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Elementary Science: A New Scheme of Instruction

The processes of scientific inquiry are stressed in a program now being tested.

Robert M. Gagné

For the past several years, a set of materials called *Science—A Process Approach* has been under development and testing as a means of teaching science in the elementary grades (*1*, *2*). At present, these materials comprise 14 booklets, parts 1 (A and B) through 7 (A and B), each part containing descriptions of about 25 science exercises, and an additional booklet, *Commentary for Teachers*. The exercises of part 1 are intended for kindergarten children, the others for children of successive grades through the sixth. Each exercise is addressed to the teacher and describes the activities to be conducted with and by the children. For each exercise there is given a set of objectives, a rationale, new vocabulary to be introduced, and a list of materials needed. In addition, a section on appraisal suggests the kind of additional questioning that may be used by the teacher to satisfy herself that the desired learning has occurred.

The development of these materials has been carried out under the direction of the Commission on Science Education of the American Association for the Advancement of Science, with support from the National Science Foundation. The major developmental work has been conducted by groups of scientists and educators assembled for "writing sessions" during the summer months of 1963, 1964, and 1965. At present, the materials are being tried out in 14 school systems, and additionally in 20 individual schools, in various parts of the country. Assessment of pupils' achievement following their participation in each exercise is an integral feature of the evaluation (*3*).

The most striking characteristic of these materials is that they are intended to teach children the *processes* of science rather than what may be called science content. That is, they are directed toward developing fundamental skills required in scientific activities. The performances in which these skills are applied involve objects and events of the natural world; the children do, therefore, acquire information from various sciences as they proceed. The goal, however, is not an accumulation of knowledge about any particular domain, such as physics, biology, or chemistry, but competence in the use of processes that are basic to all science.

The exercises of parts 1–4 concern the processes called Observation, Classification, Communication, Number Relations, Measurement, Space/Time Relations, Prediction, and Inference. A variety of content is used to support the learning of these skills. For example, observation exercises deal with colors, shapes, textures, and sounds, and involve such objects and events as magnets, plants, weather changes, rolling balls, animals in motion, seeds, and growing organisms. The exercises in each process grow increasingly complex, making use of what the child has learned before. For example, an early classification exercise treats the single-stage classification of sets of common objects (red-blue, rough-smooth). Successive exercises introduce more complicated classification problems, and an exercise in part 4 deals with a multistage classification schema applicable to collections of plants, animals, and other objects.

In parts 5, 6, and 7 the exercises deal with the most highly integrated processes called Formulating Hypotheses, Making Operational Definitions, Controlling and Manipulating Variables, Experimenting, Formulating Models, and Interpreting Data. These more complex activities clearly build upon the simpler skills and knowledge acquired in parts 1–4. The exercises have a greater number of specific prerequisites which can readily be identified as having been taught in earlier lessons. Although process rather than content remains the focus of attention, the exercises in parts 5–7 cover a range of important topics from physical science, earth science, life science, and behavioral science. In the current edition, there is a trend toward grouping "blocks" of lessons dealing with particular science content. Quite possibly, this trend will be further emphasized in later editions.

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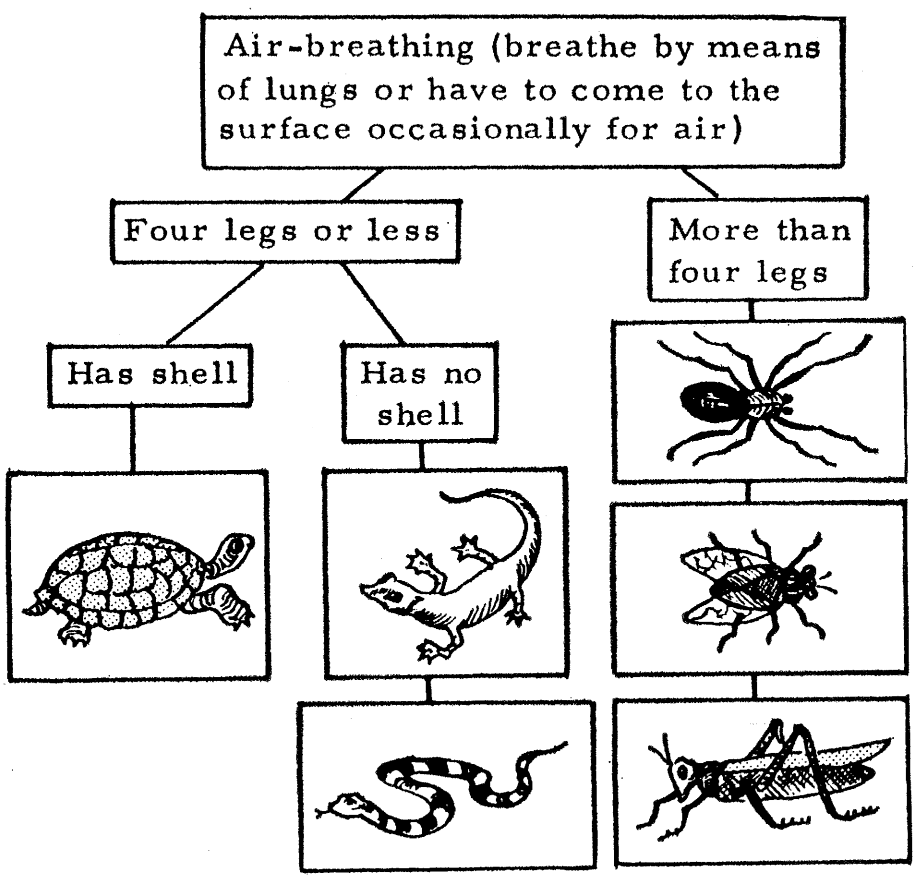
An Example: Learning Measurement as a Process

