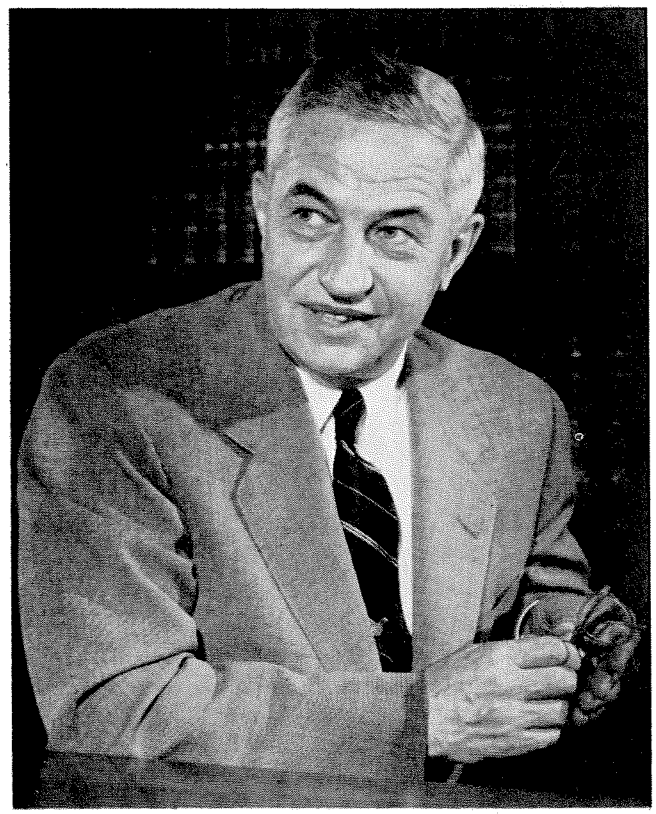
SCIENCE, THE ENDLESS ADVENTURE



By

L. A. DuBRIDGE

MUCH HAS BEEN written in recent years about science as the hope of man's future and also about science as the instrument of man's destruction. You have read of the possible glories of tomorrow's world of technology when people won't have to work—but only push buttons—and can spend endless hours of leisure speeding across the country in radar-guided, air-conditioned, pink Cadillacs at 120 miles an hour or more. And you have also read of the utter ruin which civilization would face in case of an all-out war using all the modern techniques of destruction.

You have heard of many such things which are probably true. Advancing technology is going to bring about great changes in our methods of living—changes in the next 50 years as great as those in the last 50. But it is also perfectly possible that an all-out nuclear catastrophe will intervene.

You have also read other things that are untrue or improbable. I think the imminence and practicality of space travel by humans (not to mention its desirability) have been grossly exaggerated. Cheap and abundant atomic energy is still a long way off—though in some parts of the world (not in America) it will soon be cheaper than other sources that are available. Still other promises you have heard violate basic laws of physics, or else they would be fantastically expensive.

Yes, the comic-strip artists, the science-fiction writers, as well as good solid scientists and engineers, can paint exciting pictures of the new devices, gadgets and machines that we will all have in 25 years. But these are not things I am going to discuss now.

Nor am I going to talk about whether these extraordinary things that technology is going to bring us are good or bad. In fact, no one can say—for *anything* can be *either* good or bad, depending on how it is used, whether it's a stick of wood or a stick of dynamite. *Things* aren't bad; only *people* are bad. And as to whether people are going to be bad or not there is no argument; some of them certainly will be. But whether they are or not, these new *things* are going to come anyway—*for no force on earth can stop men from thinking*, from inventing, from exploring.

But I am not going to discuss the things men will invent. I am going to talk about the things men are going to *think;* the ideas they are going to explore.

The things men invent will arise from new things they learn, from new understanding they acquire about the world. On the foundation of new ideas, men create great new technologies, new industries, new machines, new ways of doing things.

I propose to examine not the superstructure that men have erected on the foundation of knowledge, but the foundation itself. I am not going to explore the glittering

"Science—the Endless Adventure" is a transcript of a talk given at the 94th Annual Convention of the National Education Association in Portland, Oregon, on July 6, 1956.

upper rooms and towering pinnacles of technology—I propose to go to the basement and examine the foundations of science on which all technology is based.

And I propose to talk first about science not in the light of the new technology to which it may lead, but to talk about science for its own sake—science as a method of thinking, science as a method of acquiring new knowledge, science as the key to understanding, the road to comprehension of the physical world. I am going to speak of science, the endless adventure.

