INDUSTRY'S STAKE IN SCIENTIFIC RESEARCH

By L. A. DuBRIDGE

THREE YEARS AGO this week I addressed the American Management Association meeting in San Francisco on the same subject I am dealing with here. The basic ideas I set forth then are still good today, and I should like to review them briefly.

The first idea I tried to expound in 1950 was the idea of change. The conditions under which human beings live have been changing for the last 100,000 years. They will be changing for the next 100,000 years. And the chief instrument of change is new knowledge. Men do things differently today, compared to yesterday, because something new has been learned. Sometimes new knowledge gives rise to changes that are welcome. Sometimes these changes cause hardship and distress. But there is always going to be change. Hence we should be ready for it—even invite it—and be ready to guide it in such a way as to cause the greatest good and the least harm.

A second point I stressed three years ago was that the rate at which change occurs continually increases. The reason for this is simply that we have learned how to increase greatly the rate at which we acquire knowledge. Modern methods of research in science and technology result in both the rapid acquisition of knowledge and the rapid application of knowledge to new things. Thus every phase of modern life is continually reeling from the impact of change. This is the great fact—the great challenge and the great opportunity—which faces the management of American business and industry.

The third major point of my previous talk was that, since the rate of change and direction of the changes which will occur will depend largely on the nature of our progress in science and technology, American industry can, to a large extent, determine the rate and much of the direction of this future change, through the way in which it supports and carries on research in pure and applied science, and the way in which it uses the products of such research.

All of this means that American industry has an important stake in scientific research, and my thesis today is simply that the management of American industry has a two-fold responsibility:

1. To understand something about the nature of scientific research—its possibilities and limitations.
2. To formulate and carry out a policy concerning industry's relationship to research—how it will foster it and how use its results.

This is a large order. And I know that many an industry representative will at this point smile indulgently at the naiveté of a college professor.

Understand science? Develop a policy relating to research? How in the world can a company official do that? With all his worries about taxes and government controls, about markets and advertising, prices, dividends, labor relations, wages, pension systems, production, raw materials, new models, what his new competitor is going to do, what the new Congress and the new

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President are going to do—with all these inescapable worries, how is the management of a business going to give any attention to science?

Well, frankly, I don't know. That's your problem. All I say is that whether a company is still in existence and making a profit 10 or 20 years from now—or what kind of a product it will be making or selling then—is more likely to be determined by what happens in the laboratory than in the accounting office, in the sales office, or even in Congress or the White House.

If you don't believe me, think back 50 years. The changes that occur in the next 25 years will be every bit as great as those of the last 50. How many companies of today even existed 50 years ago? And of those that do date back to 1903, how many were then making products or using methods which were the same as those of today? And how many companies of 1903 have gone out of existence because they stuck to a product which became obsolete?

Yes, in 50 years we have gone from wagons and kerosene lamps to airplanes and television. And whence came all these changes? Did anyone in Washington invent radar or television? Did the political actions of Theodore Roosevelt or Woodrow Wilson create the radio industry or the oil industry?

No, the really great changes of the past—as of the future—stem from the creative ideas of men and women working in the laboratory, in the drafting room, and in the shop. And the management that ignores what goes on there is doing nothing more or less than ignoring the things that will really affect the future.

The first thing on which we must be clear is the nature of the complex process that goes on which gives rise to scientific discovery, and its eventual translation into products or techniques which are of use to human beings. Obviously, if we are going to participate in and, indeed, encourage the progress of technological change, it is important that we understand the nature of the process. Otherwise we may well be doing things which are ineffective, possibly harmful, and certainly expensive. Our disappointment will then make it more difficult for us to spend money for the right things in the future.

This process of scientific discovery and technological development, followed by large-scale use, is often grossly oversimplified. I suppose no one really believes that a basic discovery made one day can lead to a product in mass production the following day. However, there are those who seem to think that if there are more than a few months' delay, someone is responsible for negligence. But the real fact is that in the past there has quite commonly been an interval of something like 50 years between a basic new discovery in science and its practical realization in the form of a new device or technique.