The general scheme may be illustrated by the exercises in measurement. These begin very simply in kindergarten with an exercise called "Comparing Lengths." The child is expected to learn to sort into sets objects of equal length, by matching; to show that such sets can be made by matching each member with a standard; and to order objects by length from shortest to longest. Each child, or a small group of children, is provided with a set of dowels of different lengths scrambled in a single pile. A child first selects one of the dowels, and then is asked how to find all the others in the pile which are the same length. The children are encouraged to formulate the statement that this may be done by matching other dowels with the first. After a pile of dowels all of the same length has been assembled, another dowel is chosen and a second set of dowels is selected by matching. The children then learn to order the dowels from shortest to longest. They practice with other materials—straws, pieces of string, strips of paper.

The child is now ready for an exercise called "Linear Measurement," where he is introduced to the problem of defining standard units. This exercise begins with the display of a large cardboard box at one side of the room and a table across the room from it. The children are asked to tell how they could decide, without moving the box or the table, whether the box could fit under the table. As a result of discussion, unmarked measuring sticks are introduced, about one foot long. Measuring the box is undertaken, followed by decisions on how to report the measures, and what to do about "leftover" lengths. Additional activities introduce different lengths of measuring stick (units of measurement), the naming of units, crude interpolation ("between 5 and 6 oogs"), and the selection of units appropriate to different lengths to be measured. For each of these activities, a problem is stated, the children are encouraged to seek a solution, one or more of these is tried out and either verified or rejected, and some generalizing discussion follows. For an appraisal, the teacher outlines a square area on the bulletin board, and asks the children to measure and cut a square from wrapping paper which will match it, choosing from three measuring sticks 3, 15, and 28 inches in length.



Portion of a classification system that might be developed by children, pertaining to living things in an aquarium (7, pt. 3, p. 334).

In part 2 (typically used in the first grade), the children do the following exercises:

Metric Measurement: measuring tables, crayons, the length and width of the room, and other objects, with sticks that can be marked off in decimeters and centimeters, and meter sticks. The children learn the names of these units and the relations among them, as well as how to employ them in expressing lengths.

Making Comparisons Using a Balance: measuring the heaviness of objects with the equal-arm balance; relating this to earth-pull and to the concept of force.

Comparison of Volumes: comparing volumes visually; measuring them by means of standard units of liquid.

Measuring Forces with Springs: comparing forces measured by the extent of spring stretching as indicated on a scale calibrated in units chosen by the child.

In parts 3 and 4 the child estimates linear extents and relates them to British-American standard units; orders and measures areas of plane figures; makes vector representations of directions of forces; measures volume of liquids in standard units and drop by drop; measures the size of components of mixtures by mesh separations; measures temperature, rate of change in water evaporation, and changes in snail populations.

