INVESTING IN RESEARCH

New ideas in the field of science deserve encouragement. Even though they may have no immediate usefulness, they may turn out to have a profound effect on tomorrow's world.

by L. A. DuBRIDGE

SOME DAY, I HOPE, when a proper history of civilization is written, the date 1769 will be described as one of the most significant moments in human history. It was in 1769 that James Watt invented the steam engine. Never before that moment had man had any source of energy to help him with his work other than his own muscles, the muscles of his horse or ox and, for those few who lived near a tumbling stream, the energy of falling water. Up until 1769, practically all of the mechanical work of the world had been done at the expense of human and animal energy—the human energy being largely that supplied involuntarily by slaves.

Men had, of course, learned to use fire—to warm themselves by burning wood and, later, by burning black rocks which the English called "coals"—but they had not learned how to put heat to *work*. That discovery did more to change the world than any single previous event.

Curiously enough, it was at a coal mine that James Watt put his new invention to work. Most British coal mines in those days were usually flooded. It took back-breaking work by men or horses to keep them pumped dry. James Watt conceived the idea of using some of the coal to generate steam to help in the work of running the pumps. The idea was successful—except that the engine had such a colossal appetite for fuel that almost the entire output of the coal mine was consumed in running the pumps. But ways were soon found to make the engine more efficient. And in a few years steam engines were pushing ships across the Atlantic, pulling strings of cars on rails across the countryside at unheard-of speeds of 15 or 25 miles an hour, and running all sorts of machines in many kinds of factories. It was not wholly a coincidence that less than 100 years later a great war was fought in America which wiped out human slavery from the Western World. Man's *new* "black slaves" were lumps of coal.

A number of years after James Watt's invention, a man named Michael Faraday was experimenting with some queer-looking gadgets and with pieces of iron and coils of wire. As a result of his work, Watt's steam engines were soon running *new* devices called electric generators—and the Age of Power had really begun. The symbol of the new age was also a salute to the age that had passed—the unit of the rate of energy consumption was called the "horsepower".

In the past 185 years the reciprocating steam engine has been followed by other forms of heat engines—the internal combustion engine, the turbine and the jet en-

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gine. The electric generator was followed by a whole complex of devices for transmitting and transforming energy. And today men produce many, many times as much wealth per day as in olden times—and yet few men indeed have to do real back-breaking work.

Now I realize that all of this is an old, old story to you. Why do I tell it again?

I tell it because, like many other old stories, it is so often forgotten. We forget so easily how enormously civilization has changed in the past 200 years—more than in the previous 4000 years of human history. The late Dr. R. A. Millikan, who died last December at the age of 85, frequently remarked that he belonged to the first generation of men who had ever been able to say that physical conditions of living were substantially different for their children from what they had been for them. The world before 1850 did not change much from one generation to the next. Our world hardly stays even recognizable for ten years at a stretch!

A changing world

Why? Because political institutions have changed? No! They haven't changed much. If they have changed, it has been a result and not a cause of other changes.

Have men changed? As far as either mental or moral capacities are concerned, there appear to have been no changes in men for the past 10,000 years—possibly more.

Has the earth itself changed? Is it warmer? Colder? Wetter? Drier? There have been changes in the past 5000 years in certain areas—but nothing very spectacular in the last 200.

No. The cause of all the change is simply that man, after thousands of years of cumulated experience, finally developed a new way of *thinking!*

That sounds like a surprising thing to say—but I believe it is true. Note that I did not say that men suddenly became more *intelligent*. No modern man has ever exceeded Aristotle or Euclid or many other ancient giants in intelligence or in the brilliance and originality of the thought processes.

Observation, deduction, thinking

But two men—named Galileo and Newton—invented a new *process* of thinking. This consisted, first, of observing nature, and then of deducing the regularities in the way nature behaved. Now men had observed nature before. And they had speculated before on what nature was like. But the idea had never fully dawned that nature behaved in a regular way according to fixed principles or "laws", and that these laws could be deduced by careful, systematic observation and analysis. Furthermore, once this deduction had been made, men could then *predict* the behavior of nature under similar conditions.

This process of observing, deducing, predicting, followed by new observation to test the predictions and correct the deductions, was a new thing in the world in the early 1700's. This new technique enabled men, for the first time, really to understand things—the falling stone, the moving planets, the whistling wind, the running water, the spinning wheel, the tossing ship, the hiss of steam.

And so—at first slowly, then faster and faster—men used this new technique of learning, of understanding, of thinking, to *do* new things. They could now design new devices and predict their behavior. The new knowledge and the new "laws" enabled men to predict what would happen—and what could *not* happen. As nature became understandable, her bounties became usable. Man was now the master of nature—not her slave.