Fifty years sounds like a long time in these days of "high power" research. But let us take some examples. It was in 1896 that Becquerel observed that compounds of uranium gave off radiation that could penetrate black paper and then metal sheets, and affect a photographic plate. This so-called radioactivity of uranium has only an indirect relation to the fact that 49 years later uranium was first used in an atomic bomb. But Becquerel's observation was nevertheless the discovery which ushered in the science of nuclear physics.

In 1896 no one had any idea of the meaning of the phenomenon of radioactivity. The idea that atoms even had a nucleus had not then been developed. And yet, looking back, we can see the inevitable march of discovery from Becquerel to Pierre and Madame Curie, to Rutherford, to Bohr, Cockcroft, Chadwick, Lawrence, Fermi—to many others, and then—to Los Alamos. It took 49 years and 4 months.

Radar—after 50 years

Or take the case of radar. For its beginning we must go back to 1887, to some experiments conducted by one Heinrich Herz, whose aim was to test some new theories of electricity and light which had been proposed by James Clerk Maxwell. Herz was the first to produce radio waves. He showed that they could be reflected and refracted, that they traveled in straight lines like light waves—and moved with the same velocity. Again, from that discovery, it was a direct series of developments over almost exactly 50 years to the first radar set.

I could give many more examples—all illustrating the single fact that wresting knowledge from nature is not an easy job. Fact upon fact, theory on theory, experiment on experiment, knowledge grows slowly and with great effort. It is like building an enormous structure of brick and stone. Each brick must be painstakingly laid; and as each one goes in, a place for a new brick is created. Every now and then a great keystone is fitted in, and the structure suddenly takes on new form and new beauty. But always must continue the process of placing one small brick upon the other.

There are many more workers on the structure now than a few years ago; they have discovered new techniques for laying bricks more rapidly. But on the other hand the structure has grown enormously more complex. It is no longer so easy to see how each new fact—each new piece of stone—is best fitted into the whole structure. Hence many false starts are made and we must more frequently tear down and rebuild.

Scientist and layman

I suppose it will always be impossible for a scientist to explain clearly to a layman just what this process of building the structure of science—or as we call it, carrying on scientific research—is really like. I have tried many times, and—with all due respect to the intelligence of my audience—all I get is a blank stare. It's like explaining falling in love; you just can't get it across to someone who has never done it! How can one explain how endless days and nights of drudgery can be exciting? How can a perpetual chain of apparently trivial things add up to something terribly important? How can one explain the indescribable patience of men who, year after year, generation after generation, spend their lives trying to understand the structure of a protein molecule, or of an atomic nucleus, when each apparent step forward leads only to new and more puzzling mysteries?

This is the process through which new knowledge in science is acquired—the slow process of finding facts, fitting facts to the theory, altering the theory, predicting new facts, testing the predictions. This process of research, first discovered in the 17th Century, is the single intellectual discovery which has transformed the world of 1600 into the world of 1953—and will continue to transform it into the still different world of 1973, of 2053.

From Becquerel to Alamogordo

As I have suggested, however, the discovery of a single new fact or principle does not lead directly or immediately to the manufacture of a new product. Why was it 49 years and 4 months from Becquerel to Alamogordo? The chief reason is that a new product usually depends not on a single scientific discovery but on the development of a whole science. Becquerel initiated studies in a new area of science. But it was really not until 1940, after years of work by hundreds of physicists—including men like Einstein, Rutherford, Bohr, Fermi and the others—that the science of nuclear physics had reached the stage where a nuclear explosion was even thinkable.

No single discovery led to the atomic bomb, though many brilliant ones were made during the chain of events that led to it: The atomic bomb was possible because there was a science of nuclear physics, painstakingly built by hundreds of workers over several decades.

Incidentally, this is one reason why there is so much confusion in discussions of the so-called "atomic secrets." There were no secrets in nuclear physics before 1940. It was a growing new science to which contributions were made by scientists all over the world—American, British, French, German, Italian, Russian, Japanese. And when some British and American scientists finally, in 1940, sat down together to discuss the development of an atomic weapon, they were familiar with and used the whole of nuclear physics. And it was clear to them that any other group of competent scientists in the world could design such a weapon just as well as they could. I repeat, there were no secrets then. It never occurred to anyone that there was any reason for a secret. The only secrets which later developed were the particular design tricks which made the bomb an efficient, practical device.

