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OUR SCIENTIFIC AND TECHNOLOGICAL HERITAGE

Dr. Raymond J. Seeger

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Reviewed by Col. R. W. Bergamyer, USAF on 14 October 1963

INDUSTRIAL COLLEGE OF THE ARMED FORCES

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OUR SCIENTIFIC AND TECHNOLOGICAL HERITAGE

19 September 1963

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Reviewed by: Col. R. W. Bergamyer Date: 14 October 1963

Reporter--Grace R. O'Toole

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CAPTAIN BRYCE: An understanding of the role of science and technology in modern society and our national security requires an interpretation of the legacy of the past, how scientific disciplines have developed, and how scientific research and development has reached its present state, if we are to have a real insight to where science will take us tomorrow.

To highlight the features of this broad and exceedingly complex subject, it is our pleasure today to hear from Dr. Raymond J. Seeger, Assistant to the Director, National Science Foundation.

Dr. Seeger, welcome to the Industrial College.

DR. SEEGER: Thank you very much. I always like the applause at the beginning, because you never can tell about the end.

You obviously recognize that it would be rather difficult for me to cover the whole history of science and technology in 45 minutes, but I'll try.

Afterwards, ask me a question about these books. I don't want to waste time with them right now. As far as the introduction is concerned, let me start with the statement of science and technology, and I think that this is becoming almost a single word, sort of like research and development. In other words, we have so mixed up these two concepts that we treat them as a single one. There's confusion in our minds.

I would like to emphasize that, even though you may not always be able to know where to draw the line to separate them, at least the extremes are different, and it's well to keep that in mind, just as the extremes of research and development are quite distinct.

As a matter of fact, just let me put something down (on the blackboard) to make this specific. Suppose I start with pure mathematics, and then I get into applied mathematics, and I get into mathematics, physics, and I get into physics, and I get into applied physics, and I get into theoretical engineering, and I get into engineering. It's the same sort of thing. You start with something very pure and get over to something very applied. Technology is really over on this side, over here, actually, and you have all kinds of variations.

Now, having said that, let me call your attention to two problems that you are very familiar with. I think these are two extremely basic problems. That is the interrelationship between science and technology. Most of my scientific friends will tell you that it's a one-way street in which you do the science and get the technology. May I suggest to you that it's reversible reaction and that if you look at the history of science and technology you will find that they are very much interrelated. One of our real difficulties today is to make sure that these two extremes make contact. That's not as easy as it is to say.

The second question, besides the interrelationship, is what I would call the role of the individual. Now, there's a difference of opinion. I noticed Derek Bryson's book on the list of possible books to be read. Derek has the idea that all scientists are alike, just as all doctors are alike, and who believes any lawyer. I mean, they are all alike, you see. Well, I'm much more inclined to agree with something Einstein once wrote. He thinks that, because of our mass production, that just because we have replaceable parts, and one cog will replace another cog, we've gotten the idea that all scientists are replaceable and that you can have one scientist replacing another scientist. I don't believe it. I don't think that, just because a man has a Ph.D. that's equivalent to all the Ph.D.'s and that necessarily

he's going to be a great scientist.

The second aspect of this problem of the role of the individual is: How much freedom does an individual need? Well, let me remind you that, although we like to call attention to Vicenko, in Russia, as an example of what should not be done in science, it's Landau, who worked under the same system, who got a Nobel prize in the Soviet Union. I think we have to sharpen up what we mean by freedom and ask: How much freedom is academic freedom? Is it related to political freedom or social freedom or religious freedom?

The third aspect is the general problem of communication. I don't know how large a university should be, but I got an idea recently when I was out to the University of Illinois. A man said, "Well, it depends upon the size of a department, and the ability of departments to communicate with one another." So, actually, in the Chemistry Department there, which consists of about 55 full professors, they had to break it up into subdepartments, because there comes a limit to communication within a department.

I think a very interesting question is: How large can a research laboratory be and still function as a research laboratory? I don't know. I am just suggesting that this is all a part of a question of the role of the individual. To me, as you look back at the history of science and technology these two questions should be borne in mind. The first one is the interrelatedness of science and technology and the second is the role of the individual.

Now, actually, I would think that you cannot tell where you are going from where you are now. I am sure this is true. If I tell you where I am, I could go in any direction, but, if I can trace back where I was, then I have a sense of direction, and to me this is what is necessary, and this is why particularly the

immediate history of science and technology is extremely important, because it gives us a sense of direction. It isn't enough just to know what the science is today. The one thing you can be sure about is that it is not going to be that way tomorrow. So the important thing to understand about science is the direction of change, not the status quo.

Well, now, having said that--and by the way, Mr. Conant does not agree--and I think maybe that book is also on your reference list--he says the research man has no need to look back--may I just take a few minutes to tell you what I think science is. If I ever give a talk any place, this is my favorite topic. I think we've got to know what we are talking about, and so may I suggest to you what I think science is. Of course, if anybody asks me what science is, I always tell him it is something you get as a result of the scientific method. Then if they ask "What is the scientific method?" I say, "Oh, it's something a scientist does."

Now, this looks as if it were nonsense, until you realize that the what of science comes only as a result of how you got that what, with the method, which is only in terms of "Who done it?" And the what is not as important as the how, amd that is absolutely impossible to interpret except in terms of the who . The role of the individual I will very much emphasize.

Well, the first point is that we ask questions of nature. We get answers which we call facts. We would like to differentiate between a fact like two plus two equals four and an absurd fact. So we talk about facts that are absurd in science, which are the answers to the questions we ask, and sometimes we get awfully stupid answers, but after all we may have asked very stupid questions.

