Science, Systems, Students, and Society

Frank T. McClure

(Presented in the guise of Distinguished Lecturer,
Franklin and Marshall College,
September 28, 1967)

MEMBERS AND FRIENDS OF THE COLLEGE. IT is an honor to be invited to speak to you tonight.

I don't really know how you approach this evening, but I know I approach it with considerable trepidation. An invited speaker always accepts his invitation months before the occasion but as the time approaches he increasingly faces the problem of what he can say which will be both understandable and informative to his audience. The question is one which is discussed so much today—communication. We hear that the young can no longer communicate with the old, the scientist with the artist, the black with the white, the poor with the rich, and so on. The thought is that our society has become so complex that it has fragmented into separate groups, each with its own language and culture. It is often stressed that this is particularly true in the professional world. One wonders how real this phenomenon is and, to the extent it is real, how new it is. A story, purportedly told by Adlai Stevenson in quite a different context, seems peculiarly appropriate. A preacher was much concerned about the reputation of a certain woman in his congregation, and he said to her on Sunday after the service, "Madam, I prayed for you last night for three hours." And she said, "Well, Reverend, you needn't have gone to all that trouble. If you'd have just telephoned, I'd have come right over."

Tonight, I would like to speak with you about how a scientist, or at least one scientist, approaches the understanding of the world around him. I don't mean to give you any answers to burning questions, but rather to outline a way of looking at things. Let me make it clear, however, that I do not wish to imply that science alone provides insight. My theme might well be taken from the writings of John Donne, some 350 years ago:

> . . . No man is an *Iland,* intire of itselfe; every man is a peece of the *Continent,* a part of the *maine;* if a *Clod* bee washed away by the *Sea, Europe* is the lesse, as well as if a *Promontorie* were, as well as if a *Mannor* of thy *friends* or of *thine owne* were; any mans *death* diminishes *me,* because I am involved in *Mankinde;* and therefore never send to know for whom the *bell* tolls; It tolls for *thee.*

When you have heard my story these words may have even deeper meaning for you, perhaps a meaning that would have been new to John Donne.

Let me begin by speaking about science itself, and more particularly about its method of seeking knowledge. First, and perhaps above all, the scientific method is empirical. This means it starts with observation of things as they are. Experiments are performed to see what happens if the circumstances are changed. These observations form the body of facts. These facts are then arranged into esthetically pleasing patterns which lead to the statements of the laws. The general is induced from the specific rather than the specific being deduced from the general. Thus the laws, theorems, hypotheses, or whatever you may call them, of science must correspond with the experimentally observable. If they do not, they are discarded and cease to exist as part of science, although perhaps retained as artifacts in its history. Second, it calls for consistency in that an acceptable body of laws cannot be demonstrably inconsistent. In particular a general principle cannot be accompanied by a lesser principle which contradicts it. One of them will have to go. Strangely enough there are many fields of human activity in which this requirement does not seem to have gained any prominence. Third, the method allows little reverence for authority or precedent. An announcement of a new truth by an eminent man draws great interest—but it becomes part of science only after it has been checked out independently by a number of other investigators. There is no one who is more a "man from Missouri" than a *real* scientist.

These three characteristics of the scientific method are largely responsible for the forward movement of science with its ever more penetrating questions. It shucks off the unfortunate and unsuccessful ventures of its past, "phlogiston" (the fluid which was supposed to be heat) and "ether" (the fluid which was supposed to fill empty spaces) are no longer part of its structure.

But this discarding of the old and replacing by the new in science is not done with gay and destructive abandon. It is more a matter of careful and skilled surgery where thorough planning and full understanding allow the undesirable tissue to be removed, with great care being taken to preserve that which is good. The approach is constructive rather than destructive. The aim is to build something better, not merely to destroy that which is not perfect.

Enough about the methods of science. To what are these applied? Science is concerned with the study of systems. But what are systems? Let me quote a few definitions taken from the many you will find in a good dictionary.

1. An assemblage or combination of things or parts forming a complex or unitary whole;
2. Any assemblage or set of correlated members;
3. An ordered and comprehensive assemblage of facts, principles, doctrines, or the like in a particular field of knowledge or thought;
4. A coordinated body of methods, or a complex scheme or plan of procedure.

Each of these describes in one case or another what I mean by a system, although the meaning I wish to convey is most generally covered by the first: an assemblage or combination of things or parts forming a complex or unitary whole. What is perhaps indirectly implied but not clearly enunciated is the most important feature of a system. This is that it is not the simple "sum" of its parts. Its characteristics are not merely the totality of the characteristics of all of its parts. Let me take a simple example. An automobile is a system. Reduced to its simplest parts it consists of nuts and bolts and coils of wire and peculiarly shaped pieces of steel and plastic and rubber. Let us collect a complete set of such parts and put them in a large box. That is not an automobile! Shake the box up a bit—still no automobile. No, the parts must be assembled in a very particular way and adjusted to work together in a coordinated and harmonious fashion—then you have an automobile.

