Teaching Physics in the elementary grades

Robert Karplus founded the Science Curriculum Improvement Study, an experimental program designed to improve elementary school science education. Its headquarters are at the University of California in Berkeley, where Dr. Karplus is a professor of physics. The program encourages pupils to interpret their own observations under guidance.

By Robert Karplus

During the last ten years, physicists have become increasingly concerned with various aspects of precollegiate education. Of greatest interest has been the high-school physics course, which presents a student with his first opportunity to concentrate on coming to grips with our discipline. It has become clear, however, that large elements of the school population never enroll in high-school physics, and that even many of those who do cannot really take advantage of all the opportunities afforded by a modern course like that prepared by the Physical Science Study Committee. Accordingly, there is a growing involvement of physicists with attempts at educational innovation in the elementary and junior high schools.

Two characteristics of our educational system make this task qualitatively different from physics-course improvement at the secondary-school and college level: first, physics is considered part of general science and not as a separate discipline; second, only a negligible portion of the teachers have collegiate majors in physics. It may therefore be more meaningful to speak not of a physics course but of a physics contribution to the curriculum. To explore some implications of these observations, two symposia were scheduled at the annual meeting of the American Association of Physics Teachers in New York in January 1964. In a morning session under the chairmanship of Owen Chamberlain (University of California, Berkeley), six speakers described interdisciplinary projects for developing science instruction in the elementary schools. In an afternoon session chaired by Robert Hulsizer (University of Illinois, Urbana), three speakers commented on some aspects of science education for elementary-school teachers.

The morning speakers were Wallace Brode (Washington, D.C.), John K. Wood (Utah State University), James H. Smith (University of Illinois), Alexander Calandra (Washington University, St. Louis), Robert Karplus (University of California, Berkeley), and David Hawkins (Educational Services, Inc., Watertown, Mass.), in that order. While there was considerable overlap among the remarks of the contributors, there were also unmistakable differences of emphasis.

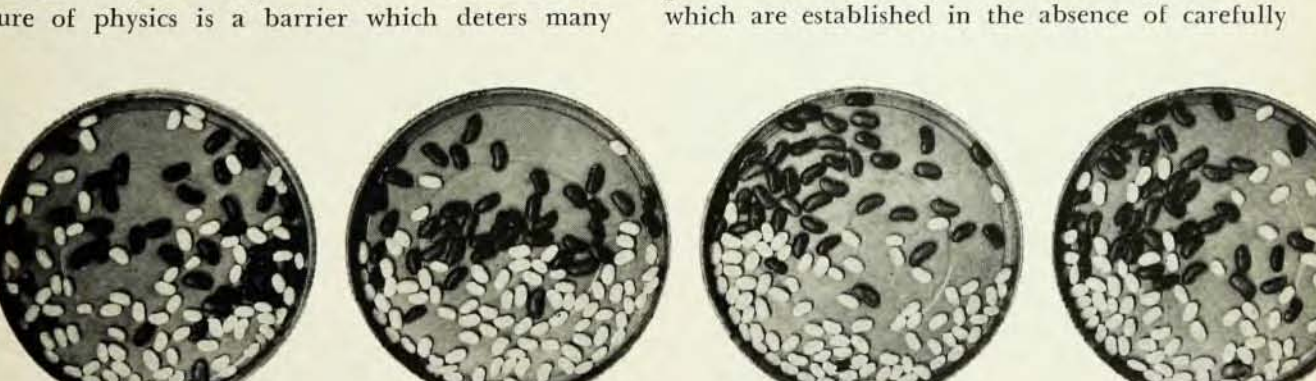
In opening the session, Owen Chamberlain called attention to the fact that, while physicists are not in a position to develop new curricula by themselves, they must and do work in cooperation with the elementary-school teachers who will ultimately select the course material to be used. Wallace Brode then described some aspects of the science program being developed by the American Association for the Advancement of Science Commission on Science Education. At present, the program is addressed to children from kindergarten to third grade. The theme of the program is a *process* approach, in which a distinct objective has been to submerge the identity of science areas in favor of processes such as observation, description, measurement, communication, classification, inference, and prediction. The choice of a scientific phenomenon to serve as illustration has been largely fortuitous. As the children mature, the continuation of this approach will lead them to a group of *concepts* such as length, time, motion, and temperature, to *applications,* and finally to subject-area *disciplines* of science. The writers of the program felt a special concern for mathematics and included specific lessons to permit the study of numbers along with the process-oriented science lessons. Dr. Brode gave one example of a lesson on inference where the illustration is taken from physics. Hollow and solid balls of about equal weight are rolled down an inclined plane; the children are expected to conclude that the difference in translational velocity permits one to make an inference about the distribution of matter in the ball without cutting it open.