From the day that man first acquired consciousness he began to observe the things about him—the nature of fire, of water, of the winds, the sea, the stars. And as he observed, he remembered and reflected. He noted the regularities of nature. Fire could nearly always be produced in a certain way and extinguished in certain ways. The sun marched regularly across the sky—though more careful observation showed that its path changed almost imperceptibly from day to day, from week to week, and at the same time the weather became warmer, then cooler, then warmer again. When these invariable regularities of nature are reduced to their simplest form, we call them the "laws of nature."

At a very early time man must have been conscious of numbers—the number of his children, the number of his wives, how many animals he killed, how many enemies he had. Primitive men had words for only three numbers—one, two and *many*. Gradually the "many" became sorted out—3, 4, 5, 10. Curiously enough, it was a very long time before men discovered the number "zero" and learned to use it.

The importance of numbers

At this juncture I should like to pause a moment and reflect upon the importance of numbers—and upon the science of mathematics which has been built upon them. How many of us realize how utterly impossible our modern way of living would be without a number system and without our science of mathematics. Suppose we had not yet invented numbers above 10. Suppose even we had to add and multiply with Roman numerals. For example, how do you multiply XVI by MCMXL?

Suppose we were unable to deal with numbers higher than a million, or even a billion. That might have a salutary effect on government budgets, of course, but there are quite a few large corporations whose gross incomes are above one billion dollars too.

But, if we come to think of it, how many people *do* know what a billion really means—or even a million? Counting as fast as you can—say 3 per second—it would take you 3 days, 24 hours a day, to count to a million—over 8 years to count to a billion.

As an illustration, let me ask you how big a house would be if it were a million times as big as your house—assuming you occupy an average size dwelling. Would it be as big as the Empire State Building? As big as an Egyptian pyramid? As big as the Pacific Ocean? As the whole earth? As the solar system? You might amuse yourself by proving that a house with a million times the dimensions of yours would have a volume some 10 to 50 times the volume of the *earth*.

My point is that very few people really know what a factor of a million really means. Especially when we deal with a million *cubed* as we do in computing a volume.

Is it any wonder that we find it difficult to realize what it means when we say that a modern hydrogen bomb has an explosive energy 20 million times as great as a 1-ton TNT bomb? But we should not be misled the other way either. For the radius of destruction of a bomb depends on about the cube root of its explosive energy. And that means a 20-megaton bomb has a radius of damage only the cube root of 20 million—or 270 times as big as for a 1-ton bomb. That's still a damage radius of 10 miles or more. But a Los Angeles paper recently published a letter expressing fear that Los Angeles people might be hurt by the blast of the Bikini tests—5000 miles away! To do that would take the power of 125 million 20-megaton bombs.

Dealing in billions

Now I am not trying to confuse you or scare you. I am only giving some spectacular illustrations of the importance of numbers in the modern world—the importance of being able to think in quantitative terms. Why do we still teach arithmetic as though numbers bigger than 100 or 1000 were too complicated to grasp? A million is 10^6, a billion is 10^9, a million squared is 10^{12}, and $10^6 \times 10^5$ is 10^{11}. It's very simple! Even a little experience with exponents would give youngsters a lot of fun—and would make it possible for them, out of their own experience, to deal with millions and billions in a more meaningful way.

I noted the other day a curious example of this inability to deal with numbers larger than a billion. A science story in a weekly newsmagazine contained the statement that in a certain volume of air there were "billions of molecules." Now, of course, that is perfectly true but it is about as significant a statement as though we said that on the earth there live dozens of people. There are, of course, many dozens of people on the earth; in fact, there are about a quarter of a billion dozen. Similarly, there are many billions of molecules in a cubic centimeter of air; in fact, there are 30 billion *billion* molecules. We feel sorry for primitive men who were unable to distinguish numbers higher than 3 and referred to everything else as "many." Some day in the future, people will think of us 20th century humans as being rather primitive because we were unable to think in terms larger than a billion.

Our whole modern civilization is built on mathematics! Not a street can be laid, a foundation dug, or a building constructed, without the use of algebra, geometry and trigonometry. Not a machine can be designed, an engine's performance predicted, an electric power plant constructed without mathematics through calculus. The design of an airplane, a ship, a guided missile or an electronic computer requires a profound knowledge of higher mathematics, while the really interesting fields of nuclear physics and astronomy use group theory, matrix algebra and non-Euclidean geometry.