Now, it was realized at about the end of the 19th century that we don't make

a list of all the facts. You select the facts. This again is very important as to who is doing the selecting, and why and what is his basis. Furthermore, even if you have these absurd facts, that is not quite enough either, because, I have to interpret my observations somehow. Let me give you an example. What do you mean by distance? What do you mean by length? I am sure that the idea of the distance from here to the moon is quite different from the idea of the distance of the diameter of an atom.

So we've said, "Well, look, it doesn't mean anything unless you tell us how you got that answer. When you say it is so many inches or so many something else, we want to know how you got it." There is always some kind of theory involved in it. So these we say are absurd operationally.

So, in answer to the question of asking nature certain questions, we get answers which are selected facts, which are absurd operationally.

I won't go into that any more. I could spend a great deal of time on it. There is a basic assumption here. When you ask a question and get an answer on Monday and you get the same answer on Tuesday, and you do it the same way, this is a basic assumption. It's the uniformity of nature, and the fact that if you ask the question on Jupiter, you get the same answer that you do here. Is this true? Who knows?

Now, the second point that I want to make in addition to that is the question of association. Somebody asked the artist, Rolfe, "How is it you are able to paint such beautiful white barks of trees in springtime?" and he said, "By looking at the snow fields in winter." Well, it's just that association that is very important.

I would like to give you three examples of such associations. The first is the matter of classification. You know, words are interesting. I learned something

this morning when I was coming over here. Take a word like influenza. There isn't really a disease of influenza. There are just a lot of sick people who are all more or less the same in their appearances and symptoms. I looked up the word, influenza, and I was surprised. It comes from the Latin, meaning, to influence. It refers back to the time when they thought that the planets had some influence upon these epidemics. So they called it influenza.

Well, take any word. It's just sort of a blurb, and if you get a sharp microscope and look at it, you'll see that there are certain points, and you can't always use the same word having the same meaning in various connections. One of my favorite words in this is the word, energy. If anybody asks me about energy after a while, I'll quote something from one of these two books. One book is a book that nobody should read, and the other one is a book that everybody should read.

Anyway, it's amazing about energy. My daughter was taking biology. Oh, no, she was taking general science. She came to the word, energy. I asked her, "What is energy?" She said, "It's the capacity to work." I asked, "What is work?" She said, "Oh, daddy, we haven't had that yet." O.K. The next year she took biology, and, lo and behold, they had energy. I don't know what kind of energy. Anyway, the definition was, the capacity to work. I asked her, "What's work?" She said, "Well, daddy, we haven't got that far, yet." So the last year she was taking chemistry. It dawned on me one day to look up in the index to see if they had energy, and, sure enough, the chemists have energy, too. And it's the capacity to work. But not a single one of the books told what work is.

Now, this is a fine way to communicate. I think that this is one of our great difficulties, you see. We begin to use words, and we really don't know what they

mean. Well, this matter of classification is extremely important. By classification I mean, "Here's a chair, and here's a chair, and here's a chair." I use the same words for all those chairs.

Another is this matter of analogy. We say he was a lion in the fight. What do you see? Do you see a man there suddenly getting big ears and a tail? What you mean is that he was like a lion in the fight. We say a man is a machine. Do we really mean that? Or do we mean he is like a machine?

We need to be a little careful about this association. As to relations, I used to be a teacher and I often had to worry about grades. I don't know what silly methods other teachers use, but I looked for one of my own. I decided how nice it would be just to measure the length of students' noses. Have you ever done it? Then why are you laughing? Anyway, I found the most remarkable thing. Some people have small noses and some people have big noses, and the rest smell in between. I looked at my grades, and they were on exactly the same curve. Why not? When a student came in to inquire, I'd say, "Don't worry. From now on you will be in this part or in that part." Well, I'm sure some of them don't do that.

Anyway, this is this business of looking for relations, associations of this with that. It's very important. Of course we did a study in temperature. What is temperature? Well, the length of a column. Of course temperature is not the length of that column of mercury, but we associate the length with this thing called temperature. We are doing it all the time. When we do that we have to be very careful.

When we usually make any measurement, of course what we do is to get a series of points. Who likes to see a series of points? We draw a curve through them, and, of course, when you do that you are making one grand hypothesis and generalization,

and some day you may find that this point is there, and you may find that this point is over here /down there. It's a problem of interpolation and extrapolation. But we are always looking for relations; relating factors I would call them. This is really a very important point.

Now there is an assumption that we like to make here, and that is that, in doing this, we have to assume that nothing else is disturbing this; in other words, that the problem is isolated and that it is controllable. This is one of the real differences between experience and experiment. Geology is largely an experiential science. You observe. You can ask nature all the questions you want, but nature doesn't answer you. So you've just got to observe and take the answer you get to a question you haven't asked. But in something like physics, if you take something like Ball's Law on pressure and you want the pressure big, you make the pressure big and then you ask: What's the volume? You can make the pressure small and ask: What's the volume? You have a certain amount of control. This is an experiment. Isolability and control have been very important in this respect.

Now, the third thing I want to mention is: Who is interested in all these facts and all these factors, absurd facts, the latest factors? We would like to have a view of the thing as a whole, just as, if you go up a mountainside and you don't want to worry about a house here and a house there, and where the road is going, you get a picture of the thing as a whole.

