

PRESIDENTIAL ADDRESS

Johnny and Relativity

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My title for tonight is a "come-on" for a discussion of science education, particularly at the elementary and junior high school level. Actually before I am finished I will discuss what to me is an exciting experiment in the teaching of the concept of relativity to school children.

I can personally recall a number of dismal experiences with elementary school science. Shortly after the Russians launched Sputnik 1, I was closely involved in one of the Crawfordsville P.T.A.'s. We bought for the Willson School a kit for science laboratory demonstration. As far as I know, it was mostly unused and was probably discarded when the old building was recently wrecked.

One night when my daughter was still a student at this school, she started the conversation at the dinner table with the question, "Daddy, do you know that there are three isotopes of hydrogen?" I admitted that this bit of knowledge was part of my store of factual information. I countered with the question, "What is an isotope?" She replied, "I don't know, but hydrogen has three of them." I went on to find out that she was full of such pieces of information but she was without understanding.

During my year in Washington in 1958-59, one of my jobs with the National Science Foundation was to distribute funds for the first summer institutes for elementary school teachers. I remember to my dismay when I visited one of these and found that the lesson for the day was on how to make the sound of the jungle animals. It was a disillusioning experience to see prospective science teachers learning how to roar like a lion.

All of us are aware of the vast improvement in the graduates of our high schools. Consider mathematics. Ten years ago at Wabash hardly anyone had more secondary school preparation than a year of algebra and a year of plane geometry. Today it is unusual if our entering freshmen have not had four or even five years of high school mathematics. Many of them have had calculus. Last September one or two started in differential equations.

Back in 1952 the Advanced Placement Program started. This is a plan whereby college work is presented in high school. It has accelerated rapidly. It is more important in eastern institutions than here in the midwest. It is my understanding that over half the class entering Harvard achieve sophomore status.

High school science has improved enormously. With the support of the Course Content Improvement Section of the National Science

Foundation, the new phenomenon of "committee writing" has developed. Through the cooperation between research workers, college and university teachers, experts in movie production, scientific illustrators, etc., we have such outstanding high school courses as the Chemical Education Material Study (CHEMS) and the Chemical Bond Approach Project (CBA); Physical Science Study Committee physics (PSSC); the mathematics courses prepared by the School Mathematic Study Group (SMSG), the University of Illinois Committee on School Mathematics (UICSM), and others; and the three biology courses with distinctly different approaches developed by the Biological Science Curriculum Study (BSCS). All these projects and dozens of others are described in a NSF publication. (1)

It is interesting to notice the tremendous and rapid impact these courses have had. PSSC physics started in 1956. During 1964-65 almost 40%, or 160,000 of the high school students taking physics are using these materials. CHEMS started in 1959, and in 1964-65 about 20%, or 220,000 high school students taking chemistry are using these materials.

Most important among the results of these high school science courses are: 1) the emphasis on the importance of experimental observation and deductions therefrom; 2) a decrease in the amount of memorization; and 3) the emphasis upon "models" (conceptual schemes) and their role in the development of science.

Lately the National Science Foundation has been giving much financial support to science instruction above and below the high school level. There are such things as the College Commission on Physics (CCP) and the Committee on Undergraduate Programs in Mathematics (CUPM). I am a member of the Advisory Council on College Chemistry (AC_c) and its Editor. Another former Academy president, Willis Johnson, is an active member of the Committee on Undergraduate Education in the Biological Sciences (CUEBS). The work of these college and university oriented groups are also summarized in the previously mentioned NSF pamphlet. (1)

Below the high school level the Foundation is supporting many studies for the elementary and junior high schools. (1) It is about these that I want to tell you.

One of the leaders in the elementary science development has been Professor Robert Karplus of the University of California at Berkeley. He points out that the most significant thing in presenting science to the elementary student is the teacher's attitude. Scientific concepts are not to be introduced in an authoritarian fashion. The teachers are supposed to furnish experimental evidence that will be truly convincing and acceptable to the pupils. If we think about this, and the scientific background of most of our present teachers, we realize what a dilemma is facing us in education in science in the elementary schools. Many of our teachers have not performed a single experiment in their college science courses.