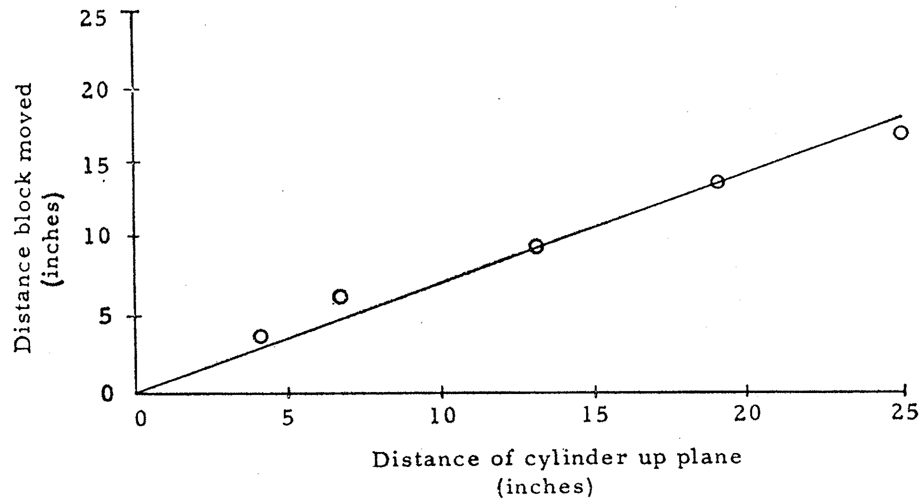
Part 5 also contains several exercises on measurement, such as those on angle sizes and probabilities. But more important, parts 5 through 7 contain exercises of increasing complexity in which measurement is applied to *prediction* (by means of graphs of recorded data); to *control of variables* (in an exercise relating the pressure and volume of air and water); to *operational definition* (relating force and work energy); to *data interpretation* (in making and reading contour maps); and to *experimenting* (in finding the relation of heat energy to work). In these and other exercises, the children use their previously acquired knowledge of measurement in a direct fashion. Thus the process of measurement begins for the children with the simplest kind of behavior in part 1 and is elaborated progressively as a component of a variety of more complicated performances throughout parts 2 through 7.

Charts illustrating these progressions for each of the processes are included in the *Commentary for Teachers* (2). These charts were planned only in roughest outline before the preparation of materials was begun, and represent an attempt to organize the individual exercises in a reasonable manner after they were written.

Example: Processes Applied in an Experiment

The way in which these different intellectual processes build upon one another may be illustrated by beginning with an exercise from part 6 on "Control of Variables—Energy and Height" and tracing back the steps that prepared the children for it. In this exercise, fifth-grade children explore the meaning of the definition "Energy is the ability to do work," by systematically plotting the relation of one physical variable to another—the height of a cylinder on an inclined plane to the distance it pushes a block when it rolls down the plane. The children are led to formulate a method of measuring the energy of motion of a cylinder when it reaches the bottom of an inclined plane and pushes a block on the surface of a table. A piece of lined paper is used to measure the distance through which the block is pushed. The children try the effect of varying the slope of the plane, as well as the initial position of the cylinder, on the distance the block moves. They plot the results graphically. If students carry out this exercise with thorough understanding (and it is expected that they will), they are really doing some fairly advanced science. How is it they can do this?

First, they understand what is meant by "the property of being able to do work." They understand that in the operations they carry out they are actually defining the concept of energy. In other words, they have already gained the idea of the operational definition. In a most direct fashion, this has come from an immediately preceding exercise ("Operational Definitions—Force and Work Energy") in which they have learned that work is force times distance. It has also come from earlier exercises, with different subject matter, which deal with operational definition.



The kind of graph children are expected to be able to construct in describing their observations on the relation of energy and height (7, pt. 6, p. 902).

How do they know what is meant by a property of an object? By now this concept has been well established by means of a number of exercises which can readily be identified under the rubrics Observation, Classification, and Communication.

The exercise on energy involves the measurement of variables, and relating them by means of a graph. Do the children know how to make a graph, and interpret it? Yes, one can find a whole sequence of previous exercises in which this capability has been developed, not only through the actual graphing of simpler phenomena but also through a development of their understanding of number.

Will the children who have made five measurements relating height to distance pushed be able to generalize this relation beyond the measures they actually obtain? Yes, they should be able to do this, since they have had experience in predicting events from data in other earlier exercises.