The Greeks had a word for it, and they called it theory. Your Greek word, theory, comes from the same word as the word, theater, which means a view of things. So we try to get a view of things. This is where the individual's imagination is extremely important. Take Newton. They said an apple hit him on his head. Well, ten years ago the historians of science said that that was obviously a myth, and

that no apple ever hit him. But then they found another person who said it, and that made it true, because if two people lie then that means it's true. Well, anyway, now we believe that an apple hit Newton on the head, and when it hit him on the head he said, "Oh, Boy! This is my lucky day. Suppose it had been the moon." Well, of course the idea that the moon might be an apple and the apple might be a moon was tremendous imagination. This was the first time we really had the universe. Up to that time we had things behaving in the earth below, with the four elements, and a different set of laws for the fifth element, the quintessence up there.

This was a great day. But I say, just imagine looking at an apple and saying, "What a lovely moon," or looking at the moon and saying, "What a great, big apple." You can use cheese, or whatever you prefer. This was imagination.

Now, the question is: How is this imagination reproducing? This is where I don't think you can do it. I'll give you an example of my friend, George Gamoff. Gamoff was a consultant to the U. S. Navy, or vice versa, during World War II, and they wouldn't let him get near Los Alamos, because he was a Russian. Furthermore, he knew nuclear physics. We were trying to figure out how to make bigger and better bombs. One day Gamoff said, "I have an idea," and he wrote something down on a piece of paper. Heaven help us. It just disrupted the entire, whole of the armed services, because there he had written down exactly what they were doing at Los Alamos, and nobody even knew anybody was at Los Alamos. I mean, you see, this was an idea, and he knew how to apply the idea.

I think the application is easily reproduceable, but having the idea in the first place is not reproduceable. Usually, when we talk about the number of scientists we need, we mean the number of reproduceable scientists, all of whom are at

certain levels, but not the man with the great ideas, the man of the great imagination. You can talk about all the monkeys you want writing Shakespeare, but I haven't met one yet who did.

It just is an amazing thing to certain people. Now I want to emphasize one thing here. I'd like to use the word factitious, and you can see that I am very deliberate on all these facts, absurd facts, related factors, factitious theory. I want to emphasize here the influence of environment, particularly the social environment. Let's go back. Fifteen hundred sixty-four was the first year of Galileo, the death year of Ascelius, and so forth--1564. Let's go back to Galileo's time and the so-called geocentric theory and the heliocentric theory of the planets. Well, now, how would you evaluate these two theories, if, say, at some time in the Industrial College they want to evaluate these two theories. It happens to be in the Pope's Palace, but, so what.

You might say, "How does it behave mathematically?" Well, there was no doubt that the heliocentric theory was a little bit better mathematically. How does it fit observations? Well, I hate to tell you this, but they were both just about equally good, because the observations weren't so hot, and when you have observations that aren't so hot almost any theory will do.

Then, how does it affect common sense? Anybody can look out and see that the sun is moving. So did Francis Bacon, so he threw Copernicus out the window. How did it agree with the philosophy and the theology of the day? You know as well as I do that the Church preferred the geocentric. All right. How did you make the decision? You got three to two. I mean, what do you expect people to do? We cannot forget the social climate and the cultural climate in which scientific theories are made.

Now, there is an assumption here. The assumption here was uniformity. The assumption on the second one was isolability and control. The assumption here is comprehensibility. Einstein once said that one thing that was incomprehensible to him about the universe was that it was comprehensible. Why should you expect, just because your staff is going to make a theory, that nature will allow you to.

Well, now, these are three essential elements of a theory, and of course they go in sort of a spiral. I'd like to mention three things. One is that it it is open-ended. Science is the endless frontier, and you can begin any place in here that you want. And, finally, it is cumulative. One of the few sane results of looking at history is to see the cumulative progress of science.

All right. So much for what science is. Let me now say a few words about the major periods in the history of science. I will begin with what I will call practical beginnings. I am using that word in a very real sense. I mean: What does the word, science, mean, anyway? Well, if you go back to the Latin, it means knowledge. For instance, if you go to the National Science Foundation in Switzerland, it includes theology; it includes all knowledge.

I would like to differentiate between science, so I object very strenuously when people talk about science back in the period of the Egyptians and the Calabeans, because I don't think we're talking about the same thing. If they want to use the word , that's fine, but why not put a little quote mark on it, so I can identify what they are talking about.

Well, of course, you have astronomy and you have the agricultural means and the astrological means, and the religious peace, all of which require some kind of calendar, observing the progress of the moon and the sun, and this might very well

be called a practical beginning.

Then, secondly, in mathematics, the Babylonians had some very good arithmetic, even verging on the solution of some great problems. And in Egypt they had learned the so-called 3-4-5 rule that, if you have a triangle it's a right triangle, and with 3, 4, and 5, you can stretch the ropes out and get a right angle. These are practical beginnings.

I do not regard them as the beginning of science. But I do believe that the birth of science occurred in Greece. I would say that this period was from about 624 B.C., during the Pales, to 201, A.D., which was the death of Galen.

Let's look at this. First of all there are the Ionians. These people looked at nature, and they were the first ones who said, "It's real." And not everybody believes it's real even today. They said, "It's interesting," and a lot of people don't think it's interesting, and they said, "It's comprehensible." This was an amazing thing.

Now you go over to the West, in Italy, and you find the Tagorians, and they had sort of an emphasis upon mathematics. They were interested in taking a string. If you clamp the two ends you'll get a certain musical note. It you clamp the middle, you'll get another one. If you divide it into 102 or 103, you get music. They said about the universe that mathematics was built into it. They said everything was mathematics. There are still people like that today. They claim that you can find out more by not looking at the universe and just looking at mathematics. I used to say to a friend of mine who used to argue this, "Well, go ahead. Tell me something about the universe right now, will you?" Of course, he never did.

The third thing in this birth of science of the Greeks is Athens itself.