The basic objective

The point I am seeking to make, however, is this: the new things of the future will arise not so much from isolated spectacular discoveries or inventions as from the growing knowledge of science. The first objective of people interested in material progress, then, is to insure the future growth of science. This basic simple step is the one which we in America seem most likely to neglect or forget.

A second stage in this process of change—in this transition from discovery to use—is the stage of what we might call "applied science" or "technology." Modern radar and radio and television were, of course, impossible before Herz discovered radio waves and J. J. Thompson discovered the electron; before R. A. Millikan had measured the electron and identified it as the basic unit of electricity, before these and many other workers had created the science of electron physics. But to know all about the nature and behavior of the electron—though this was necessary—was not sufficient. Someone familiar with electron physics had to use this knowledge and develop an electron tube. Fleming and DeForest did this. And then many physicists, engineers, and inventors had to develop practical, versatile tubes, and useful and ingenious methods for using them.

Electron physics and electronics

The science of electron physics was thus followed by the technology of electronics. The electron, as it turned out, was the most extraordinarily versatile particle. Hence, there is a bewildering and ever-growing array of electronic devices—radio tubes, television tubes, amplifiers, oscillators, rectifiers, magnetrons, klystrons, travelling wave tubes, and so on.

And so it is in every field. Upon the *science of mechanics* there have grown several technologies: the technology of structures (which we usually call civil engineering); the technology of machines, or mechanical engineering; the technology of fluid dynamics, of which one part is aeronautical engineering. The science of sound leads to the technology of acoustics; the science of light to the technology of optics, of optometry and illumination.

In the same way, the various branches of the science of chemistry lead to a whole array of technologies covering various fields of chemical engineering, such as industrial chemistry, petroleum chemistry, high polymer chemistry. So, too, upon the science of plant biology we build the technology of agriculture, and on the science of animal biology, the technology of medicine.

Science, technology and change

A strong science and a strong technology; these are the elements that make for rapid and constructive change. It is the growth of these two realms of human activity, and the growth of the relation between them during the past 200 years—and especially during the past 50 years—that has led to the profound changes that have occurred in our way of living. It is the strength of science and technology which guarantees change for the future.

It seems to me, therefore, relatively obvious that industry in America should be aware of these elementary facts. And, I submit, they are not very complicated facts. Yet the consequences of being alert to them are both profound and far reaching. Let us examine these consequences. Let us proceed to the second question which I raised at the beginning: What policies must American industry adopt as it faces the future?

It would be presumptuous for me to attempt a general and complete statement of policy which would be adequate to insure the future of any or all industries. But I would like to suggest four elements which a complete policy must certainly contain. In the language of the mathematician, my four elements are *necessary* but probably not *sufficient* conditions for a promising future. I will state them in the form of propositions.

For a promising future

Number One is simple and obvious—one of those truisms which bears daily repetition: "No industry can be stronger than the community of which it is a part."

If I emphasize that the word "community" is to be interpreted broadly, the proposition is, as you see, a truism. It means simply that the welfare of your industry depends utterly on the welfare of your city, your state, your country—and upon the free world of which your country is a part. No one is isolated any more. Obscure events in far places may affect your future. This does not mean that every company manager must take on his shoulders the burden of assuring the welfare of the whole world. But it does mean that each company owes a responsibility to its local community and to the nation. It does mean that it is good business to contribute something to the welfare of the community and the nation. It means that it was inevitable that the leaders of American business and industry should do precisely what they have done in recent years; namely, take a broad and not a narrow view of their responsibilities.

The broad view

It is obviously not appropriate here to expound further on this first proposition. It was however necessary to state it as an axiom. For unless it is accepted, my other propositions become meaningless. Unless management takes a broad and not a narrow view, it will not be interested in science and technology at all.

Proposition Number Two is a little more definite—and equally a truism: "Progress depends upon people."

Of course every manager knows that. Doesn't he spend a good share of his time finding and assigning the right people to the right places? And it doesn't help any if I qualify the statement by making it read "key people" or "top people." They are all the harder to find. Exactly! And this leads me to my point—where do top people come from? In industry, in business, in science and technology, in the life of the community and the nation we grow ever more dependent on competent, high-minded and well-educated men and women. And where does one look for the source of such people? To the colleges and universities.