Science—a new thought process

This new way of thinking—of learning, of understanding—is called science, from the Latin word meaning "to know". And this new process of using the knowledge of science to produce new things is called technology. It is science and technology joined together which have changed the face of the modern world. Science and technology—new ways of thinking!

It is so easy in these days to forget the importance of the human mind—of thinking. We send children to school to memorize letters and words, to learn tables of numbers, names and dates, how to move their pencils to write. All of these things are fine and necessary. But do we—about the sixth grade, say—ask if the child is learning to think? Or do we—if his bothersome questions suggest that he really is thinking—berate the teacher for putting strange ideas in his head? A famous *New Yorker* cartoon pictures a mother sending her daughter off to college with the admonition, "Now I hope you don't come home from Vassar with any *ideas*." Most parents actually hope the same thing. How they hate to see their offspring thinking—especially if he or she thinks up something they don't agree with!

And we don't restrict this aversion to thinking to our children. We admire the adults, too, who are "doers", not the ones who are thinkers—the great football player, the man who finds oil, builds a factory, flies an airplane. Fine! Sometimes these achievements require thinking, too. But it is the physical achievement, not the thinking, that we praise and reward.

Congress looks at science

Four years ago the Congress of the United States was debating a bill which had been before it intermittently for five years. No one was much against it. But only a handful seemed to be really for it. It did finally pass, and later the munificent sum of $250,000 was appropriated to implement it.

Was this a bill to build a monument to a dear old Kentucky Colonel? To widen the creek that ran through a Congressman's ranch? To air-condition the Senate office building? Oh, no! They would have passed easily.

This was a bill to create a National Science Foundation and to enunciate for the first time that the Government was interested in the progress of science and would even spend a little money to advance the kind of thinking that had revolutionized the world—and had, in the process, handed untold billions of dollars in wealth to the American people. Congress would not invest too much money, of course! Not as much as it would cost to build a new battleship. Not even a new destroyer. What about a couple of tanks? That was about right for the first year. For the second year, after a long argument, Congress appropriated about the amount that would have built a fighter aircraft. Four years later, today, there is a desperate hope that next year, at last, the amount will be brought up—to 100 million? Heavens, NO! 50? No! 20? Still dreaming! Actually, the budget request is for 13 million dollars. Thirteen million dollars to lay the base for the future! Thirteen million dollars—not enough to build a decent shoe factory!

Science and survival

Now it is not my contention that the progress of science will be halted if Congress fails to appropriate more money to the National Science Foundation. Science will find ways of moving ahead (more slowly, perhaps), no matter what Congress does. But I think it is disgraceful that only a small handful of Congressmen realize that it makes any difference what happens to basic science in this country (and I would guess that Congressmen are good representatives of the average citizen on this point). The issue before Congress is thus *not* whether it shall insure the *survival* of science, but whether or not it is to the selfish interest of the government and the country to *accelerate its progress* beyond what non-government funds can support. And this question refers not to whether we accelerate progress in the development of new weapons and products, but in the discovery of new *knowledge*.

Inventing before understanding

To illustrate this point, let us take some examples.

The invention of the steam engine was actually a very unusual type of event in the history of technology. Here an invention was made and put to use before the principles underlying its operation were understood. The science of thermodynamics—the interconversion of heat and work—was developed after the steam engine had come into use—not before. It was indeed the steam engine which stimulated research in this field. There have, of course, been a few other examples where invention preceded understanding, in cases where simple and well-known things like wheels and levers and hissing steam were involved.

Nevertheless, the invention of the steam engine did come after, and not before, the development of the scientific method by Galileo and Newton. It is since Newton that man's understanding of nature has grown so rapidly and uncovered so many wholly unexpected phenomena. Soon it became the standard pattern for new knowledge to lead to invention rather than vice versa. It is still true that every invention which proves useful stimulates further scientific studies which lead to improvements and to more new inventions.

Science leads to invention

The development of the technology of electricity is a perfect example of this flow from science into invention. The simple phenomena associated with static electricity —such as sparks from rubbing cat's fur—were known for 2000 years before systematic investigations were undertaken. Then came Gilbert, Franklin, Coulomb, Volta, Ampere, Oersted and, finally, Faraday and Maxwell. Within a space of 100 years, the science of electricity was created, and the basis laid for the technology of the electrical age.