Now, Athens went a little bit more over into the humanistic side, but it had two great people. One is Plato and the other is Aristotle. Somebody has remarked that almost everybody is either Aristoterian or Platoist.. I think it is probably true. I happened to do some investigation some years ago on Galileo. I found that half the people said he was an Aristoterian and the other half said he was a Platoist. I didn't think he was either.

Well, now, actually, what Plato said was, "Look, if you really want to know ideas, don't look at things." I mean, for example, if you want to talk about the ideal woman, don't look at your wife or any other wife. Close your eyes, and dream. Well, there's something in that. But Aristotle, who was really quite a good scientist, particularly in biology, said, "You've got to look at things, and we've got to look at the form and shape of things that are in order to tell something about the shape of things to come."

I want to give you a quotation from Aristotle's Physics: "The natural path of investigation starts from what is more betterly knowable, the things I see, and more evident to us, and proceed to what is more self-evident and intrinsically more intelligible." In other words, I can understand general laws. Let's look at moving things. Old Francis Bacon said, "If you want to know anything about motion, just make a record of all the things that are moving, and then also those that are not."

Well, it sort of leaves you with some kind of indigestion to do that. It's much easier to say, "Aha, when I look at a fallen leaf, I don't worry about the fallen leaf. I say, 'Aha, it's the principle of inertia.'" And it's intelligible. The world of phenomena becomes intelligible in terms of general principles. That's the idea of the thing.

These people had tremendous influence. It really is the rational approach

of Plato, and the empiracal approach of Aristotle, and the history of science and technology is really an interplay of the two, the rational and the empiracal.

Now, to stay in the Greek period, I want to move over to Alexandria, the real Alexandria. This was really a tremendous place for the development of science. In mathematics there was Euclid. Now, Euclid really did his geometry because he wanted to prove something for Plato on Plato's ideas. He did this thing, you know, starting with axioms, and so forth. Then you deduce certain things. As a matter of fact, I still think that we might do better to go back to Euclid today. Now we are running around in circles. You don't do anything logically any more.

You ask a youngster to prove a theorum. All I know is from reading my youngsters' textbooks that they study--in quotes. You start with A and you get B. Then you get C. Then you get A from C or you get C from A. You never know where you are beginning on the thing. You run around in circles. A is true because of B. Why is B true? Because of A. It's that sort of thing. Well, Euclid separated this out. He started this very good postulation of methods.

Appolonius came up with conics, you know--very interesting. The Greeks knew all about conics. They were working like mad, you know, on/probably government-sponsored projects to find out how the planets should go. Nobody bothered about Appolonius with his conics, because that probably was kids' stuff. And they had real problems to do. Well, there is that.

Now, Archimedes got into/the mathematics game. In all of Euclid he talks about the ratio of the circumference of a circle to the diameter and its radius, but the one thing he never got was the calculation of the value of parts. Mind you, it's in application by now. They give you all the theory in the world, but they never

think of relating it to anything that you know anything about. When Archimedes calculated Pi he came up with 310-70ths to 310-71sts. That's not bad. After all, he was just a Greek. As a matter of fact, the method that he used became a very good method. In other words, he took a circumscribed polygon around a circle. He took it inscribed. He made the sides come closer. Finally the poor circle was squeezed in between the circumscribed and the inscribed. That was the start.

Well, if any of you want to appreciate why the Greeks didn't get very far, just look at the way they had their number system. They had one thing. When they wrote down Alpha, Beta, that was a number. It didn't make any difference whether it was Beta, Alpha, because each of them was the same. Like this is 61 and this is 160. It still made 61.

I always tell my friends, if you want to calculate in Roman numerals, just multiply IV by VI, and you'll see why the Romans didn't get any place in arithmetic. As a matter of fact, the Greeks and the Romans--the Greeks particularly--solved arithmetic problems by geometry. It's quite different nowadays. We solve geometry problems by arithmetic, except I don't think we do. In other words, if you ask me about a triangle, I don't write down all those algebraic equations. I try to see if I can't intuitively solve it. This is something I think we are missing in some of our education today.

Now, leaving mathematics and going to astronomy, Aristocchus sort of determined the possibility of the distance to the sun and the distance to the moon. Hipparchus made a very careful list of observations. Among other things, he was able to detect the procession of the equinoxes, which you know takes place once in every 26,000 years. And Ptolemy tried to put the whole thing together

and did what the Greeks called save the phenomena. The word, phenomena, means appearances. You see, these planets, when you look at their motion, they sometimes look horrible, and somehow there has to be circles. How to get that to look like circles is a nice job. So he used a method which we would say was analogous today to something like a method of approximation. He was able to show that this could be made up of circles.

Well, I want to point out to you that we can say what we want about Mr. Ptolemy, but his method was used for observation and taking observations until the 15th century. Now, if you and I can do anything that lasts a century we are not bad, even with the stupid people around us. But just think--15 centuries.

I have to point out that Archimedes was undoubtedly the greatest mathematician of this period, and he did some very fine things in physics. Among other things, he got interested in fluids and he discovered the Archimedean principle. But in this matter of the fluids he did something more. He invented a term, specific gravity. This is the first known scientific concept to be invented. He noticed that the weight of something divided by the weight of an equal volume of water always gave him the same number, whether he had big bottles or little bottles.

Then also he did not do this: He did not say, "Let us take the Pi power and the E power." That's equally true. He used simplicity. This is something we have to remember. When we invent concepts we try to take simple ones, not because nature is simple but because we are, and we have to be very careful.

Archimedes also got into mechanics. He tried to prove the law of the lever. In addition, he invented another concept called the center of mass, or the center of gravity.