There is an organization known as Educational Services, Incorporated, which has prospered from some of the profits of PSSC physics. (2) It is currently one of the strong centers in developing elementary

science education. Let me tell you about one of their products, an experiment called "Mystery Powders—An Introduction to Analytical Chemistry."

This is an experiment planned for fourth graders. It deals with five white powders: starch, baking soda, powdered sugar, boric acid and plaster of Paris. Each of these can be identified by a rather specific test—sugar, for example, by its taste or by its caramelization as it is heated; or plaster of Paris by its hardening when moistened and then dried. After studying the identifying tests the students are asked to devise methods of analyzing any possible mixture of the five powders.

More important than the details of the tests is the set of suggestions offered to teachers who use the experiment. Let me read them to you. I have added a few parenthetical remarks to help you grasp a few of the tests which may be unfamiliar.

"Do all of the experiments yourself. Add your observations to the discussions. 'When I did it, mine turned yellow.' Pretend you don't know what the powders are and that you are trying to find out with your kids. It may be that a teacher who really didn't know what the powders were would be able to teach this material better. Be enthusiastic. Look with excitement at what the children do. Jump up and down over a blackened spoon (over-caramelized sugar) or a tiny lump of hardened powder (dried plaster of Paris).

"There are no absolutely correct answers. Don't characterize an answer as right or wrong. The identification of the mystery powders should be based upon the results of the experiments. Even if you know that there is no starch in a particular mixture and a preponderance of observations show a black color with iodine (this is a test for starch which I did not discuss), the conclusion should be that starch is present. Remember that the correct determination of the powders is unimportant (except to the students), and is used only as a means to get the children to act and think as we would like.

"Teaching by the 'discovery method' is very time-consuming. You spend a lot of time without apparently accomplishing anything. But learning is a slow process. There must be time to 'fool around,' time to make mistakes, time to try something over and over again, and time to think. Don't worry about things moving too slowly. If the children are doing science and thinking science, they are learning."

Now we come to the topic set out by my title. This is one of the developments of Dr. Karplus whom I mentioned earlier. He is the Director of the Science Curriculum Improvement Study Center at the University of California at Berkeley. Here is one of his books, "Relativity of Position and Motion." (3) Notice on the cover the teacher pointing to "Mr. O." Now most of you would think that relativity is a topic probably reserved for graduate school. When I was in high school back in the twenties the apocryphal story was circulating that there were less than a dozen scientists in the world who understood what Albert Einstein had written about relativity in 1905. We do talk a lot about relativity to the Wabash undergraduates and even have a large section on relativity in the physics-chemistry

course for the non-science major. As of now, however, we do not count on our students having the background in relativity that I'm going to tell you about.

First of all, let us talk about "Mr. O." Here is what Karplus (3) has to say about this fictitious puppet which he and his associates have invented to help elementary school children understand relativity of position and motion.

"* * * we have created an artificial observer whom we call Mr. O. Mr. O directs his attention to the objects in the system of our choice. At all times he knows where every object is, but he always describes the location of everything relative to himself. Also, he never wonders 'why'—why events happen, or why objects appear the way they do. He reports in his egocentric way only what can be observed and what does happen.

"If, for example, a Mr. O on a table were asked, 'Where are you?' he could only answer, 'I am right here,' perhaps while pointing to himself. If he were asked, 'Where is the table?' he would say, 'Underneath my feet.' To the pupils in a class, of course, Mr. O would be on the table. Such a point of view, however, subordinates Mr. O to the table. For Mr. O, he himself is the central reference point. The way he faces defines the reference directions such as right, left, up, down, front, and back. Such a reference point, together with reference directions, is called a reference frame. In other words, Mr. O makes concrete the idea of a reference frame.

"Is Mr. O like a real person? No, of course not. Since he has no senses, he cannot be limited to the use of his own senses. His characteristics are created to help the teaching program and not to make him resemble a person. In his 'reports' he summarizes all the knowledge of the person who uses the Mr. O concept. He does not have to depend on his vision or on his hearing to detect what happens. Objects that block light or sound, therefore, do not interfere with his 'observations.'

"Despite Mr. O's rather unusual characteristics, three examples will show that everyone's common-sense outlook makes use of the Mr. O concept, even if he is not aware of this.