In other words, no one from a grocer's clerk to the nuclear physicist can do without mathematics—and the study of mathematics can be a great adventure in the methods of quantitative thinking which will provide to everyone a lifetime of better understanding of a technological world.

Journey to the sun

But let us turn now to adventures in the world of physical science rather than mathematics. I should like to start the adventure with a journey to the sun. Adventurers who climb Mt. Everest are pikers; we are going to explore (in our minds at least) what we would find at the center of the sun.

Now the first thing we notice about the sun is that it is hot. It is very hot, in fact. The surface temperature is about 11,000°F. That is higher than any temperature ever observed on earth except in the burst of an atomic bomb. That is far above the melting point of any material we are familiar with; it is far above the boiling point of most materials. Therefore, the sun is very much like a ball of hot gas.

But the surface of the sun is its coolest part. It is easy for an astrophysicist to prove that, because the sun is so massive and the gravitational forces are therefore so enormous, the sun would promptly collapse into a very much smaller object unless the central part of the sun is at a very high pressure and temperature. In fact, the central temperature is probably about 23,000,000°F. The pressure is so great that the central portion has a density 10 times the density of lead, though it is still a gas—in fact it is mostly hydrogen.

The age-old question about the sun, of course, is what keeps it so hot. We know that the earth has been at roughly its present temperature for 4 billion years or so. The sun must have been at about its present temperature equally long. Where does all that energy come from?

Up until just before World War II—very recently you see—not even the beginnings of a satisfactory answer had been found. We know now that the only source of energy possible is the transmutation of matter—specifically, in the case of the sun, the transformation of hydrogen into helium. The sun, in other words, is a big continuously-operating hydrogen bomb. It would, in fact, explode just like a bomb except that the gravitational forces are so enormous that it is all held together in a very nice balance.

Fortunately, there is a lot of hydrogen still left in the sun—enough to last for another few billion years in fact. Some day, however, it will be gone. What then? Will the sun collapse and cool off? No, it will collapse and get hotter! The gravitational energy developed in contracting generates still more heat, so the interior will get hotter as the sun gets smaller.

And then? Eventually the internal temperature will rise to about 200,000,000°F, at which point something new will happen. The helium which was formed by the conversion of hydrogen will now be at a temperature where it can begin to "burn." Three atoms of helium can join to make one atom of carbon; four atoms of helium can make one atom of oxygen. In both cases energy is again released so that this source of heat will maintain the internal temperature of the sun at 200,000,000°F. until the helium in turn is all used up. At this stage the sun will start to collapse again; the internal temperature will rise still higher until the point is reached at which the carbon and oxygen atoms will begin to combine to form still heavier atoms, building up eventually to elements in the neighborhood of iron. By this time, the temperature of the center may have reached several billion degrees F.

During these various processes, there are intervals of possible instability and the possibility of an explosion arises. We do not know precisely the conditions under which an explosion might take place, but explosions of distant stars have been observed in the heavens. They are known as supernovae. But at this point our knowledge gets very vague indeed. In fact, it is only in recent months that a detailed quantitative picture of the evolutionary history of the stars and of the process of atom building has been worked out by combining the knowledge of astronomy with knowledge recently acquired in the laboratories of nuclear physics. Again the problems and techniques of mathematics play an important role. Just recently Dr. Fred Hoyle of Cambridge has evolved a project for making detailed computations of the evolutionary history of the stars, a project which will require five years to complete on one of the fastest of modern computing machines. (Incidentally, those who wish to pursue this whole subject more thoroughly could do no better than read Dr. Fred Hoyle's very recent book, *Frontiers of Astronomy*, or the special issue of *Scientific American* for September, 1956).

A daring and intricate adventure

This, I claim, is one of the greatest of all adventures in science—the most daring, the most intricate. The sun is only one of a billion stars in our galaxy. And there are millions of other galaxies equally large scattered through space. The faintest that can be seen on the plates of the great 200-inch telescope at Palomar are 2 billion light years away. Yet we know that the same elements—the same kinds of atoms and molecules—occur in these distant stars as in our own sun. The same laws of physics apply—the same sources of energy must exist. No doubt there are some stars which are fairly young—are just beginning to "burn" their hydrogen. Others are probably old and hot. Some stars have gone through the explosive phase. Some supernovae are still glowing after many years; some appear to be "decaying" with a half-life of two months or so, like a radioactive element. Indeed there is evidence, recently noted by Fowler, Burbidge and Hoyle at Caltech, that possibly the great explosion did produce a vast quantity of radioactive material—just as does the explosion of a thermonuclear bomb.