The program described by John K. Wood also focuses on pupils of the primary grades. The objective is to teach a combination of interrelated processes and concepts by presenting a physical system whose behavior poses a problem. The observed changes with time are then related to the interaction of the participating objects. This approach is applied to a variety of phenomena. For example, a heating coil is permitted to interact with a detector (child or radiometer) and various obstacles or reflectors. The children draw a diagram of the system and are required to indicate the path of the radiation.

In his contribution, James H. Smith identified three roles of the physicist in the improvement of science teaching. He envisions a grade level where it is appropriate to distinguish among the sciences; in his first role, then, a physicist would prepare materials for instruction in physics. Dr. Smith pointed out, however, that the mathematical nature of physics is a barrier which deters many elementary-school teachers from studying and teaching straight physics. Fortunately, there are other curricular areas (such as astronomy and geology) which a physicist, playing a second role, may consider as vehicles for physics teaching even though that is not their direct purpose. A third role for physicists is in the design of rugged and inexpensive apparatus that will permit individual students to make their own exploration of natural phenomena. One teaching program Dr. Smith described in some detail was developed for the fourth grade by Richard Salinger of the School Science Curriculum Project at Illinois. The study of motion is introduced by means of photographs showing blurred objects, and an attempt is made to identify the manner in which motion is responsible for the blur.

Alexander Calandra has experimented with teaching of science and mathematics in grades two to nine. He recommends that the systematic study of physics may begin in the seventh grade and that adequate mathematics teaching should precede and accompany it. By postponing science instruction until after the very early grades, it becomes possible to draw on the maturity that develops through the normal process of growing up. Dr. Calandra has also been concerned with techniques for reaching the teacher with the help of very explicit printed materials and by relating the science program to language-arts skills. He found a booklet, *Symbols: A Language Arts Introduction to Mathematics and Science,* to be serviceable and to alleviate teacher anxieties caused by their marginal competence in science.

The idea of postponing science instruction was considered ill-advised by Robert Karplus, who described the Science Curriculum Improvement Study's program for developing scientific literacy. Dr. Karplus pointed out with examples that the patterns for thinking about natural phenomena which are established in the absence of carefully



The contrast between "natural" and "unnatural" time sequence in a process is illustrated by puzzle above: Between each photograph the beans were shaken up but not touched individually by hand. In what order were the pictures taken?

planned instruction reflect and perpetuate prevalent cultural attitudes and superstitions concerning scientific matters. These form an effective block to later learning of science by most individuals. A desirable program that builds scientific literacy and prevents this difficulty must provide for two aspects: giving the student opportunities to observe a wide variety of natural phenomena and introducing the student to an analytical approach that modern scientists find useful in thinking about these phenomena. An example of the latter is the reversible idealization of ordinary phenomena. By projecting motion pictures so as to create a time-reversed illusion, it becomes possible to identify those aspects which reveal the sense of time and therefore manifest deviations from the ideal reversible process.

In the morning's concluding paper, David Hawkins presented an analysis of the central role that laboratory activity should play in elementary-school science. The laboratory, however, should not serve a teacher's didactic purposes but should afford the pupil an opportunity for understanding according to his own impulses and at his own pace and level. It should facilitate a genuine match between the learner and his environment. Of course, achievement of such a match costs time. One of Dr. Hawkins's participating teachers reported her work on geometrical optics under the title, "How to Take Six Weeks to Teach What You Could Tell Them in a Half Hour". Her class explored shadows, the effect of bent black tubes, and other simple situations that depended on the rectilinear propagation of light. She was rewarded by one pupil's discovery that a small obstacle can be considered a reciprocal or negative pin hole and will produce an image. Dr. Hawkins contrasted the tangible or operational understanding that is derived from manipulation and experimentation with concrete objects and a kind of verbal understanding that can be related to other words but cannot be related to actions in concrete situations. Between these two there is a gap. Schools have traditionally nurtured the latter kind of understanding. The elementary science program offers an opportunity to build the former.