"Example 1. Mother drives her daughter to school. The girl starts to climb into the back seat. 'Don't move around so much. Sit still,' mother says. The daughter obeys. That satisfies mother. But is daughter really not moving? That depends. To a Mr. O in the car, she is indeed sitting still. To a Mr. O on the sidewalk, however, the car, the mother, and the daughter are moving past at perhaps 30 mph. Mother automatically uses both of these Mr. O's: one inside the car when she thinks about her daughter's behavior, and one on the sidewalk when she thinks about the car as a whole.

"Example 2. In a bus, the situation is still more interesting. As the bus starts suddenly, the passengers seem to fall backwards. Do they really fall backwards? Not to a Mr. O on the road; to him, they are moving forward, but more slowly than the bus. To a Mr. O on the bus, of course, they do move backwards. Who is right?

"Example 3. In astronomy, everyone learns that the earth rotates on its axis and moves around the sun. Is this true? To an observer

on the sun, it is. But to an observer on the earth, the earth doesn't move at all; it is fixed beneath his feet. To him, the sun and moon move around the earth and show certain seasonal variations. Which idea is right?

"These examples suggest that the concept of motion of an object is not an absolute one. Like the concept of position, it makes sense only when it is related to a certain reference frame, such as a Mr. O. The reference frame may be selected consciously or unconsciously. In the common-sense view, motion is usually seen relative to the reference frame provided by the immediate physical surroundings of the object of interest. Thus, the daughter is seen relative to the automobile interior, the automobile relative to the road, the road relative to the surrounding countryside, the countryside relative to the whole earth, the earth relative to the sun, the sun relative to our galaxy, and our galaxy relative to the system of galaxies called the universe. To avoid confusion and misunderstanding, the children will use Mr. O as the reference frame instead of using the physical surroundings."

Perhaps the significance of "Mr. O" will become more obvious to you as we talk about a story that Dr. Karplus has prepared for the elementary children. It is entitled "Joey, Spots and the Wagon." You can see that it is illustrated like a first or second grade reader, and it reads like one.

"Joey lived on a farm.

Joey liked to play with his dog Spots and with his wagon.

He liked to ride in the wagon while Spots pulled it along.

Then he felt so good he thought just about Spots, the wagon, and himself.

Spots, the wagon, and Joey himself were the only objects in the system about which Joey thought."

The rest of the tale is one based on misunderstanding which arises when the reference frame is not specified. Here is a synopsis:

"Joe goes for a ride one day in his wagon. Spots pull them, into a forest, and they get lost. Mother looks for Joe, and she calls him when she can't find him. 'Joe. Joe. Where are you?' Joe answers, 'Here I am, in my wagon!' Was that right? Yes, it was exactly right. His mother replies, 'You stay where you are. I'm coming after you. Don't move.' Joe, who is a good boy, stays right where he is in the wagon, but Spots, who can't understand words, keeps on walking. Did Joe obey his mother? Yes, he did, he didn't move at all. After a while his mother calls again, 'Joe where are you? I told you to stay where you were! And Joe answers, 'I'm right here in my wagon where I was before . . . ! Eventually, the wagon hits a rock and tips over. Joe's daydream is shattered. He hears his mother calling him again, 'Joe, where are you?' This time Joe answers, 'I am next to the largest tree in the forest,' and his mother soon finds him.

"Children, who are very often literal, understand and enjoy the misunderstanding between Joe and his mother."

Now I hope that even the least scientific among you has some idea of what is meant when we talk about "frame of reference."

Now that you have heard the story of Joey and Spots and seen how Dr. Karplus works with the children, you might be very interested in Dr. Karplus' advice to science teachers.

"In all this work, encourage the children to report their observations frankly. They should describe what they see, hear, feel, smell, and so on. Accept a variety of descriptions, even if they appear to contradict one another. Then look for a resolution of the disagreements by letting the children recognize that they were thinking like different Mr. O's. The children should not get the idea that you expect a certain special answer; if they do, they will give you that answer and stop making observations. For this reason, we should like you to ask, 'What have you observed today?' Then each child can give an honest answer. Some teachers ask 'What have we learned today?' This question causes pupils to try to remember what they were supposed to have learned. They will repeat the teacher's statement of the lesson's objective and will stop analyzing their observations independently. It is very hard for the children to know what they did learn.