This is one of the most exciting aspects of the great adventure of modern astronomy—the intimate way in which it brings the sciences of spectroscopy, of nuclear physics, of electronics, of cosmology, of quantum mechanics—each one helping to fit in some piece of the vast jigsaw puzzle.

Radio astronomy

There are other exciting developments in astronomy. Many years ago a radio physicist named Jansky was tracing down some of the sources of noise in a sensitive radio receiver. There were faint hissing sounds which he could not trace to electric motors, spark plugs, thunderstorms, or the other usual sources of "static." He eventually found that these flickering radio waves were coming from the sun! So began the science of radio astronomy.

It was not until 1946, however, that electronic techniques had been developed to allow radio observations to be made consistently and exactly. Today we know of hundreds of objects in the sky which are sources of radio waves. Some are stars like the sun; some are distant galaxies. Possibly the most interesting source is the great cloud of hydrogen gas which exists in the Milky Way galaxy and which gives off radio waves of a frequency of 1420 megacycles—a wave length of 21 centimeters, about 8 inches. In fact, there are parts of our Milky Way which are obscured by clouds of dust in space so that no light gets through. However, the radio waves from the hydrogen clouds do come through and so the only direct knowledge we have of the other side of our own galaxy beyond the dust clouds is supplied by radio waves. And from them we can learn something about the structure and velocity of that part of the galaxy.

Radio waves from the stars! Who would have thought it possible a few years ago? Or who would have thought that obscure studies at Columbia University on the energy levels in hydrogen could have led a couple of physicists — one in Holland and one at Harvard — to guess that hydrogen in space could emit 21-centimeter radio waves — then to look for such waves and find them? Today great radio antennas, radio telescopes—far larger than the 200-inch, but less expensive—are being built all over the world to explore further the nature of the stars as revealed by the radio waves which the racing electrons in their outer atmosphere emit. Since radio waves penetrate air, haze and clouds, a radio observatory does not have to be located in a clear climate, like southern California, or on a mountain top. In fact, the flat plains of Holland and the clouded moors of England and Australia have been primary locations for radio work.

They have there detected waves from sources which are so distant that for their waves to be detected here they must have been projected from a source as strong as a 50-kilowatt broadcasting station—multiplied a *million billion billion billion* times over! The power radiated is the inconceivably large figure of 10^{33} kilowatts. That's as much energy as the total energy from a hundred billion suns. It is lucky indeed that that source is so far away. If it were much closer, the earth would be so blanketed by radio "static" that radio and television broadcasting would be completely impossible. It is possible that radio telescopes may be detecting objects that are so far away that they cannot be seen or photographed, even with the Palomar telescope.

We see then that astronomy, though it is one of the oldest sciences, is being rejuvenated even today. New telescopes have made our distance measurements more accurate; new electronic techniques are extending the power of both optical and radio telescopes; new knowledge of nuclear physics is helping us understand how the energy of stars is produced, how all the different chemical elements are built up from primordial hydrogen, how the stars evolve, how some blow up, condense again and begin a new existence.

I am told that back in the 15th century so few people could read that millions of young people who were contemporaries of Columbus, Magellan and the other early explorers had never heard of their explorations—never knew that the new world had been discovered or that a ship had sailed clear 'round the earth.

The language of modern science

Today we run the danger that because our school children are unable to "read" the language of modern science, they too will miss knowing about the great explorations of this generation—the intellectual examination of the frontiers of space. It is true that some day people may travel out into space beyond the earth. But such excursions will be limited indeed. We could conceivably reach the moon in one day of travel at 10 times the speed of sound. We could reach Mars in 6 months. But to come into the vicinity of even the nearest star would require 100,000 years. Even at 100 times the speed of sound it would take 10,000 years. Hence, the only experience that human beings will have with the far reaches of space will be through the messages brought by light and radio waves. And even these, the fastest of all messengers, have been on the way for millions or billions of years.

So let us make it possible for our new generation to have the fun of understanding these marvelous adventure stories. Just a little familiarity with mathematics and science will help a lot.

The adventures of science are by no means confined to outer space. And the chief practical reason for learning the language of science may not be to understand about distant galaxies, but to understand what is going on right here on earth. There are adventures in each day's routine.