The automobile may be used to illustrate another feature of systems. They often consist of interdependent assemblages of other systems, called subsystems in this case. The automobile has a fuel system, an electrical system, etc. The subsystems may also be ensembles of systems—now called sub-subsystems if you wish. The fuel system has among its components the carburetor and the fuel pump, and the electrical system has the battery, the generator, the coil and distributor—each of which has characteristic properties which can be examined separately from the automobile itself and which are not in any simple sense the sum of the properties of the bits and pieces of which they are made. This observation is not really as trite as it may seem. Suppose your automobile is performing badly. You don't simply kick it or set fire to it. Neither do you tear it down to the last nut and bolt and start over again. You ask what subsystem could be responsible for the undesirable behavior, and then what sub-subsystem until you finally find the faulty part or the incorrect adjustment that prevented the harmonious interaction which gives the automobile its desired characteristics as an effective operating system.

Enough about automobiles! I really didn't intend to give a short course in automotive mechanics. Let me mention a few systems which you might find scientists studying. You might find one studying the very small elementary bits of matter and how they are put together in various ways to form the nuclei of the various atoms. You would call him a nuclear physicist. Or one might be studying how electrons associate with these nuclei to form the atoms of the chemical elements. You would call him an atomic physicist. You might think of those who study how the atoms may be linked together to form the hundreds of thousands of kinds of molecules—both those which occur in nature and those created by man.

These men work at the science of chemistry.

But there is an even more complex system which is of deep personal interest to each of you —namely, you. Each of you is a system. And you are composed of subsystems—circulatory, nervous, urinary, digestive, etc., and the subsystems are composed of sub-subsystems—heart, liver, stomach, brain, etc. Although much more complicated, it's all much like the automobile, including the diagnosis and cure of illness.

What are your simplest parts? I suppose most biologists would say they are the billions of cells which make up your body—and which seem to be the kind of entity common to all life, both plant and animal. These cells, however, are also systems with a myriad of interacting parts within them. A particular one interests me tonight. In each cell there is a nucleus and in that nucleus there are chemicals called nucleic acids. Among the nucleic acids is a class called deoxyribonucleic acid—or DNA for short. The DNA molecule is very, very large. Its molecular weight is in the hundreds of billions. It consists of a long strand built from small molecules called nucleotides, with a molecular weight of about 300—so that you can see that the DNA is a string of perhaps a billion nucleotides. But there are only four kinds of nucleotides, and they may be arranged in any order along the strand. Think of it as a string of beads made up of beads of four colors—red, green, yellow and blue. Going along this string we might see the sequence: blue, blue, red, blue, green, yellow, yellow, green, red, red, blue and so on. Sounds like a secret code message, doesn't it? Well, that's exactly what it is—although it is not quite so secret now since the molecular biologists have made so much progress in decoding it. The long DNA molecule is demarked into shorter segments of perhaps 1000 nucleotides each which tend to act as entities themselves. They are what the biologists have long called genes. The code within the gene specifies the manufacture of a particular protein in the cell. Thus all the tens of thousands of different proteins which make up your body and its functions are written out in this code in the genes. That is your blueprint. That is you—written out in code along a molecule of DNA.

How did you get specified like that? DNA has another property. The code in DNA also allows it to specify itself so that an exact copy can be made within the cell, and then when the cell divides, each new cell will have the blueprint. The copy is nearly always exact. Sometimes a damaged region occurs, sometimes a copying error is made and perhaps sometimes a new bit of DNA gets added in. These are called mutations. Most of them are lethal—that is, the copy is non-functional and gets nowhere; others may delete a gene and very rarely something new and different and interesting is added.

We see how each cell in your body gets a copy of your biological blueprint, but where do you get your molecules of DNA to start the process? From your parents—half from each. They got theirs from their parents in turn, and we might trace this back generation by generation into antiquity. Of course, back a few hundred thousand years the ancestors you would find might startle you a little. After all, this business of mutation and selection—or, as we call it, evolution—has been going on, so changes were made.

In our minds we might follow this search for the starting point of this DNA right back to the beginnings of life on this planet in the primordial ooze perhaps a billion years ago. Of course the code on those early molecules would have practically nothing in common with yours because of all the mutations which have occurred in the generations since that time. Nevertheless, your molecules of DNA are your biological inheritance from a billion years of trial and error experiments. That is why you are so wonderful—it took a billion years to invent you!