"Let us now discuss the tendency of teachers of science to try to tie things up in a neat package every time a new experiment is performed. At the end of the period, many teachers feel they should summarize what has happened during that period. This is such a common tendency among teachers that we have given it a name, Lysiphobia—the fear of leaving 'loose ends.' If you have this common malady, you will find it hard to resist the temptation to summarize. Nevertheless, try. Leave some loose ends. These you and the children will pick up during some future experiments. The children's recognition that the old and the new experiments are related is a discovery which will thrill them and increase their interest."

The Commission on Science Education of the American Association for the Advancement of Science has prepared an elementary science program which emphasizes the processes utilized in scientific investigation. (4) In kindergarten through third grade the following processes are emphasized:

- Recognizing space/time relations
- Recognizing number relations
- Observing
- Classifying
- Measuring
- Communicating
- Inferring
- Predicting

It is interesting to note that arithmetic and mathematics is naturally included in the science course. First experiments in mensuration are done in arbitrary units, and then the metric systems is used in preference to the English system.

In the fourth and fifth grades the experiments are designed to include the additional processes of:

Formulating hypotheses
Making operational definitions
Controlling and manipulating variables
Experimenting
Formulating models
Interpreting data.

I wish that time permitted a detailed description of some of the first teaching units such as emphasis on observation by perception of colors by kindergartners or emphasis on measurement by first graders using "rulers" of arbitrary length to report the length of a table as between 7 and 8 "blips." The necessity of such a result leads to the early introduction (second grade) of the notion of fractions. Would you be surprised to learn that the fourth teaching unit (used with kindergarten children) has as its object the process of observation and as its title—"Sets and Their Members?" Among the materials needed to teach this unit are: party hat (cone shaped) solid rubber ball, metal pipe or rolling pin, Christmas tree ornament (sphere shaped), cube of sugar, funnel, picture of Egyptian pyramid. Sounds interesting, doesn't it?

I could go on with many descriptions of other elementary science projects. Dr. Karplus' study includes a unit on entropy (that awe-inspiring word associated with the second law of thermodynamics). (5) Professional astronomers and science education specialists at the University of Illinois have cooperated with elementary teachers to develop a course on basic astronomical themes and relying heavily on mathematics, physics and chemistry. (1) "Time, Space and Matter: Investigating the Physical World," is the title of a junior high school science project under development at Princeton University. (1)

To me, one of the significant things in these courses for elementary and junior high schools is the lack of lines of demarcation between the various sciences. Science is a natural enterprise growing out of experimentation and not full of foreboding boundaries. The major research achievements of our time have been in the inter disciplinary fields—biochemistry (molecular biology), space, nuclear energy—to mention a few. Perhaps there is here important implications as to the way science ought to be taught at advanced levels.

Before I conclude let me ride one of my pet "hobby-horses"—the order in which we teach the various sciences, especially in high school. The traditional parade of biology,—chemistry—physics has been based on an order of difficulty of the material. Think about it in terms of the background required for understanding modern developments. Chemistry is based on physics. Biology, especially the rapidly expanding and exciting field of molecular biology, is based on chemical principles and knowledge of organic chemistry. Why can't we change the order to physics—chemistry—biology or perhaps, even better, consider interdisciplinary courses.

I hope I have conveyed to you a sense of the excitement and revolution in the air today concerning science teaching. There is much change and experimentation ahead. Everyone of us here tonight should be interested and play a part in the upheaval. The Indiana Academy of Science should also do its share. I personally am grateful to be a science teacher at this time..

Literature Cited

1. NSF Publication 64-8. 1964. Science course improvement projects. (Available from U. S. Government Printing Office).
2. Review of Current Programs, 1965. Educational Services, Inc., 108 Water St., Watertown, Mass., 02172.
3. Karplus, Robert. 1964. Relativity of position and motion. Science Curriculum Improvement Study, University of California, Berkeley 4, Calif.
4. AAAS Commission on Science Education. 1964. Science—a process approach. American Association for the Advancement of Science.
5. Karplus, Robert. 1964. One physicist looks at science education. Science Curriculum Improvement Study.