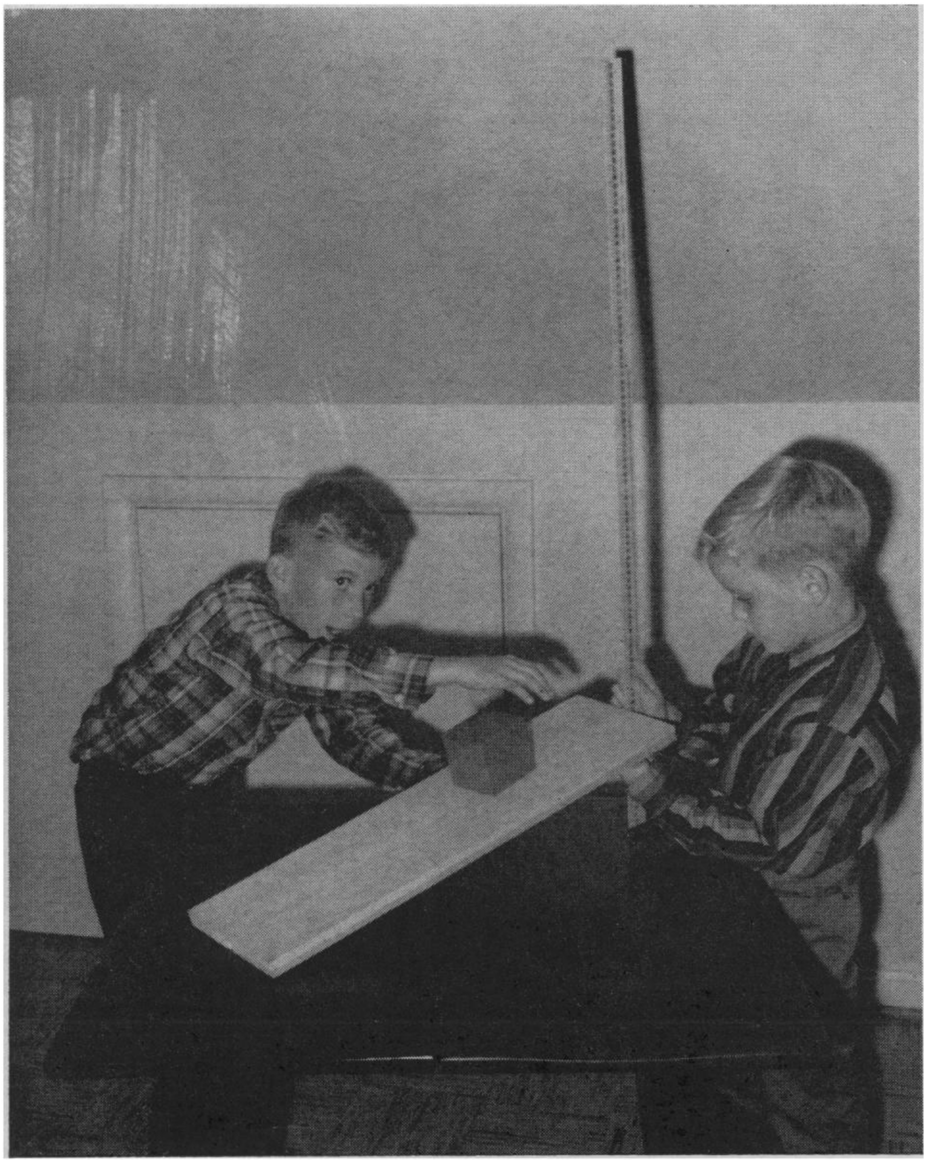
Are they able to report what they have done in relating the height of the cylinder to its energy? The preceding exercises on Communication have prepared them to do so. If one says to the child: "A cylinder on an inclined plane is said to have a certain amount of energy. Tell me how to measure this energy," his previous experience in Communication exercises will lead him to talk not about "things" or "pushes" or "ups" and "downs" but about cylinders and planes and forces and distances.

In short, by the time the students of *Science—A Process Approach* reach this exercise on systematic manipulation of variables involved in energy, they know a great deal about how to set about it. The fairly complicated sequence of thought and action demanded by this exercise is not too difficult for them, because they have been preparing for it beginning as far back as in kindergarten and the first grade.

Other Approaches

There is probably a high degree of agreement among informed people concerning the goals of science education. In contrast, the practical matter of how to achieve these goals is likely to be the subject of disagreement. The existence of differing points of view is made particularly apparent, perhaps, when science education begins with the earliest grades of school. Mature scientists are generally aware of their lack of knowledge of what the kindergarten child is like—what interests him, and what he is capable of doing. Moreover, if one is to begin science education at the earliest school level, one must have a rationale that connects adult behavior with child behavior. There must be a point of view about *human development*. This is the subject about which most disagreements arise and concerning which, on the current evidence, alternative views are possible. Two prominent viewpoints toward science education which have been discussed at various times during the development of these materials are as follows:

