WHAT IS SCIENCE?

Richard P. Feynman

I thank Mr. DeRose for the opportunity to join you science teachers. I also am a science teacher. I have much experience only in teaching graduate students in physics, and as a result of the experience I know that I don't know how to teach.

I am sure that you who are real teachers working at the bottom level of this hierarchy of teachers, instructors of teachers, experts on curricula, also are sure that you, too, don't know how to do it; otherwise you wouldn't bother to come to the convention.

The subject "What is Science" is not my choice. It was Mr. DeRose's subject. But I would like to say that I think that "what is science" is not at all equivalent to "how to teach science," and I must call that to your attention for two reasons. In the first place, from the way that I am preparing to give this lecture, it may seem that I am trying to tell you how to teach science -- I am not at all in any way, because I don't know anything about small children. I have one, so I know that I don' t know. The other is I think that most of us (because there is so much talk and so many papers and so many experts in the field) have some kind of a feeling of lack of self-confidence. In some way you are always being lectured on how things are not going too well and how you should learn to teach better. I am not going to berate you for the bad work you are doing and indicate how it can definitely be improved; that is not my intention.

As a matter of fact, we have very good students coming into Cal Tech, and during the years we found them getting better and better. Now how it is done, I don't know. I wonder if you know. I don't want to interfere with the system; it is very good.

Only two days ago we had a conference in which we decided that we don't have to teach a course in elementary quantum mechanics in the graduate school any more. When I was a student, they didn't even have a course in quantum mechanics in the graduate school; it was considered too difficult a subject. When I first started to teach, we had one. Now we teach it to undergraduates. We discover now that we don't have to have elementary quantum mechanics for graduates from other schools. Why is it getting pushed down? Because we are able to teach better in the university, and that is because the students coming up are better trained.

What is science? Of course you all must know, if you teach it. That's common sense. What can I say? If you don't know, every teacher's edition of every textbook gives a complete discussion of the subject. There is some kind of distorted distillation and watered-down and mixed-up words of Francis Bacon from some centuries ago, words which then were supposed to be the deep philosophy of science. But one of the greatest experimental

scientists of the time who was really doing something, William Harvey, said that what Bacon said science was, was the science that a lord Chancellor would do. He spoke of making observations, but omitted the vital factor of judgment about what to observe and what to pay attention to.

And so what science is, is not what the philosophers have said it is, and certainly not what the teacher editions say it is. What it is, is a problem which I set for myself after I said I would give this talk.

After some time, I was reminded of a little poem:

A centipede was happy quite, until a toad in fun

Said, "Pray which leg comes after which?"

This raised his doubts to such a pitch

He fell distracted in the ditch

Not knowing how to run.

All my life, I have been doing science and known what it was, but what I have come to tell you -- which foot comes after which -- I am unable to do it, and furthermore, I am worried by the analogy with the poem, that when I go home I will no longer be able to do any research.

There have been a lot of attempts by the various press reporters to get some kind of a capsule of this talk; I prepared it only a little time ago, so it was impossible; but I can see them all rushing out now to write some sort of headline which says: "The Professor called the President of NSTA a toad."

Under these circumstances of the difficulty of the subject, and my dislike of philosophical exposition, I will present it in a very unusual way. I am just going to tell you how I learned what science is. That's a little bit childish. I learned it as a child. I have had it in my blood from the beginning. And I would like to tell you how it got in. This sounds as though I am trying to tell you how to teach, but that is not my intention. I'm going to tell you what science is like by how I learned what science is like.

My father did it to me. When my mother was carrying me, it is reported -- I am not directly aware of the conversation -- my father said that "if it's a boy, he'll be a scientist." How did he do it? He never told me I should be a scientist. He was not a scientist; he was a businessman, a sales manager of a uniform company, but he read about science and loved it.

When I was very young--the earliest story I know--when I still ate in a high chair, my father would play a game with me after dinner.

He had bought a whole lot of old rectangular bathroom floor tiles from some place in Long Island City. We sat them up on end, one next to the other, and I was allowed to push the end one and watch the whole thing go down. So far, so good.

Next, the game improved. The tiles were different colors. I must put one white, two blues, one white, two blues, and another white and then two blues--I may want to put another blue, but-it must be a white. You recognize already the usual insidious cleverness; first delight him in play, and then slowly inject material of educational value.

Well, my mother, who is a much more feeling woman, began to realize the insidiousness of his efforts and said, "Mel, please let the poor child put a blue tile if he wants to." My father said, "No, I want him to pay attention to patterns. It is the only thing I can do that is mathematics at this earliest level." If I were giving a talk on "what is mathematics," I would already have answered you. Mathematics is looking for patterns. (The fact is that this kindergarten had some effect. We had a direct experimental test, at the time I got to kindergarten. We had weaving in those days. They've taken it out; it's too difficult for children. We used to weave colored paper through vertical strips and make patterns. The kindergarten teacher was so amazed that she sent a special letter home to report that this child was very unusual, because he seemed to be able to figure out ahead of time what pattern he was going to get, and made amazingly intricate patterns. So the tile game did do something to me.)

Mathematics is looking for patterns.

I would like to report other evidence that mathematics is only patterns. When I was at Cornell, I was rather fascinated by the student body, which seems to me was a dilute mixture of some sensible people in a big mass of dumb people studying home economics, etc. including lots of girls. I used to sit in the cafeteria with the students and eat and try to overhear their conversations and see if there was one intelligent word coming out. You can imagine my surprise when I discovered a tremendous thing, it seemed to me.

I listened to a conversation between two girls, and one was explaining that if you want to make a straight line, you see, you go over a certain number to the right for each row you go up, that is, if you go over each time the same amount when you go up a row, you make a straight line. A deep principle of analytic geometry! It went on. I was rather amazed. I didn't realize the female mind was capable of understanding analytic geometry.