It is astonishing to reflect on the rather simple series of observations and discoveries which laid the basis for modern electrical technology. Coulomb measured the tiny attractive forces between two charged pith balls—and showed that electric forces were like gravitational forces. He thus laid the basis of electromechanics. Oersted observed the deflection of a magnet placed near a wire carrying a current and Ampere analyzed the data and discovered the law of force on which all modern electrical machinery is based. Faraday thrust a magnet into a coil of wire and noted a momentary electric current—the phenomenon underlying all electric generators.

These simple experiments were, of course, repeated, elaborated, refined and subjected to extensive analysis and further tests by scores of other workers before the science of electricity was a complete structure. And even today it is still being built.

Intellectual "dreamers"

Now these men I have mentioned were not inventors—they did not themselves invent practical machines or electrical devices. These men were dreamers, "impractical guys". They were probably called "eggheads", or the equivalent, by the anti-intellectuals of those days. Their primary concern was the *understanding* of electrical phenomena.

It was another group of imaginative men who used this new knowledge as a basis on which to devise the motors, generators, lights, telephones, radios and other electrical gadgets that are so much a part of our modern daily lives. You know the names—Edison, Marconi, Bell, Westinghouse, and many others.

By the early part of the 20th century, it was evident that electricity was here to stay and that it was big business. Consequently, special laboratories were established by electrical companies to extend the bounds of knowledge about electricity, to improve electrical machinery and devices and to develop new uses for electricity. Thus began the industrial laboratory which proved in a big way the commercial value of applied scientific research.

Such applied research indeed has built our modern industrial civilization. There is hardly a single major industry in this country which is not now largely built on products or techniques which were mostly unknown a century ago. Many are new in the last quarter century.

But, while industrial laboratories have been turning out new products, the university laboratories have been equally busy uncovering new knowledge. In the 1890's, for example, while electrical machines were just beginning to come into practical use, the physicists in the universities in England, France and Germany were busy looking into still newer things. They found that electricity could be conducted through gases at low pressure and from a host of exciting experiments came the discovery of X-rays, of emission of electricity from the surfaces of hot bodies or surfaces illuminated by light. This electricity, it was found, consisted of charged particles—the electrons. Thus, the basis for the modern electronic industry was laid. The discoveries of the university laboratories again became the basis for new developments in industrial laboratories.

Common sense can be a handicap

At about the same time, while investigating the recently discovered X-ray, the French physicist, Becquerel, discovered radioactivity. No one knew what that was going to lead to. Indeed, physicists struggled with their attempts to understand radioactivity—and the new science of nuclear physics which it led to—for 40 years before anything of practical value emerged. Here was a really new and puzzling area of science—what goes on in the unimaginably small nucleus of the atom. A whole new set of techniques had to be developed and a whole new way of thinking about things. In this subatomic world our old "common sense" ideas no longer hold. In fact, common sense is a distinct handicap in doing research in this field. For common sense, after all, is only the accumulated and systematized past experience of human beings, leading to a sort of innate feeling that we all have about how things *ought* to behave. Common sense tells us that water, left to itself, flows down hill, not up—which is true. It used to lead people to the belief that the sun and planets rotate about the earth—which is *not* true. It tells us that heavier things fall faster than light ones—which is, in general, *not* true.

The atom contradicts

But human beings haven't had much experience inside the atom. It turns out that things are different in there. Things that ought to be particles turn into waves, and vice versa. An atom which has been sitting around the earth quite peacefully for several billion years, suddenly blows up—for no determinable reason! Worse still—it apparently is not even sensible to ask what the "reason" was!

You can understand, perhaps, how the physicists of the 1920's and 1930's appeared to many people to have gone quite crazy. The industrialists, especially, were disgusted with the nuclear physicists—they seemed to have lost all contact with the "real world". They were no longer talking "common sense"—which was true. They were talking about things wholly new to human experience, things for which common sense—by its very nature—could not be any guide.

Dreaming into reality

Today—with the excitement about the H-bomb ringing in our ears—there is no longer any argument about such studies being "useless". We may wish they had never been undertaken, because some of the consequences are so unpleasant. But we realize now that the dreamy nuclear physicists of the 1920's and 1930's were doing things which would have far more influence on man's future than the activities of all the businessmen, engineers and politicians put together. Again we see an example of the oft-repeated truth—that it is not the "real" world but the *dream* world of today which leads us to the "real" world of tomorrow.