Are you perfect? No, not really. You surely carry some of the genetic mistakes that were made, along with the successes. A few useful genes were surely lost along the way. Some very useful genes occurring in other living forms were probably not invented in your branch of the genetic tree.

You may ask, if we know so much about this why don't we do something about it. Why don't we take a hand in correcting the errors and perhaps also deliberately add some new desirable genes. Well, I don't think we know quite enough yet, but we are learning; and some scientists in genetics and molecular biology are already speculating about the possibilities. Man could begin to control his own biological evolution. Of course, this modifying of the results of a billion years of experiment will have to be done with great care and knowledge to be sure that we keep the good and don't create a disaster.

Why not be really adventurous and do the revolutionary experiment? Why not take some of my DNA, put it in a test tube, break it down into individual nucleotides, and then zip it all up again and see what we get? This would mean destroying the intricate code which has evolved over all those years and replacing it by a random code. We know what we would get—just a sticky goo on the walls of the test tube!

But let us now turn to another system of great interest to all of us here, namely Franklin and Marshall College. Yes, a college is a system. It has subsystems: its buildings, its books, its students, its staff and its friends. What do I mean by its friends? I mean the trustees, philanthropists, alumni and all those who give so generously of their time and fortune to make the college possible. As with other systems a college is only a successful system if all its subsystems work together with reasonable coordination and harmony.

A college is like a living system; it evolves. If you don't believe that, go back and look at the curriculum and methods of colleges of hundreds of years ago. Evolution is still going on. New things are being tried—students grading teachers, for example. Why not?

What is the purpose of a college? A little while ago I spoke of your biological inheritance. I said you were all nicely specified by the code on your DNA. Now that really wasn't exactly true. That was just your biological specification. This specifies your chemical and physical constitution. It does somewhat more than that, by means we do not fully understand. It specifies a certain class of elementary behavior—that behavior which we call instinctive. Sometimes these instinctive behavior patterns are startlingly complex. For example, the different intricate patterns of webs woven by the different spiders are biologically inherited. Other examples of quite complex instinctive behavior are the various architectures of nests built by various birds, and even, in fact, the intricate love dances performed by some of them.

There is, however, another type of behavior—called learned behavior. This refers to behavior patterns learned by experience. Even some of the animals low on the intelligence scale can learn reactions which adapt them to their particular environment. In the higher species the parents may teach their young some of these learned reactions. Thus they pass on not only their biological genes but some of their life experience. With man this process has evolved into something even grander. We attempt to preserve and pass on from generation to generation all the knowledge so painstakingly acquired over the several thousands of years of recorded history. We not only try to pass on the knowledge discovered by someone but also the techniques and methods the discoverer invented which led him to his discovery. That is, we try to tell about the truth that is known and about ways of going about finding the truth. This process of inheriting the accumulated experience of previous generations means that each of us doesn't have to start at the beginning. We learn in a few years what others took centuries to learn, and then move on from there. It is so important a phenomenon that a good friend of mine likes to call it tribal genetics. It opened a complete new path of evolution. It is almost solely responsible for the fantastic emergence of man to his pinnacle in the animal world. As an animal he hasn't the speed of a cheetah nor the keen eyesight of an eagle—but he can fly faster than the speed of sound and see, instantaneously, a picture from a thousand miles away.

We call our system of tribal genetics an educational system. A college is one of its finest parts. I mentioned that a college was like a living system. Its parts have analogies with life. The faculty, for example, might be compared to the enzymes or catalysts, whose purpose is to make it easier to carry out the function—in this case the transfer of knowledge. The books are the genes. They are the record accumulated over the years—and they are being passed along to you in the sense that they become yours when you know them. By "know" them I don't mean memorize them. I mean you are familiar with them, know how to find them, and know how to read them. Then the accumulated knowledge of mankind is available to you.

This is not a stagnant thing. New truths are continually being found and new ways of carrying on the quest are being evolved. Like other collections of genes, the collection of books is not perfect. There are errors as well as great truths. New books get added and some stuck back on the shelves as curiosities. Libraries evolve.

One of my sons has a rather puritanical view about errors in print. When he finds a mistake in a book he becomes quite furious and seems about to throw the whole thing in the trash. Fortunately he calms down. Of course, the proper approach is to smile tolerantly, you're not perfect either, you know, correct the error and move along.

So a college is a vital and evolving part of our system of tribal genetics. To what end? Well, this is all only a subsystem of our *society*. Society is a system. It is the system by which men live together. It has its subsystems—its governments, its churches, its schools, its transportation, its communications, its distribution. The parts include highways, railroads, airplanes, radios, telephones, city councils, congress, police, stores, and countless others.