There was a friend of his by the name of Aristophanes, and he actually determined the radius of the earth. And in medicine this man, Galen, was actually concerned with anatomy and a theory of physiology, and it was very successful for just as long as Ptolemy.

I was invited some years ago to give a talk to some classicists, and I knew what they wanted. They wanted somebody that they could put on the altar of specialization and say, "Look at this narrow specialist." So I got up and I thought a good offense is always the best defense. I said, "There is one thing that I've always thought was wrong with the courses in Latin and Greek I had, particularly in Greek, because they told me all about Athens and they never told me that Alexandria was in Greece. In other words, the Greek scientist was just as much a miracle as anything else in Greek science."

This is sort of a speculative period, and the one thing you have to be careful about is that it is a period in which philosophy and science are sort of mixed up together. It's a speculative period.

There is a second period that I'll just call the chrysalis stage. This is a time when the Roman indifference let the Greeks do their work for them. The Byzantine was geoplatonic. They were always looking at the world that isn't and didn't worry about the world that is. The Islamic influence, of course, was that the Arabs translated the things in which they were interested. They did some little things. And of course the Christians were very other-worldly, because they thought, what's the use of worrying about living here when you have to live in hell tomorrow. You might just as well find out about hell. So that's what they did.

You come to Thomas Aquinas in the 13th century, and Thomas said, "There are

two criteria for truth." Not the one Aristotle had, whether it is intelligible, but two. One is this one, if it agrees with observations, that's a good criterion. But you can never rely upon it. I mean, I go along the street and I meet a man with a black eye. I go along 10 feet further and I meet another man with a black eye. I say, "Aha, there's been a fight. There are two men with two black eyes." I was wrong. Each man has a wife, and there were two fights.

You never can tell. There is never a unique theory. So he said, "Really, the much better way is the idea of Aristotle, that you can deduce something from something intelligible, and this is better." He gave two criteria, and that was the beginning of science.

Now I want to go to the rennaissance of science, because in this period we do have the rennaissance of science. I will first of all mention two people. I think this period would begin with 1543, when Copernicus published his De Revolutionibus on the fabric of the human body.

The real problem was this: The people were always trying to deduce from philosophy. Here you have philosophy and here you have your scientific observations. These are the intelligible principles. Then you would like to deduce the scientific observation, but you never could do it. You couldn't do it in astronomy, and you couldn't do it in physics. Finally, Galileo had a marvelous idea. He said, "Let's quit trying." He said, "There is something that we can deduce this thing from, and let's be satisfied with that, even if it isn't philosophy." So this is science theory.

This was the great, final divorce. From that time on people in science deduced things from scientific theories that they could deduce them from, and said fiddlesticks with the philosophy. That was the beginning of the great

gulf between philosophy and science which still exists. Well, Galileo, you remember, used the telescope for observations. He introduced the concept of acceleration which is used in mathematics, and he did a great deal toward publicizing it.

A lot of people today would like to look at Descartes, who said that there is mind and matter. This was very bad, because it separated the mental from the physical. He got the philosophers interested in just the mental side. So you get somebody like Immanuel Kant saying that you can't see things, that there is something which is in adults which you can't see. So you got the philosophers talking about things that they couldn't see, and this left the scientists out in the cold.

Well, I notice Francis Bacon is in the list of references. I give Francis Bacon credit for one thing. He publicized science. If anybody asks me about a good example of a research laboratory that Francis Bacon suggested, in the question period, I'll tell you about it. It's very interesting. He didn't understand science, really.

Then you come to an experimental group--Kettler, Harvey, Pascall, and Boyle--and you come finally to the theoretical development of Newton which culminates this whole period of the rennaissance of science. From that time on I think I would say, beginning either with 1687, which was the publication of Principia, or the death of Newton in 1727, I think we come to what I would call modern science.

In the period of modern science we come to specialization. We no longer treat science as a whole. In this period of Thomas Aquinas you have philosophy and science, and actually he didn't have that. You have science and a part of philosophy under Thomas Aquinas. And now you have philosophy and science really separated.

You come to a certain positivistic school in the modern theory in which you put philosophy in science and science on the outside.

Now you go into chemistry and geology and biology and find out it's true that the development of science depends upon the knowledge of certain other sciences, and there's sort of a hierarchy.

I would like to go back just for a moment and say something about Schwringer. Schwringer wrote a very interesting book, called Nature in Greece. He thinks everybody should go back and look at Greece, because it will help you in nuclear physics. It isn't that the Greeks knew more than we do, but they were prejudiced, and so are we. The trouble is, we cannot see our prejudice by looking at ourselves. We've got to look at somebody else. It's always easier to criticize the other fellow. So he advocates going back and studying.

Of course you know that's true in the case of geometry. Euclid said through a given point you can draw only one straight line parallel to another. He said it's an assumption. People say he was crazy. Anybody can prove it. They spent 2,000 years not proving it. Finally someone said, "Let's give up. Let's agree it can't be proved." That was the beginning of commutative geometry.

Well, we have it over and over again. Somebody looks back at the motion of a body and says, "How do you determine space and time and speed?" So somebody says, "Well, obviously, we've got to think and view," so one begins with the relativity theory.

There have been profound changes, as we've noticed. There have been changes not only in sociology, not only in technology, but also in ideas.

I want to take the last couple minutes to take one of these cases of the development of electricity and magnetism, and just illustrate it. It began back

with three unusual things--the stone, magnatite, found in Asia Minor, the pebble, a piece of amber, found up in the Baltic Sea, and a frog that arrived in an experiment by Caldan. The strangest story of history is how these three things got together and produced the electrical age. It's just that business of curiosity and those things being neglected, and then suddenly someone begins to examine them and put them together.