1) *The "content" view.* This view is that the best way to learn science

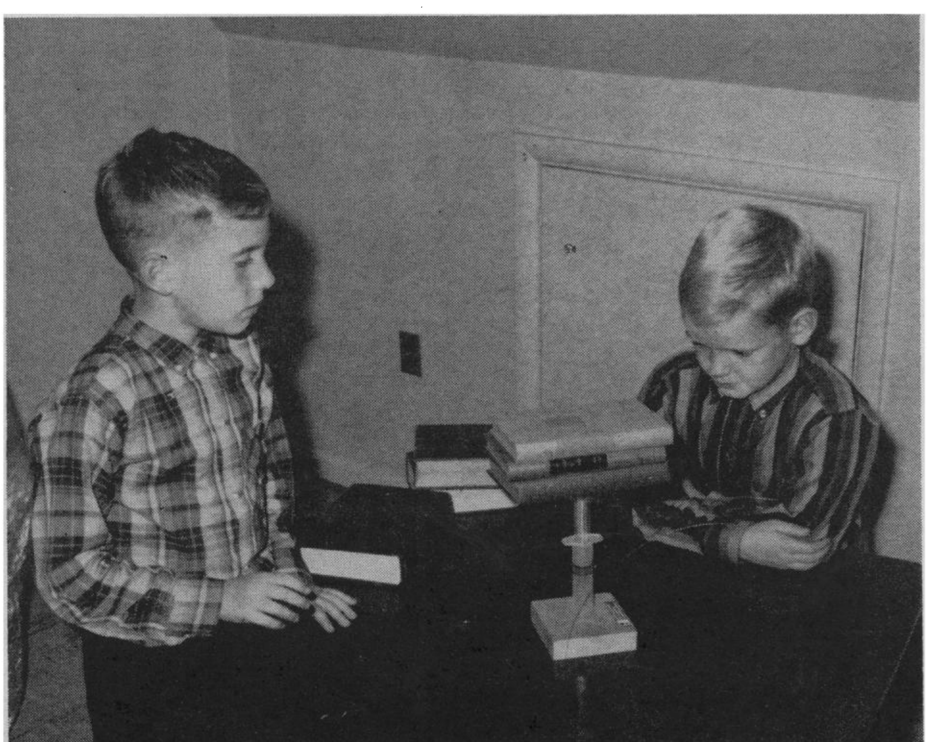


(Left top) An exercise dealing with the determination of smoothness in terms of resistance to sliding.

is to start to study physics, or biology, or chemistry, in the earliest grades—not "how a seesaw works," but the relation between force and energy; not "how to feed a rabbit," but the process of metabolism. Naturally, one can't teach these scientific ideas very rapidly in the early grades, but one can painstakingly build up an understanding of them, beginning with very simple notions. This view has some merit, and probably no one would want to say that it is wholly infeasible. For one thing, it correctly suggests the deficiency in much elementary science teaching as the imparting of isolated facts which perhaps never are connected with a structured body of knowledge. And it is surely correct in its premise that the children are not too young to learn about science systematically, just so long as what is presented is understandable to them in terms of their previous knowledge.

The difficulty is that, whatever the content undertaken, a great deal of instructional time must be spent in providing the child with background knowledge about the methods of science. One can't get very far with force and energy without teaching the child how to make systematic observations, measurements, and inferences. And if one proposes to do this in order to teach force and energy, the question naturally arises whether one might try to teach observation, measurement, and inference with reference to animal digestion, solutions of chemicals, and many other kinds of content. By this line of thinking, one is led back to a "process" view after all.

2) *The "creativity" view.* A very different point of view is that since scientists are creative individuals, one should undertake deliberately to "train creativity." In its extreme form, the argument is that there exists in every individual a general trait, creativity, which is subject to improvement through training, and which will when so developed express itself in a variety of fields, including science. The kind of training needed to accomplish this, presumably, is a series of situations in which the individual practices



(Left bottom) Using books to apply units of force in an experiment relating to pressure and volume of air in a cylinder.

having novel ideas and is rewarded for having them.

This point of view has some grain of truth in it. There is evidence that children or adults who are rewarded for having novel ideas do tend to produce more of them (*4*). One experimental study of this effect showed clearly that training children to formulate new questions, to restate a given problem in their own words, and to generate ideas about it created a generalized tendency for them to do this when they were presented with entirely new and different problems (*5*). Moreover, this result could be obtained with training that lasted only a few hours. In a way this is disturbing to those who favor a "creativity" point of view; it is almost too easy. The authors of the study point out that these manifestations of "creativity" may be merely the result of "sensitization"—that is, of alerting the children to the feasibility and desirability of behaving in such a fashion (*6*).