Accelerating discovery

Now it is so easy for the layman to appreciate how the discoveries of *past* years have led to the commonplace things of *today*. It is less easy to visualize that this process of discovery is still going on *today*. Still less that there are things we can do to affect the rate of discovery. Industry long ago proved that once a discovery is made, it is possible to accelerate the process of making practical applications. But the idea of accelerating discovery itself is new and its possibilities are not fully realized. How does one go about it? Only a few simple things are required:

1. Find the good and the promising scientists. (This is quite easy.)
2. Pay them enough so they can stay in science, rather than go into engineering and administration. (That is not so easy!)
3. Provide them with the facilities they need. (If our government spent one-twentieth as much for *science* as for weapon development, we would be fairly well off!)
4. Encourage the education of young scientists. (The Russians have twice as many young scientists in training as we do!)

And yet, right now we are drafting into the Army thousands of graduate students in science and engineering. Thousands of others, seeing what happens to their friends, enlist for an even longer period. These kids laugh in a rather hollow way at those of us who keep insisting that our country needs more scientists. If the need is so great, why has not the Selective Service System heard about it? Possibly you know the answer to that. I don't! It is another example of the failure of our people to understand that our future welfare and security depend so vitally on a few thousand people who are seeking new knowledge.

Now I have suggested that great new discoveries still lie ahead. I believe indeed that our mode of living will change as much in the next 50 years—assuming we survive them—as in the past 50.

Research into the unknown

What are the discoveries that are going to be made? If I could answer that question, obviously the research would not have to be done—for we would already know the answers. That is one of the great difficulties in explaining the situation to many Congressmen. They say, in effect, "Tell us what discoveries you want made and how much it will cost to make them and how valuable they will be, and *then* we will decide whether to supply the money." And how helpless one feels in trying to explain that that is like asking one to provide a photograph of what an inhabitant of Mars would look like—if Mars had an inhabitant. It is *so hard* to describe the unknown! It is even hard to convince some people that there are things still unknown. It is hard to explain how one seeks the unknown. For example, how could anyone have proposed in 1938 to undertake a project to discover nuclear fission when the very idea of fission was not in existence? That discovery, like most others, came out of general research work, seeking not a particular end—but merely to learn more.

Financing discovery

How, then, can one finance discovery? I have already outlined the steps—one must find good people, have faith in them and help them do what they want to do. To a Congressman that seems like a frivolous waste of taxpayers' money. But Congressmen and taxpayers must learn that it is the most important use they can make of a few million dollars a year.

Now, of course, scientists do not work completely in the dark. It isn't as though they had *no* idea what they were looking for. One explores the unknown by starting with what is known. We know a little about nuclear physics—and we understand only a little of what we know. It is obvious we should seek to learn more, to understand more. Every nuclear physicist can pose enough questions to keep himself busy answering for a lifetime.

As it happens, nuclear physics, having proved to have "practical value", is now receiving fairly adequate support.

But let us take low-temperature physics. Physicists can now attain in the laboratory temperatures as low as a few millionths of a degree above absolute zero. That ought to be close enough, you might say. But it isn't! Every tiny fraction of a degree reveals new information—and opens up endless questions of how matter behaves when *all* its thermal energy has been removed. Does it have other kinds of energy left? Are the molecules really "at rest" at absolute zero? Do all substances become perfect electrical conductors near the absolute zero as some do? Liquid helium, at very low temperatures, becomes a wholly new type of substance, never seen before. It is neither solid, liquid nor gas. It looks like a liquid, but spontaneously leaks out over the sides of any vessel in which it is put. The study of this curious stuff is causing basic revisions in our theories of matter.

Of what practical value will it be to learn about these things? I haven't the faintest idea—because I don't know what things will be discovered in finding the answers. I do know that understanding how matter behaves at low temperatures will certainly help understanding how it behaves at high temperatures. And it is *understanding things* that leads to inventing new uses for them.

Discovery of new knowledge

Let us take another example. We know a little about the chemistry of living things—very little, in fact. I think I need not argue the value of knowing more in this field. You and I are just big (or little) chemical factories and chemical machines. If these machines never got out of order, we might not be so curious about their workings. But they *do* get out of order—and when they do, it usually *hurts!* So we have powerful incentives for learning more. A good deal of money is available to those working this field. The only difficulty is that too often a worker, before he gets the money for his research, must prove that the things he has not yet discovered will be of value in the cure of cancer, or polio or some other disease. This is bad. It is quite right for money to go into some research which has to do *directly* with the study of a disease. But more should go for supporting the discovery of new knowledge, for helping good men find answers to questions *they* think are important, even if the application to a disease is not evident. Some really new discovery may provide at one stroke the cure for a dozen diseases—as did penicillin. And the discoverer might not be working on a cure for any disease at all.