So you find in electrostatics in the 17th century there were only four facts known--attraction, repulsion, conduction, and induction. Franklin was the one who introduced the conservation of electric charge. We talk a great deal about the conservation of energy but if there is one principle that is even more important it probably is the conservation of electric charge. And it came out of the amateur, Benjamin Franklin, doing certain things.

But, when people began to measure speeds and electric charge, then you had something quantitative, and once you have something quantitative then you can develop something mathematical. And we have the mathematical theory of potentials and the philosophy of French equations development.

Now you come into the period of electromagnetism. Electric current has a chemical and eating effect and vice versa. This was the thing that got Farraday interested. He said, "Suppose I were by means of some change in magnetism to produce an electric current?" That was his great concept. He got the idea that surrounding a body is a field of influence. Maxwell came along and put that in mathematical terms. What Maxwell did was pull something out of the great blue sky and wrote it down and predicted that life was just an electromagnetic phenomenon. It was very difficult to test the thing out, but around 1886, in that period, or 1888, Hurtz actually did the experiment and found out that Maxwell

was right. This was a tremendous comprehensive theory which combined light and magnetism and electricity. So it wasn't surprising that Einstein devoted a good deal of his time trying to pull in gravitation to get a unitary view of this.

The interesting thig is that in 1907 one of the great physicists, one of the few physicists who did something practically, like the laying of the Atlantic cable, Lord Kelvin, said he didn't believe Maxwell--1907. Well, as a matter of fact, about this time came, you know, the electrical theory of matter. There was a dilemma at the end of the 18th century. The question was: Is it one fluid or two? You could explain everything equally well.

Then there came the dilemma of the 19th century: Does fluid come in little packages or is it continuous? I mean, when you get your milk, does the cow give it in quarts or does it just squirt continuously? Well, this was the problem that Farrady worked on. People got tired. They had determined that the conduction of electricity was solved. Then came the dilemma. They developed the conduction of electricity in liquid. Up came the dilemma. So nobody was interested in the conduction of electricity. As a matter of fact, they said, "It's just replacing a little tube." People just looked at it for the fun of it. Yet, in that very area was the answer to the two dilemmas. It was the discovery of the electron.

I think it is very interesting that, when you began to apply the electron to an atom, as Rutherford did, the first thing you realized was that the whole theory of electromagnetism said that it couldn't be, because the little electron would radiate and the atom would be unstable. Everett said, "What do we do?" Moore said, "I've got an idea. Let's forget the electromagnetic theory. Let's assume it doesn't radiate." That's the big thing of the process of mechanics in one sentence. And of course we now have other things.

Well, I want to end with just this note. We do live in an electrical age, but for the most part scientists have not applied their results. There have been very few exceptions. On electrical power there was Von Semings in Germany, Ferranti in Great Britain, and Edison in the United States. On electric lights there was Wann in Great Britain and Edison in the United States. On communications, for telegraphy there were Morse and Cook; telephone, Bell; radio, Marconi. These were engineers and inventors, and not scientists. As a matter of fact, Edison discovered the thermyonic effect that might have been useful in radio tubes and this might have had some influence on the communication industry that he was sponsoring. But he had no interest, somehow, in juice. .

So in 1876 you find a cooperative laboratory. Said Edison, "There must be other people like me. Let's getthem all together, and let's cooperate on inventing." This was a systematic program. Then in 1900 you had the establishment of the GE Research Laboratory, where the problem was to get scientists to work on needs that were relevant to GE. It's all right for scientists to work on other things, but, after all, if you want GE to be GE, somebody has got to worry about the things GE is interested in. So they established their own laboratory, and they had an uncommitted inquiry. And of course you had very famous people like Langmuir and Coolidge, and they found that there was some technological profit by allowing scientists to work on things they were interested in. Of course you had a certain lapse of time.

Then we come along to Bell Company. They said, "Look, we just can't take the old knowledge we know, everything that people are doing. We've really got to start completely fresh." No one was interested in sound or in speech or hearing. They started to do research in these fields. They were quite unknown. The

universities were not interested in that stuff, at all. So you have the very great laboratory.

Well, as you know, the upshot of this whole matter is that the lapse of time between basic research and technology has very often decreased. It was 50 years from the time that Farraday discovered the dynamo effect until the opening of Edison's power plant on Pearl Street, New York City. In the case of the atomic bomb, of course, you know it was from 1939 until 1945, and in transistors, it was even more so.

I want to just suggest to you in closing that, as one looks at the history of science and technology, I think these two questions that I raised with you at the beginning are the fundamental questions: What has been the relationship between science and technology? I think you will find that as time has gone on there has been an increasing reciprocal relationship which somehow has to be continued. But more important is: What is the role of the individual? I believe that this is one of the problems that we have not yet completely realized, that the number of real geniuses is going to be very small, and we want to be awfully certain that we don't miss the real geniuses.

Thank you.

QUESTION: Dr. Seeger, are we diluting our scientific talent in this country by assignikg scientists to managerial and political roles in our government structure?

DR. SEEGER: When I think of what some of them do as managers, I think the answer is yes, but obviously you do have to have some people manage. I don't know. I am sort of torn betwixt and between on this whole thing. It depends upon the person. I wouldn't say that necessarily a person is a good manager because he

is an economist or because he is this, that, or the other. Wherever you find a good man I think you had better take him for a managerial position. In other words, I have a feeling sometimes that it might be better to have a person at the head of a scientific organization that doesn't know anything about science.