You arise in the morning to the ring of an alarm clock—an electric clock, no doubt, synchronized within seconds to millions of other clocks all over the country, all over the world. Synchronization is achieved by the miracle of alternating current in our power lines, connected in a network extending hundreds of miles, and connected by radio to other networks far away. Adventures? Just follow those alternating current impulses back along the wires to a transformer on a pole in the street, to higher voltage lines leading to a substation, to still higher voltage lines strung across the countryside to a power station by a dam in the mountains.

Or maybe the power station burns coal or oil—where man's most primitive discovery, fire, is producing his most modern carrier of energy, electricity. Think of the inventors, engineers, scientists—back through the generations, the centuries—who made that possible. Think of Michael Faraday in a little laboratory thrusting a magnet into a coil of wire and noting that a current was produced; pulling it out, the current was reversed—an alternating current!

A day's adventure

And so, even before we awake in the morning of each day, our adventure has begun. We get out of bed, put on nylon hose, a dacron shirt or an orlon sweater—fabrics made of coal and air and water. Shades of the alchemists who tried to make gold from lead! They would have been far better off if they had made nylon from air! And as you dress be glad you are not a silk producer of Japan or a wool grower of Australia whose very livelihood is being threatened by synthetic fibers made in America. Yes, adventures in science have their tragedies too.

Your breakfast is another kind of adventure—food brought to you from the far corners of the earth, prepared over a flame which burns gas piped from Texas. And as you eat you read of world events only a few hours old—long stories, and even pictures, which have been flashed with the speed of light from London, or Calcutta, or Cairo. Only a few years ago—less than 100—a famous British physicist, Lord Kelvin, slaved away years of his life supervising the laying of a cable across the Atlantic through which feeble electric impulses (dot-dash-dot) could be pushed—slowly, but thousands of times speedier than the fastest ship.

After breakfast you step then into a real miracle—your car. You seldom look under the hood to witness the bewildering array of examples of the laws of thermodynamics, of mechanics, of electricity, of metallurgy—of almost every science and technology. All we care is that this device converts a gallon of gasoline into many miles of travel—at speeds much faster than we ought to drive.

As your day passes, you will skirt the edge of many adventures: a jet plane will streak above you; you will read that Congress is arguing about guided missiles, about satellites which leave the earth, and you wonder if the Congressmen know what they are talking about.

You read that a group of scientists visited Russia—and that they found themselves in full agreement with the Russian physicists on the neutron capture cross-sections of nuclei and also on the best design of a synchrotron. You were not interested of course—but you should have been. It was another example of the fact that adventures in science are international. All countries agree on the laws of physics. We may fight over the writings of Karl Marx—but not over those of Isaac Newton or Albert Einstein. Not even in a dictatorship is it possible to suppress for long the findings of science. A fake genetics promulgated by a certain Lysenko was given official state sanction in Russia for a time. But Lysenkoism is now dead; politics cannot for long suppress the facts of nature. We have tried it here too. We thought that nuclear physics could be kept secret; we forgot that scientists in other countries can ask questions of nature too—and get the same answers that we do. We also learned that secrecy in science is very expensive, for secrecy impedes the advance of science and also the advance of technology.

But your day's adventures have only begun. You drive past a TB sanitorium that is being closed—for lack of business. You pass a hospital where once fatal illnesses are cured in a few days. You may see some youngsters getting polio shots and know that another dread disease is on its way to extinction.

Inside a living cell

If the adventures in the stars or the atomic nuclei do not interest you, what about adventures inside a living cell? In recent years giant strides have been made in unraveling the chemistry of living things. The structure of protein molecules has been worked out. And now it is found that viruses, too, are complex molecules built in the form of multiple helices. These virus molecules can be crystallized and kept on a shelf for years, like any other chemical. But when they are given a chance to enter a living cell, they begin the miraculous process of sorting out the substances in that cell and building up a new molecule just like themselves. These molecules can reproduce themselves; they possess one of the essential features of living things.

The properties and behaviors of viruses can be studied now with all the modern techniques of physics and chemistry—not solely by trial and error, but by systematic analytical methods. One by one the different harmful viruses will be isolated, bred and studied until methods of destroying or controlling them are evolved. Beneficial viruses—those that kill harmful bacteria—will also be studied and used in the control of other diseases. The days of bacterial and virus diseases are numbered. It may be years and there will be some exhausting struggles, but these elementary substances now can be understood and controlled.

