many areas of scientific innovation; also, greater institutional flexibility, to re-orient or re-structure development efforts to exploit promising ones, might have been more effective.

Whether or not this would be among the implications of a complementary prospective study, I seriously propose that such a study should be undertaken by the DOD in order to provide a more balanced picture of the relations between research and weapon-making.

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Early Information Evaluation

In a recent editorial (7 Oct., p. 74) I noticed Abelson's reference to a new method, involving data available from the Automatic Subject Citation Alert (ASCA), which may be useful in providing evidence as to the recognition received by a scientist's publications by ascertaining the frequency with which