I'll give you an illustration of what I mean. I was always impressed with two things: If a man doesn't know anything, he always listens carefully to all sides. I have found some civilians in other places, and the trouble was that they did know things, so they didn't listen. The other thing I was impressed with was that when they made a decision they made it promptly. I think these are two very good characteristics.

So I would say that I wouldn't buy using a man who is a scientist or not a scientist. I think you have to find the man who is a good manager. There are not so many of us who are good managers.

QUESTION: Doctor, is the National Science Foundation doing anything to clarify nationally the difference between scientists and engineers? You point out there is an overlapping and confusion in this area.

DR. SEEGER: I think, off the record, no. We do the easy problems. We spend money.

QUESTION: Could you give us a few words about the application of scientific management to humanities?

DR. SEEGER: You have to put another sentence on there.

STUDENT: Let's say specifically the intelligence function in the services.

DR. SEEGER: Yes. I have an article which I gave the Captain, and which I may have mentioned to you, on the Sociology of Science, which deals with the whole question of science as a social proposition. Obviously, sociology is very, very

difficult, primarily because you don't have the isolability and control.

Well, this gives me an opportunity. This book, Yellow Peril, do not read. This is on science and history, written by a lawyer. He wrote a very good musical play called Fiorello. He's a man by the name of Kuneo. He interprets all history in terms of science. All the problems, including the one that you mentioned, are all given in this book. For example, he says among other things that energy is a velocity, as a horse, which is certainly an interesting point of view.

I think that something can be done, and I believe that the methodology is the same as the methodology in the physical sciences, but it will not give as fruitful results in as short a time. This is 1963, by the way.

Maybe I haven't answered your question.

The other book I recommend very highly, because it's by my former teacher. This just came out, Science in Civilization, by Arthur Swinns. He is Dean of the Graduate School of Physicists, and an acoustics man. It's really very good. He has a chapters on science and the humanities, science and philosophy, science and history, science and technology, science and the state. It's excellent.

QUESTION: Sir, would you discuss military science? In a sense the physical sciences have contributed much more to our military capabilities in the past 40, 50, or 100 years. It is possible to generate it through military science?

DR. SEEGER: In other words: What are sciences and what are not? You see, one of the real questions is: Is sociology a science? It's very interesting to look in universities and see where they put the sociology department, or the history department. This is a very interesting question. Half the historians say it is, half say it is not. I belong to a school that believes that there is

a basic method of science. Conant does not believe that there is a method of science. I think we disagree in this. I believe that there is one general method which can be applied with varying degrees of success, depending upon the material that you have before you.

Obviously, where you get into the experiment of lovemaking, it's very difficult to come up with an objective analysis of the thing. So sociology has not gotten far, not because people haven't spent money on it. I read a book recently by a sociologist. He says, "All you have to do is have the National Science Foundation put a lot of money in sociology and we'll get just as far as the physical sciences." Nuts. He doesn't understand. The reason we have gotten far in physics is because physics is easy. It's simple. We can ask questions and we can get answers. You can ask questions all you want to in sociology and it's very difficult tp get am amswer/

I think coming back to this other question, it is: Is theology a science, is law a science, is the military a science? Yes. I would say that as parts of sociology these are all sciences, but they are very, very difficult. I am sure that what they call military science that I took as an ROTC was probably neither military nor science.

STUDENT: Of the $9 billion that goes into research and development that goes into the physical sciences.

DR. SEEGER: Yes. You know why. Because we can get someplace. I mean, I just don't know.

STUDENT: What have we had in 50 years from the physical sciences that helped the military?

DR. SEEGER: Oh, this is very difficult. I mean, regarding the physical

sciences, I think in general, if you bring close connection between science and technology you are going to be able to find uses for things. This is a matter of experience. This is what I call that same optimism, that when we have discovered something we find we can use it. Man is very ingenious on that. I can't predict just what it will be used for, tut I'll bet you four cents that it will be used.

In the last century over in England, I think it was, there were two professors of mathematics. One was in applied mathematics and the other was in pure mathematics. The applied mathematics professor pooh-poohed the man in pure mathematics because he wasn't interested in applications. Well, today, nobody knows what the man in applied mathematics did, but the man in pure mathematics happened to be working on major steel, which is very much applied at the present time.

I remember when I was in the Navy, Bureau of Ordnance, I was a civilian. One man came over to me and he said, "Look, while you are piddling around scratching those old marks on a piece of paper, why don't you do something for the military?" I said, "What are you doing?" He had an idea of how to improve the efficiency of a projectile one tenth. I said, "That's fine." And I kept scribbling away. Now I happened to be working with John Benoyen. He was the greatest mind that I have ever had contact with in my life. Johnnie Benoyen, I remember, was working on something as to what would be the best position to drop the atomic bomb in. He got the medal of merit for that, and I got some kind of a distinguished service award for helping him. But I was just piddling. Rather dangerous, you see. The other fellow, I think, did improve the thing a tenth of a percent. But, who cares.

QUESTION: In a recent study of science in the United States Dr. Hutchins

and others criticized the current conduct of science, and they particularly questioned the capability of scientists to formulate a proper strategy for the current conduct of science. Will you comment on that?

DR. SEEGER: Yes. I didn't read that. What I would say is this: I think we have to distinguish very carefully between science and technology. In other words, I believe it is very possible to plan technology. I believe this is very possible. A very good example of it is the atomic bomb. It speaks for itself. But as far as planning science is concerned, every scientist would be scared of this.