These then are a few of the thrilling adventures of today's science: the understanding of genes and nuclei and stars; the unraveling of the laws of atomic physics and cosmology and chemical biology. There are also adventures in the application of this understanding to new things to make people healthier, more comfortable, and to improve their way of life.

These adventures are daily getting more exciting. And they are adventures that more and more people will eventually participate in. The fraction of the United States working force engaged professionally in scientific and engineering pursuits has multiplied by 5 in the past 50 years. It can't multiply by 5 again else it would be getting up to 100 percent. But it may well double. The need is great and the opportunities are endless. The great challenge of our school system is to help every child with potential talents to develop them to the utmost.

The enjoyment of science

But men and women without professional interests in science may still enjoy these adventures of science. The language of the atom can be learned. After all, people enjoy music who do not perform. People enjoy literature who do not write. People enjoy adventure stories who cannot walk. Lawyers and businessmen and English teachers have learned to enjoy science.

For the exciting adventures of science have a great immediacy. From morning alarm to evening TV program we are living in a world which has resulted from adventures in science. Just as the great adventure of Columbus opened a new continent, so the inspired adventures of many scientists—from Galileo to Einstein; from Newton to Bohr; from Faraday to Edison to the thousands of trained men and women working today in laboratories throughout the world—have created on this new continent a new kind of civilization. There are certain things about this civilization that we are not satisfied with. It is far from perfect. But the defects will be fixed by those who understand the nature of the world in which we live. The world will be made better by knowledge, not by ignorance.

But the adventures in science are not only fun; they are an essential part of our everyday intelligent living. I have referred to Congressmen who vote on vast technical projects which they cannot possibly understand. But men and women in everyday life, in business, in law, in politics, are experiencing and making decisions on things which they too cannot understand. We spent strenuous efforts in this country to reduce illiteracy, to make it possible for every man, woman and child to read and write. We succeeded—but we face a new type of illiteracy today in which citizens are unable to read and understand the things about which they must make decisions, all the way from spending billions on nuclear energy to investing a few thousand dollars in a new chemical company; decisions as to what to do about smog; about putting fluorine in drinking water; about paying higher salaries to teachers of science. The ability to understand the adventures in science has a real practical value in addition.

But there are certain illusions about science and mathematics that must be eliminated before the adventures of science can be appreciated and advanced more rapidly in America.

The first illusion is that mathematics is too hard for young minds to grasp. That is false. Properly presented and properly taught mathematics is an exciting adventure—especially for youngsters. What has made it seem hard is the endless procession of dull and useless problems which are normally taught—"How many square rods in 19½ acres?" or "If A has 3 apples and B has twice as many as A and C together . . . ?"—you know the kind. Why crush the glorious excitement of the great principles of algebra, geometry, trigonometry—yes, and calculus—with an avalanche of useless detail? I suggest that to prepare a really first-class series of 7th- to 12th-grade texts on mathematics that really arrest a youngster's imagination, challenge his curiosity, and develop his quantitative reasoning, would be the greatest project that a teachers' group could undertake.

The second illusion that must be eliminated is that mathematics can be taught by teachers who don't know any math—or are only a chapter ahead of the student. As long as teachers of math must take 16 hours of education and only 3 hours of math, mathematics will be badly taught. For it is a subject which becomes really alive only with years of study and can be conveyed in simple and exciting ways to students only by those who have themselves caught its true spirit. In this respect, it is like most other subjects of real intellectual content—it will certainly be taught badly by those who know nothing about it, no matter how much methodology they have learned.

A liberal education

A third illusion that needs crushing is that mathematics and science are narrow, technical or vocational subjects and that only humanities and social science are "liberal" and "broadening" and teach one how to get along with human beings. Nonsense! Mathematics and science are great intellectual adventures that have enlarged and broadened men's intellectual horizons, freed the human spirit from ignorance and fear, and elevated him above a primitive existence. They are a proper part of every liberal education. And if our country is to continue to make progress in evolving the material tools necessary to insure attaining the economic, political and moral goals which we seek, then we as a nation had better re-examine the adequacy of our school curricula in preparing young people to talk the language and understand the problems of *tomorrow*.

For if we are cheating our children of the opportunity of enjoying the adventures in science, we are also cheating our country of the benefits of profiting and prospering from the talents of its people.