The process approach has in it a little of both the "content" and "creativity" approaches. Though it rejects concentration on any particular science, it extends the notion of teaching generalizable ideas and skills. While it rejects the notion of "creative ability" as a highly general trait, it adopts the idea that productive thinking can be encouraged in relation to each of the processes of science—observation, inference, communication, measurement, and so on. The argument is that if transferable intellectual processes are to be developed in the child for application to continued learning in sciences, these must be separately identified, learned, and otherwise nurtured in a systematic manner. It is not enough to be creative "in general"—one must learn to carry out critical and disciplined thinking in connection with each of the processes of science. One must learn to be thoughtful and inventive in observing a variety of specific phenomena, in manipulating many different objects in space and time, in predicting a number of kinds of events, as well as in generating hypotheses.

The sixth grader who has learned science processes in this manner should be capable of studying science in the higher grades in a way which is not now possible. What is he ready for in terms of additional science instruction? This is a most important question, concerning which one can only guess at the present time. It seems probable that such a student will be able to learn about any given science, presented in accordance with its theoretical structure, in far less time than would otherwise be required. Certainly he should have a better conception of science as a way of thinking and discovering.

References and Notes

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2. *Sci. Educ. News* **1963**, No. 11, 1 (1963); Commission on Science Education, *Science—A Process Approach: Commentary for Teachers* (AAAS, 3rd exptl. ed., 1965); *Comm. Sci. Educ. Newsletter* **1**, No. 1 (1964).
3. In the assessment, the results of each exercise are systematically tested. The teacher (or in certain instances, another person), administers a "check list of competencies" individually to three pupils selected in accordance with a predetermined random order. The check list contains simply worded questions (to be checked "yes" or "no") designed to make possible unambiguous observations of the processes the child is able to perform shortly after he has had the exercise. The intent of these check lists is simply to obtain an answer to the question "Has the child learned what the exercise set out to teach him?" An additional test, intended for administration to individual pupils at the end of the school year, is designed to measure children's capabilities in generalizing their knowledge of science processes. Other kinds of evaluation are planned to assess the changes in attitudes and interest which are hoped for as a result of this sort of science instruction.
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5. R. S. Crutchfield and M. V. Covington, "Facilitation of creative thinking and problem solving in school children," paper presented at the Annual Meeting, AAAS, 29 Dec. 1963.
6. This article is obviously not an appropriate place to deal extensively with the many and complex research questions that have been investigated in the attempt to understand cretivity. An excellent summary of educational implications derived from studies of the characteristics of creative persons is the chapter by D. W. MacKinnon, "Personality correlates of creativity," in *Productive Thinking in Education*, M. J. Aschner and C. E. Bish, Eds. (Nat. Educ. Assoc., Washington, D.C., 1965), pp. 159–171.
7. Commission on Science Education, *Science—A Process Approach* (AAAS, Washington, D.C., 1964), pts. 1–6.

NEWS AND COMMENT

Scientists and Civil Defense: Dialogue at Berkeley

Berkeley, California. Since the limited test-ban treaty went into effect in 1963, civil defense as an issue of public policy has lain practically dormant. A symposium on civil defense at the AAAS meeting last week may have anticipated the revival of debate, since a decision on deployment of antiballistic missiles is said to be imminent in Washington and an expanded civil defense program is viewed as an integral part of an ABM system.

The symposium was conceived, as AAAS president Henry Eyring said in introducing the all-day session, as a means of meeting the scientific community's "duty to provide our fellow citizens with an objective account of the technical data relevant to the grave issues of public policy on war and defense." The scientific credentials of the panelists were impressive, and their efforts to maintain the standards of scientific discourse evident. But the discussion demonstrated both the complexity of the problem and also how widely scientists may differ on matters of public policy where facts needed to support conclusions are unobtainable.

Takeoff point for the symposium may be said to be the Project Harbor report produced by a summer study group at Woods Hole in 1963. The Assistant Secretary of Defense for Civil Defense had requested that the National Academy of Sciences make a study in the field of civil defense. A group of 60 scientists and engineers headed by Nobel prize-winning physicist Eugene P. Wigner produced a report of some thousand pages.

The full report was not widely circulated, but a summary published by the Academy was made generally available. A "preliminary statement" included in the summary, which appears to have attracted more attention than anything else in it, said that the present limited civil defense program was "considered to represent a minimum level of significant protection below which a na-