How well does the system operate? I think the answer is: not well enough! It evolves. It is quite different now than when I was your age. But does it evolve rapidly enough? The system is in great trouble—all over the world. Racial problems, poverty amidst plenty, pollution of the air and the water, crime, overpopulation, contests for power, wars and threats of wars—all these threaten the survival of society, and perhaps the survival of the species. There are those who scoff that threats could ever be that serious. They forget that failure to evolve in an effective way brought the dinosaurs to an end. Their evolution led them along a course not adaptable to the changes in their environment—and they disappeared from the face of the earth.

Of course the dinosaurs had no control over their fate. Their problem was in their biological genetics. Ours is in our tribal genetics. Man created his society and he alone can modify it. He can expect no help from nature here! It is his invention and it should be within his power to make it workable. It would be ironical indeed if the unadaptability of his own invention should prove to be his undoing.

Those who at least admit the need for change fall into two groups—the evolutionists and the revolutionists. The evolutionist would proceed carefully in correcting the wrong, while preserving the right. The revolutionist argues that this process is too slow. He thinks you must demolish the old and build anew. Unfortunately he nearly always offers clear plans for demolishing the old but only vague words about constructing the new. As he walks with his torch, crying "burn, baby, burn," is he also thinking about with what and by what means he will replace what he has burned? Will it be something really better? Has he plans for a cry of "build, baby, build"? There are perhaps times when a revolution is the right answer—but the responsibility is very great for knowing what you are doing and what better things you will produce. Violent reaction without a concern for the aftermath is not revolution, it is simply rebellion.

Permit me my love of analogies. Suppose you are unhappy with your house. A pipe leaks. Well, repair or replace it. But perhaps the problem is more serious. The windows and walls are not properly placed. Well, remodel it. But be sure you have the necessary props to keep it from falling down in the process and the materials and skills to effect the desired changes. Maybe the problem is more serious and no reasonable renovation will make you happy. Then demolish it—but be sure you have the plan and the materials on hand to replace it with something you will find better—otherwise you may find yourself sleeping in the field.

Within my lifetime, but before yours, a new group of leaders appeared in a great country. They explained that their troubles were not really theirs, but the result of unfortunate history. This history had to be obliterated. They burned the seat of government. Then they burned the books. They took books from the libraries and piled them in the streets and put a torch to them. They danced and chanted in the light of the flames. Having thus freed themselves from their tribal inheritance they decided to take equally brave steps with their biological inheritance. They decided to burn people, the ones they perceived to have the wrong genes. They built special furnaces and burned people—several million, in fact. They also decided to bring their fine new culture to their neighbors—and they did this with guns and bombs and fire. Soon almost all the great nations in the world were in conflict and tens of millions more people died. When it was all over, the strange new culture and its priests were gone—and a very large part of Western civilization lay in ruins. Hardly an enviable contribution to mankind.

Now let me turn back to my opening remarks and say a few words about communication. It is often said that failure of communication is a source of many problems in our society. The act of communication has three essential ingredients: a message, a sender and a receiver. The message is most important. No amount of histrionic activity will convey a message if there was no information content to begin with. I am afraid that the biggest problem in communication is that so many people do so much saying without bothering to think very clearly about what it is they are trying to say. The next problem is the sender. The sender must really wish to convey some information to the receiver—not merely revel in the sound of his own voice. He must try to convey the message in the manner most likely to be understood by the receiver. It is necessary that the receiver be interested in receiving the message—otherwise the sender is wasting his time. It also should be remembered that the receiver's reception is modulated by his own thinking at the time—so that he may receive something quite different from that which the sender thought he sent. One of the things I have most trouble explaining to people engaged in endless arguments is that it is not what you say that matters, it is what the other person hears.

Some time ago I found myself listening to the late George Lincoln Rockwell—leader of the American Nazi Party. He was spouting fiery rhetoric about the advantages of bringing the horrible culture I mentioned earlier to America. But that was not the message I received. The message I got was: that is a very, very sick man—and if it wasn't so obvious he is very, very sick he would be very, very dangerous. I am afraid this is the kind of message I get from many public speakers, although I am sure that is not what they think they are sending.