It appears to me that an awareness of Dr. Hawkins's last point is shared by all of the morning's speakers. They all believe that the source of information for the elementary-school pupil should be a phenomenon taking place under his observation. Answers to questions posed by the pupils or the teacher should be sought in the behavior of the experimental system and not in the tell-tale behavior of the teacher who knows the "right answer" all along and either coaxes the class to construct it or states it for everyone to copy. Yet there are different approaches to creating bridges over the gap between operational understanding and general verbal formulation of an idea. Dr. Brode prescribed early training in the processes of science by which direct sense experience is organized, is converted to empirical evidence, and leads to general conclusions. Dr. Calandra suggests that instruction be postponed until, presumably, the pupil is sufficiently mature to build the bridges without external assistance. My own recommendation is to accompany the students' experiments with suggestions as to one or more ways the students might think about the experiments. The student would be free to follow the suggestions or to adopt a different point of view, but he would be asked to make some effort to justify his decision. Dr. Hawkins, finally, counsels patience. Before I leave the point, let me add that I consider bridging of the gap between the manipulative and the conceptual to be crucial for science instruction at all levels. The reader might ask himself by what means and how well this problem is solved in high-school, collegiate, and graduate education.

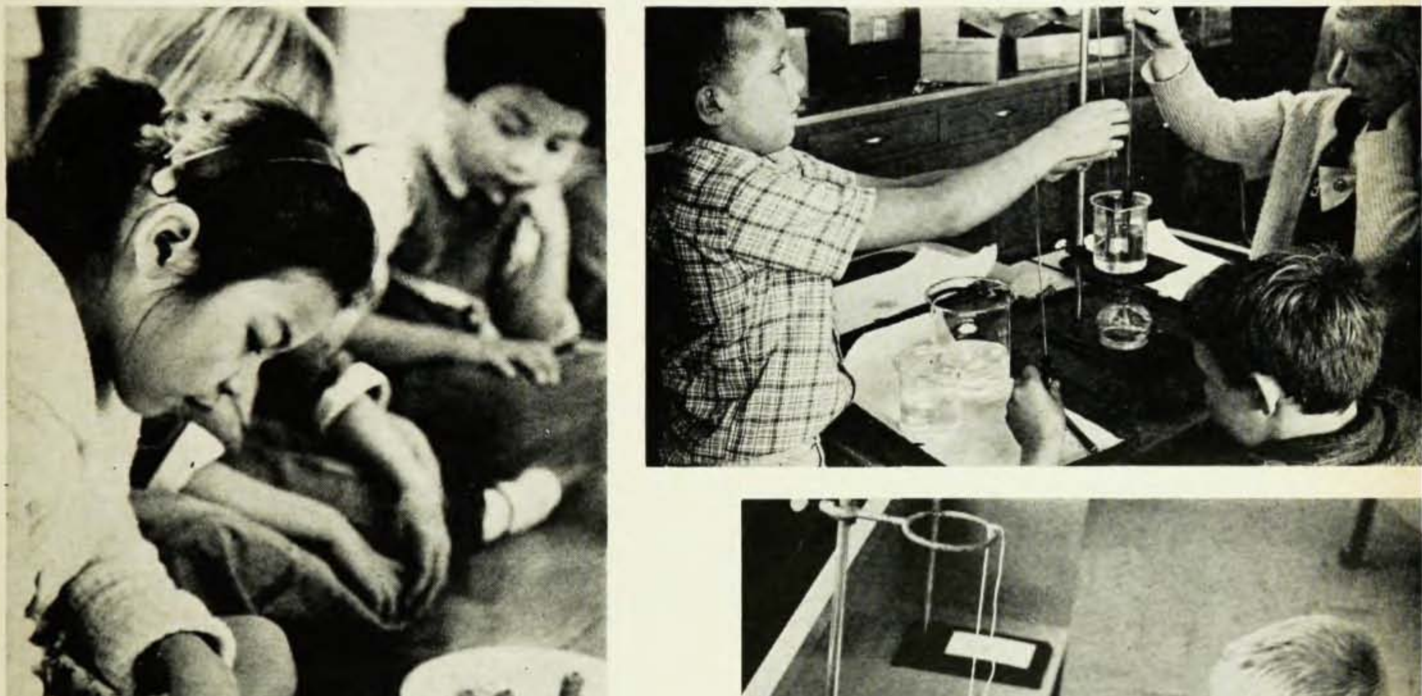
Another matter of concern to several speakers was the mathematics program and its relation to science instruction. Since mathematics instruction is in a state of flux at present, the inclusion of some needed mathematics with science as Drs. Brode and Calandra described seems to be the only sound plan for an experimental science program. One group, the MINNEMAST project at the University of Minnesota, is developing an integrated science and mathematics curriculum, but at the time of the symposium its work had not advanced sufficiently to make possible a report on this special aspect.