Earthquake as a scientific tool

In some fields of science the areas of discovery and of practical value lie very close together. The problem of the nature and structure of the interior of the earth, for example, has always been a challenging mystery—a mystery still largely unsolved. We can drill an oil well down 16,000 feet into the earth's crust—and we have learned much from this and other methods of looking at the earth's skin. But 16,000 feet is only three miles—and it is about 4000 miles down to the earth's center. What lies below the reach of our drills? How can we begin to find out? The tool that is used is a surprising one—the earthquake. To the ordinary person an earthquake is something that shakes down houses and buildings and starts fires—something terrifying and wholly bad. To a geophysicist an earthquake is just a procession of waves in the earth, spreading out in all directions like the sound waves from a bursting bomb. These waves travel in the earth. Some go through the crust, some are reflected from deep-lying structures, some go clear through the center of the earth, being bent or reflected in complex ways during their journey. These seismic waves thus constitute subtle probes which yield up secrets of the earth's interior. Geophysicists even start small earthquakes of their own by exploding buried charges of TNT, to get information on rock formation, often useful in the search for oil. But it takes a really big natural earthquake to generate waves intense enough to go clear through and around the earth.

The physicist and the earthquake

Hence it was that in 1952, when a severe quake shook Tehachapi, California, a swarm of geophysicists—mostly from Caltech—descended on the area to set up instruments to record all the aftershocks that they knew would come. Their enthusiasm for the job gave the local inhabitants the distressing feeling that these visitors were actually *glad* there had been a quake. In watching the gleeful pride with which they now exhibit the miles of records they have obtained of the thousands of small tremors that followed the main one, I am convinced they *were* glad the quakes occurred. More has been learned from that one series of quakes which has been going on now for nearly two years, than in all previous quakes put together. Modern instrumentation is revealing things never before suspected.

What is being learned? First, more about the structure of the earth—of its surface rocks and of its central core. Second, more is being learned about earthquakes themselves—the nature of the complex earth motions that occur. And this knowledge will better enable us to study the effects on structures, and thus to design buildings which will stand up and hold together under these motions. Finally, these wiggly lines on sheets of paper that constitute the records of earth motion give the scientist information about the strains in the earth's crust that *cause* earthquakes—thus giving hope that some day in the distant future in certain special locations it may be possible to predict whether an earthquake is likely soon to come.

Discoveries from astronomy

To jump to another field; some men study the stars! Why on earth should anyone spend money on studying the stars? Curiously enough, men have been willing to spend money on astronomy for hundreds of years. Long before the nuclear physicists dared think about asking for a million dollars to build a cyclotron, astronomers were building or using giant telescopes costing many millions. Why? There have been practical results, of course. All of navigation and time-keeping are based on astronomy. Helium was first discovered in the sun—and in the sun was discovered the first thermonuclear reaction. The sun and all other stars are indeed just giant continuously operating H-bombs.

Curiosity forces study

But I think we would encourage research in astronomy even if there had been no "practical" results. The stars in the heavens stand as a continual challenge to man's divine curiosity. Those stars—what are they? What do they mean? What is beyond them? What are they made of? What keeps them shining? How did the universe begin?

These questions, in my opinion, illustrate the most important of all reasons for studying science. Man's unquenchable curiosity *forces* him to study it. Some men are challenged by the mysteries of the stars, some by the mysteries of the atoms, others by the mysteries of living things, including ourselves. Pity the poor man who is challenged by none of these mysteries! He is the man who also can't understand why men try to climb Mt. Everest, or why they explore the South Pole or the bottom of the sea. Pity the man who does not feel—in a vicarious way at least—the challenge of the unknown. He does not know that the chief way in which men differ from the beasts is in their urge to explore, to know, to understand.

I realize that today I am talking to a group of "practical" men who do not waste time and money on useless things. You are men for whom the most derogatory of all epithets is "impractical." You have only contempt for the impractical dodos who clutter up the world—your business, your community, your government. You, as business men, avoid them like the plague. They lose money for you.

A plea for the dreamer

And yet I have the nerve to come before you and plead for the impractical guy—the dreamer. And I do it on the paradoxical grounds that it is *not* always practical to *be practical;* indeed, being impractical is often eminently practical. Or, to abandon a mere play on words, what I am trying to say is that new ideas in the field of science, which may appear to be without *immediate* usefulness, may turn out to have a profound effect on tomorrow's world. We ought to go out of our way to encourage such new ideas. We should invest money in them. As we bring to practical use today the new ideas of yesterday, let us do what we can to creat those conditions which will nurture more new ideas which will come to fruition tomorrow, or possibly the day after. We shall not be able to foretell which ideas will be most valuable, or when. We must have faith that new understanding will be useful. And, in any case, we must believe knowledge is good for its own sake.