It is only right that I should say a few more words to give our meeting this evening a proper perspective. The totality of the topics I have touched represents only a subsystem of a system of incredibly greater scale. In the vast reaches of the universe there float billions of galaxies. Each of these galaxies is composed of billions of stars. One very common type of galaxy is the spiral galaxy (Fig. 1). About one-half way out in one of the spiral arms of one of these galaxies there is a very ordinary star called the Sun. Around this there revolve something under a dozen small, coolish, mudballs called planets—an occurrence which must be common to countless stars. The third mudball away from the Sun is called the Earth—hardly an entity of great cosmic significance. But if we look at this mudball a little more closely, say from 20,000 miles, as shown in Fig. 2, we see that it has structure. It has oceans, continents, mountains, clouds and storms. One of these continents is called North America. In it is a quite small city called Lancaster, and there, there is a group of people discussing things. This places me in perspective. I am one of several billion people on the third mudball of a very average star in a very common galaxy. Somehow the thought makes my responsibilities seem just a little lighter.

Fig. 1—Photograph of a spiral galaxy.

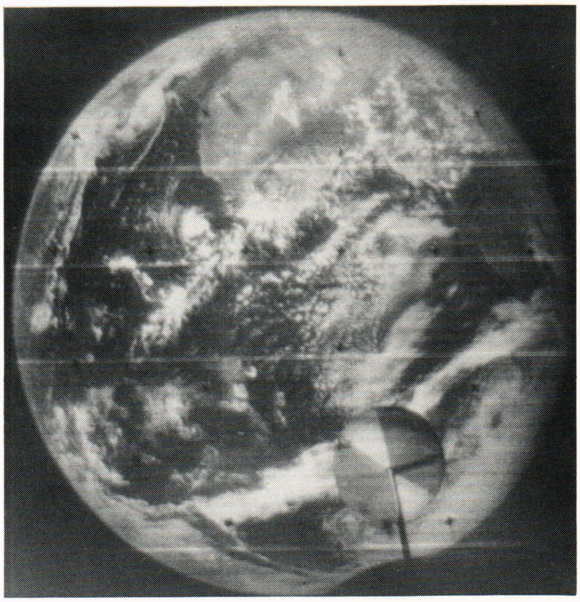

Fig. 2—Photograph of the earth taken by the TV cameras of the DODGE Satellite. The circular object in the bottom of the picture is a sectored sphere, mounted on the satellite, that is used for color calibration studies.

I have talked about a lot of things tonight, but really about the place you and I have in the scheme of things of which we are but a part. We come into this world and after a time we leave. We receive our biological inheritance and, if we have progeny, we pass it along, perhaps a tiny bit modified through no effort of our own. If that is all we do, we have served our biological purpose as fully, and no more so, than a cat, a dog, a gnat, or a flea. On the other hand we may accept our tribal inheritance, make our positive contribution to its constructive modification, and pass it on. The world will then be a little bit better because we lived. And this would be the finest fulfillment of our purpose—for indeed we would be involved in mankind.

Combustion Instability in Solid Fuel Rockets

Frank T. McClure

(Delivered before the Wellington-Waterloo, Ottawa and Arvida Sections of the Canadian Institute of Chemistry, February 28, March 1 and March 2, 1962)

I. Introduction

LET ME FIRST STATE THAT IT IS AN HONOR AND a pleasure to have the opportunity of addressing this section of the Canadian Institute of Chemistry.

My lecture tonight will not involve much chemistry in the classical sense. Rather it is designed to bring out an aspect of modern science and technology that is increasingly common. More and more frequently we face problems, which by their inherent nature cannot be categorized as chemical, physical, or biological. In acoustic instability of solid fuel rockets we shall be discussing a phenomenon in which chemistry and a variety of branches of physics are so intimately intertwined that understanding is simply not attainable without simultaneous application of the several disciplines.

Recognizing that this audience represents a group with widely divergent backgrounds, I shall devote the first part of this talk to a description of some of the less esoteric properties of a solid fuel rocket, so that we will all be together when we discuss our more complicated principal subject.

II. The Solid Fuel Rocket

A rocket may be visualized as something like a champagne bottle. The high pressure gases within the bottle are expelled through its neck. The forward thrust of the rocket is the recoil from the expulsion of these gases. In order that this forward thrust may continue, there must be provided a method for continuously regenerating high pressure gases which in turn will be continuously expelled through the neck of the bottle. In the case of the solid fuel rocket, on which we will focus our attention tonight, the source of these gases is the burning of a solid fuel. A block of solid material, containing chemical reactants in rather intimate mixture, continuously evolves hot propulsive gases. Typically these gases are at a temperature of the order of 3000°K. On the usual Fahrenheit scale, this represents a temperature of approximately 5000°.

Now, in the uses to which rocket engines are normally put, the penalty for excess inert weight is very severe. Ideally a rocket should be all fuel, and failure to achieve this goal by more than a few percent tends to represent a disaster in the ultimate mission of the rocket engine. For the