A third item of concern to all the speakers was teacher education, both for college students who are planning to teach and for teachers currently active in their profession. During the morning this matter was mentioned only briefly, but the afternoon symposium revealed some of the current thinking on the subject. The afternoon speakers were Martin Mayer (New York City), Walter D. Knight (University of California, Berkeley), and Philip Morrison (Cornell University).

Martin Mayer challenged one of the premises as stated at the beginning of this review. He considers it essential that some college physics concentrators should become elementary-school teachers. This proposition is related to a prospect of an increasing need for specialist teachers in the elementary school. The problem then becomes one of identifying the point at which the educational program being pursued by future research physicists becomes different from the program being pursued by future secondary-school teachers and by future elementary-school teachers. A single physics course for liberal-arts majors, in Mr. Mayer's view, will not be adequate. There is the hope, however, that the current intellectual ferment in science education will make the teaching profession look attractive to greater numbers of capable science students than is the case at present.

The other two speakers addressed themselves to the task of providing some science instruction for the majority of the prospective teachers who will not major in a scientific area and whose interest in science is peripheral to their main interest. The instructor of these students faces the problem of reaching them because they may have enrolled in his course with reluctance. Walter Knight, in his paper "The Art of Science", pointed out that the common view of science as involving systematic procedures for gathering data and a connected body of demonstrated truths is not really very attractive and is seriously incomplete. There must be added what is usually suggested by "art", a creative or productive quality which brings into existence a synthesis of experience. The practice of the art of science, which is the principal activity of physicists, is perhaps best appreciated by others through esthetic reactions evoked by beauties of the scientific engagement.

Philip Morrison shared Dr. Knight's concern that the synthetic aspect of scientific work receives little attention in most science courses, which devote themselves instead to an analysis of natural phenomena. The effort to achieve high intellectual quality by stripping everything down to a conceptual minimum is appealing, but dangerous. Of



Phenomena taking place under their observations: (left) kindergarten pupils observing and classifying simple objects; (top) fourth graders constructing and calibrating thermometers; (right) third grader looking for evidence of interaction at a distance between a nail and a mysterious object.

course, the analysis is invaluable, but it misses that which is most exciting about the scientific enterprise and which motivates the participants. For the students who are not mechanically or mathematically minded, who do not have much experience in manipulating objects, the course should involve a quite free use of simple materials combined with some analysis of the use of these materials. Most any object can be used as an element in a structure that spans a gap or reaches an elevation; a multimeter can be combined with simple electrical circuits; systems of lenses can be used to create images; crystals can be grown and their symmetry analyzed. Dr. Morrison's principal point is that only a very small number (three or four) of these possibilities should be included in one term. Their exploration should be leisurely and should permit the student to carry out rambling studies following his own interests and not the dictates of the instructor or of an inflexible course outline that has been constructed to facilitate efficient coverage of the material. The suggested program effectively allows the student interested in literature or in interpersonal relations to feel at ease in a situation that involves only him and the physical world.

The importance of the educational problems discussed in the afternoon suggests that a larger and concerted attack on them could well be justified. As a matter of fact, the Commission on College Physics has accepted the challenge and is studying the development of programs for prospective teachers who concentrate on physics, and of isolated courses for prospective teachers (and for others, too) who will concentrate their studies in nonscientific fields.

Another aspect of this problem was brought up by Dr. Calandra: the education of teachers who are professionally employed and who no longer think of themselves as students. All but those interested in the most long-term efforts at curriculum reform must face this issue.

The attendance at the symposia and the response of the audience gave evidence that physicists are concerned with the problems of education for the scientific lay citizen. I hope that this review will carry some of the salient points to a still larger interested group and that it will stimulate inquiries to the speakers for more details about their work and ideas. Each community will need the encouragement, assistance, and support of the scientists who are among its residents if the programs that were described here are to reach a significant fraction of the elementary schools in this country.