Let me give you an example. A hundred years ago, or 85 years ago, what would the National Science Foundation be spending its money for? I think I know. Ether theories. Because all the main people in science were doing ether theory. Well, that went down the drain. Maybe there is some byproduct of it, you see. I know one person we would never have supported. I'll just use his initials--A.E. You see, A.E. worked in a patent office. In the first place, we would never support anybody in government, you see. We have some kind of assumption about that. So we wouldn't have supported that. In the second place, he was in the Patent Office Who would be so silly as to think that any great mind would come out of the Patent Office. In the third place, if he submitted a project, we would send it around to the senior scientists in universities who would review it. And of course, they'd be the ones who wouldn't let him teach in the university.

Of course, that was Einstein. In the year 1905 he came up with three miraculous papers, when he was in the Patent Office. He was doing it on his spare time. They were the special theory of relativity, the photoelectric effect on mechanics, and the bounding movement which helped to establish the atomic bomb.

Now, I have a feeling that the best thing we can do here is not to put up so many restraints but to allow freedom insofar as a person can use freedom. I think this is my answer. But on technology I believe it can and should be planned. It must be, I think.

QUESTION: Dr. Seeger, in your talk you said you had some other comments on Francis Bacon. I would like to hear them.

DR. SEEGER: Boy, I'm always glad to have these paid people in the audience. Francis Bacon wrote a little thing called The New Atlantis, because Plato had said that out in the Atlantic there was a submerged continent, called the Atlantis. So Bacon went out to the Pacific, and he said there was a new Atlantis. In that he described a research establishment. This is really quite interesting. He called it Solomon's House. It had the following objective : "The end of our foundation is the knowledge of causes and secret motions of things." Solomon's House contained specialized facilities for various types of investigation. There were deep caves for exploring phenomena beneath the earth, as well as high towers on mountains for observing meteorological phenomena. There was a special laboratory for high temperature investigation, one for objects, one for acustics. A special room was provided for the artificial production of rain. One room contained primarily engines, including some for ordnance. Finally, there was a mathematical room, filled with appropriate instruments. It was recognized that the proper utilization of these facilities would requisition the entire time of the workmen.

Novices and apprentices were to be differentiated from what we nowadays call professional personnel. There were to be 36 fellows in all, grouped as follows: Twelve merchants of blood who roamed about the earth in search of observed data; three perpetrators, who sought such data in books; three individuals who collected

data from current experiments; three pioneers who collected data from new experiments; and three compilers who tabulated and classified all these data. There were three benefactors whose primary function was to determine how to use all the results; three planners of new experiments; three others who performed the experiments and reported on them; and, finally, three who interpreted all the discoveries that were made.

It is to Bacon's credit that he sensed the importance of a cooperative enterprise, of the specialists having unusual equipment and books. I think that's a very good description of a modern laboratory.

QUESTION: You suggested that you might expand some on the atomic theory.

DR. SEEGER: Oh, I was telling about this one little problem I ran into. We are getting a notion now. I admit this to you. I am having great difficulty selling physics to people. I am teaching the history of physics. I suppose it may be the reaction to Conant's saying, "Do you know, I was really discouraged. I was up visiting a very fine professor at Yale recently, and he said, 'You know, one thing I don't have time for nowadays and it's to read the current articles in my field. So I was bothered. So I just started from scratch.'"

I know this is true. Whenever you give out a development contract--this was years ago and it wouldn't be true now--every, single person in development started out to read the same material and write reports on it. And it was years before anybody got around to doing anything new.

There is a tendency now to say, "Well, let's get on. Let's not worry about the past." I don't like to get lost in the past, but I'd at least like to see where I am going. Well, a physicist, I say, just can't be bothered. I picked up a very fine book on physics, general physics, and where was Galileo? He is not

even mentioned. So I think this is rather amazing.

Well, anyway, my daughter took chemistry last year. She came home one night, and she said, "Daddy, who was it that founded the modern atomic theory?" It's a tough thing to have kids ask you these questions. So I thought: What does modern mean? Modern history begins about the industrial revolution or someplace around there. So I said, "How about Dalton, in chemistry?" "No," she said, "Dad, that's wrong." Well, I said, "Get me your textbook and let me see whose picture is in that chapter." Well, it turned out to be Nils Bohard. I said, "Nils Bohard?" She said, "No, daddy, that's wrong." She said they were using another textbook for the test. "Aha," I said, "Bring me that book and let me see that picture." It turned out to be Rutherford.

Well, I've been going around asking some of my colleagues. Recently I was down in Durham, and I asked the Chief of the Army office down here. He's a chemist, and he had one of the chief physicists there. And I asked Hobbs, the Dean of the Graduate School at Duke. We were sitting around a table, and I said, "By the way, let me ask you this question." These three finally came up with Dalton, Rutherford, and Bohard. Well, I saw Henry Smythe one day, and I was talking to him. I said, "How would you answer that question?" He wanted to know why I wanted the answer. I said, "Look here. This is just a kid's examination. Don't ask me all these questions. I've got 49 others to do." He said, "Well, I would say Dalton." I said, "That was right, and you're wrong."

Well, anyway, this alarms me, you see. Of course it was obvious to me after a while. We talked about atomic energy, and of course, we end up with Rutherford. But I am very much disturbed over this. I want to emphasize again that science is a vector quantitative. It's not just the skilled quantity that has position. It

also has direction. The only thing I am positive about is that the science we have today is not what they taught me in school. So we should prepare our youngsters today, because the science they are learning today is not science.

CAPTAIN BRYCE: Dr. Seeger, I think you have answered all the questions. On behalf of your audience, thank you for a stimulating and an interesting treatment of your subject.

DR. SEEGER: Thank you.