She went on and said, "Suppose you have another line coming in from the other side, and you want to figure out where they are going to intersect. Suppose on one line you go over

two to the right for every one you go up, and the other lines go over three to the right for every one that goes up, and they start twenty steps apart," etc. I was flabbergasted. She figured out where the intersection was. It turned out that one girl was explaining to the other how to knit argyle socks.

Therefore, I did learn a lesson: the female mind is capable of understanding analytic geometry. Those people who have for years been insisting (in the face of all obvious evidence to the contrary) that the male and female are equally capable of rational thought may have something. The difficulty may just be that we have never yet discovered a way to communicate with the female mind. If it is done in the right way, you may be able to get something out of it.

Now I will go on with my own experience as a youngster in mathematics. Another thing that my father told me--and I can't quite explain it, because it was more an emotion than a telling--was that the ratio of the circumference to the diameter of all circles was always the same, no matter what the size. That didn't seem to me too unobvious, but the ratio had some marvelous property. That was a wonderful number, a deep number, pi. There was a mystery about this number that I didn't quite understand as a youth, but this was a great thing, and the result was that I looked for pi everywhere.

When I was learning later in school how to make the decimals for fractions, and how to make 3 1/8, I wrote 3.125, and thinking I recognized a friend wrote that it equals pi the ratio of circumference to diameter of a circle. The teacher corrected it to 3.1416.

I illustrate these things to show an influence. The idea that there is a mystery, that there is a wonder about the number was important to me, not what the number was. Very much later when I was doing experiments in the laboratory, --I mean my own home laboratory--fiddling around--no, excuse me, I didn't do experiments, I never did; I just fiddled around. Gradually through books and manuals I began to discover there were formulas applicable to electricity in relating the current and resistance, and so on. One day looking at the formulas in some book or other, I discovered a formula for the frequency of a resonant circuit which was f = 1/2pi sqrt(LC), where L is the inductance and C the capacitance of the circle? You laugh, but I was very serious then. Pi was a thing with circles, and here is pi coming out of an electric circuit. Where was the circle? Do those of you who laughed know how that comes about?

I have to love the thing. I have to look for it. I have to think about it. And then I realized, of course, that the coils are made in circles. About half a year later, I found another book which gave the inductance of round coils and square coils, and there were other pi's in those formulas. I began to think about it again, and I realized that the pi did not come from the circular coils. I understand it better now; but in my heart I still don't quite know where that circle is, where that pi comes from.

When I was still pretty young -- I don't know how old exactly -- I had a ball in a wagon I was pulling, and I noticed something, so I ran up to my father to say that "When I pull the wagon, the ball runs to the back, and when I am running with the wagon and stop, the ball runs to the front. Why?" How would you answer?

He said, "That nobody knows!" He said, "It's very general though, it happens all the time to anything; anything that is moving tends to keep moving; anything standing still tries to maintain that condition. If you look close you will see the ball does not run to the back of the wagon where you start from standing still. It moves forward a bit too, but not as fast as the wagon. The back of the wagon catches up with the ball which has trouble getting started moving. It's called inertia, that principle." I did run back to check, and sure enough the ball didn't go backwards. He put the difference between what we call it very distinctly.

Regarding this business about names and words, I would tell you another story. We used to go up to the Catskill Mountains for vacations. In New York you go to the Catskill Mountains for vacations. The poor husbands had to go to work during the week, but they would come rushing out for weekends and stay with the families. On the weekends, my father would take me for walks in the woods. He often took me for walks, and we learned all about nature, and so on, in the process. But the other children, friends of mine also wanted to go, and tried to get my father to take them. He didn't want to, because he said I was more advanced. I'm not trying to tell you how to teach, because what my father was doing was with a class of just one student; if he had a class of more than one, he was incapable of doing it.

So we went alone for our walk in the woods. But mothers were very powerful in those days as they are now, and they convinced the other fathers that they had to take their own sons out for walks in the woods. So all fathers took all sons out for walks in the woods on Sunday afternoon. The next day, Monday, we were playing in the fields and this boy said to me, "See that bird standing on the wheat there? What's the name of it?" I said, "I haven't got the slightest idea." He said, "It's a brown-throated thrush. Your father doesn't teach you much about science."

I smiled to myself, because my father had already taught me that that doesn't tell me anything about the bird. He taught me "See that bird. It's a brown-throated thrush, but in Germany it's called a halzenflugel, and in Chinese they call it a chung ling and even if you know all those names for it, you still know nothing about the bird. You only know something about people; what they call the bird."

"Now that thrush sings, and teaches its young to fly, and flies so many miles away during the summer across the country, and nobody knows how it finds its way," and so forth. There is a difference between the name of the thing and what goes on.

The result of this is that I cannot remember any body's name, and when people discuss physics with me they often are exasperated when they say, "the Fitz-Ceonin effect" and I ask "What is the effect?" and I can't remember the half of it.

I would like to say a word or two -- may I interrupt my little words and definitions -- because it is necessary to learn the words. That doesn't mean just because it is not science that we don't have the words. We are not talking about what to teach; we are talking about what science is. It is not science to know how to change Centigrade to Fahrenheit. It's necessary, but it is not exactly science. In the same sense if you were discussing what art is, you wouldn't say art is the knowledge of the fact that a 3-B pencil is softer than a 2-H pencil. It's a district difference. That doesn't mean an art teacher shouldn't teach that, or that an artist gets along very well if he doesn't know that. (Actually, you can find out in a minute by trying it; but that's a scientific way that art teachers may not think of explaining.)

In order to talk to each other, we have to have words, and that's all right. It's a good idea to try to see the difference, and it's a good idea to know when we are teaching the tools of science, such as words, and when we are teaching science itself....