The problem of educating men and women for future leadership becomes especially critical if we look at the case of scientists and engineers. Modern civilization is truly one which depends heavily on such people. There are 20 times as many scientists and 5 times as many engineers per million of population in the United States now as there were in 1900. And the need has continually outrun the supply.

Sir Ewart Smith, Director of the Imperial Chemical Industries of England has recently stated flatly that the fact that United States productivity per worker is 2½ times greater than the British is directly attributable to the fact that there is a 2½ times greater supply of United States scientists and engineers per million of population. Clearly it is important to maintain our source of supply.

The managers of the future

Furthermore, as you probably know, the managers of American industry are more and more coming from the ranks of the scientists and engineers. In a representative group of American managers, about 40 percent began their careers in science or engineering. This figure is rapidly growing and the chances are that most of the managers of the future will be men now on your research or engineering staffs.

All of this leads to a simple consequence. Because industry leans so heavily on college-trained men, especially on scientists and engineers, it will be to the advantage of industry and the country if you make it a matter of policy to assist colleges and universities to survive and to keep flowing the supply of competent educated young people.

Proposition Number Three: "Knowledge Is Power."

After what I have said I don't need to explain this idea any further. *Knowledge is the difference* between today and yesterday; between today and tomorrow. The search for knowledge is one of the great and exciting endeavors in which human beings engage. It will be to your advantage to encourage and support those engaged in this adventure—seeking new knowledge in many fields.

There are many people these days who, knowingly or unknowingly, are discouraging rather than encouraging this search for new knowledge. They ignore or even deride those in scholarly pursuits; they derogate the intellectual; they point the finger of suspicion at new ideas; they persecute those who express unconventional opinions; they foster misguided notions about scientific "secrets," and thus impair the freedom of communication which is the life-blood of science and of the search for truth in any field.

You, the industrial leaders of the nation, have the obligation—for the sake of the future of your business, your community, your country, and free men everywhere—to stand out in favor of intellectual adventure. You, the trustees of free enterprise, know full well how the road to success and progress is strewn with risk, with dangers of trodding untried paths. Free enterprise is precious in the intellectual world too—and the road to new knowledge is also a dangerous road to tread. But tread it we must, and the pioneers who lead the way must be given encouragement and support, even if they make mistakes—as they surely sometimes will.

Where is the search for truth primarily pursued? You know the answer. The universities of the world have always been the primary homes of those who sought the truth. What can business and industry do to help? Here let me quote a few excerpts from a recent talk by the head of one of the country's largest corporations, C. F. Greenewalt, president of DuPont. Said he: "Our prospects for the future depend on a proper and harmonious blending of fundamental and applied research . . . We must at all times have a steady flow of basic knowledge . . . For this we must rely primarily upon our universities, for only in the academic environment can fundamental research in its true sense really flourish . . . It is unfortunate that financial necessities of some of our universities appear to have driven them more and more into the field of sponsored and applied research. This is a disquieting trend and I think it is one of industry's prime responsibilities to do what it can to reverse it."

DuPont has a very practical way of helping on this—cash; grants-in-aid for basic research. Your company may be able to find a better way—but it won't be easy. But the conclusion from Proposition Three is this: Encourage and support basic research in the universities.

My final proposition is simply a gratuitous piece of advice: "Support your own research organization."

It is not my intention to give you a long essay on how industrial research laboratories pay off and how every company should have them. You have all, no doubt, been exposed to the argument many times, and your companies have made their decisions one way or the other. But I need only point out that, as the university is the source of new knowledge, industry is the source of new technology.

A window to the world of science

For those companies who have research organizations I only wish to suggest that they be regarded by management not only as organizations for grinding out new products and processes but that the research and development staff be looked upon as a window to the outside world of science and technology. No one wishes to be left behind in the march of technological progress. One of the key functions of a research and development organization, even if it consists of only one person, is to keep the company alert to new developments and to keep the management informed as to their significance and potential impact upon the company. No speeches or articles or books can keep management informed of new developments which might affect it, but an understanding and alert group of trained scientists and engineers will give you a chance, at least, of staying in the running.