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ABSTRACT

This 15 page booklet describes the Conceptually Oriented Program in Elementary Science (COPES). Problems encountered in science education are stated and the rationale for the conceptual schemes approach is developed to solve these problems. The purpose, objectives, and concepts of the COPES program are defined. The five main conceptual schemes upon which COPES is based are: (1) The Structural Units of the Universe; (2) Interaction and Change; (3) The Conservation of Energy; (4) The Degradation of Energy; and (5) The Statistical View of Nature. The Conservation of Energy concept is more fully developed as an example of the program. A list of staff and advisory committee members is included. (BB)

COPES is a science curriculum development project for kindergarten through sixth grade centered on certain of the major conceptual schemes in science.[1] The project is a logical extension of a successful pilot study[2] that investigated the feasibility of this approach by developing and testing materials for a sequence devoted to a single conceptual scheme that pervades all of science—the principle of energy conservation. This approach will now be broadened into a full-scale elementary science curriculum centered on five interrelated conceptual schemes.

THE PROBLEM

We accept the premise that general education in science is a necessary part of the educational structure, not so much for whatever practical values it may afford as for its pure intellectual stimulation and enjoyment. There is a growing awarenesss among the general public of the ever increasing impact of science and technology on modern civilization. Yet paradoxically our society is very poorly informed in science. The educated adult population holds the most naïve views of the natural world and of the scientific enterprise. Moreover, while admitting the dominant role of science in modern life, formal exposure to it is shunned by most of our citizens, some of whom display their ignorance of science almost as a badge of honor.

Thus, if one of the goals of science education is to help develop in the individual a grasp of the nature of the scientific enterprise, it follows that at present such education, for the most part, fails to achieve its purpose. Science belongs with those disciplines that traditionally have been regarded as essential to man's cultural enrichment; yet the average person fails to see it in this light. Perhaps the reason is that, unlike history or literature, the natural world cannot be described in a casual manner, and, unlike music or art, science cannot be enjoyed without understanding. But whatever the reason, clearly our educational system is at fault. It is likely that past efforts to minimize the intellectual challenge in science curricula have succeeded only in distorting the nature of the enterprise in the minds of most school children. By the time these youngsters reach high school, their natural curiosity and interest in science appear to be greatly diminished, and when they enter college most are actually repelled by science.

RATIONALE FOR THE CONCEPTUAL SCHEMES APPROACH

Granted the premise that some understanding of science is important for everyone, the question then follows, "What is the best way to help students attain a level of understanding and appreciation of the scientific enterprise that will serve them through their adult lives?" Our answer is to focus their attention on the "great ideas" in science, the broad, inclusive conceptual schemes in terms of which we seek to account for the familiar facts of nature. Such unifying ideas as the kinetic-molecular theory, the statistical view of the universe, the conservation principles, the gene theory of heredity, etc., are the main goals of science and we believe should form the core of a science curriculum. They represent the pinnacle of explanation in science and must surely be classed among man's greatest intellectual achievements.

The use of conceptual schemes in science education is not new, of course. But it seems that for the most part these substantive ideas have been submerged in a morass of detail or overshadowed by undue emphasis on natural history and technology. Our approach is to stress the

[1]Morris H. Shamos, "The Role of Major Conceptual Schemes in Science Education," *The Science Teacher*, XXXIII, No. 1 (January 1966), 27-30. *Theory into Action in Science Curriculum Development* (Washington, D.C.: The National Science Teachers Association, 1964).
[2]Morris H. Shamos and J. Darrell Barnard, *A Pilot Project to Develop an Elementary Science Sequence*, United States Office of Education Project No. H-281 (New York: New York University, 1967).

great conceptual schemes, to place them up₁ most in the minds of the students and to relate all else in science, wherever possible, to these central ideas. We believe that such an approach may have genuine survival value, that long after he has forgotten the facts of science an individual exposed to such a curriculum may at least possess the main conceptual schemes and retain some feeling for the nature of the scientific enterprise.

There is another aspect to the conceptual schemes approach that we think is important, that is, to start such a curriculum as early as possible, preferably at the time a youngster first enters school. There is a growing conviction among many scientists and educators that it is in the elementary grades that the greatest impact can be made in science education. It is apparent that much more can be accomplished at this level than was believed possible in the past; the motivation and ability of children in the primary grades to deal with scientific concepts appear to have been grossly underestimated. It is also believed that many youngsters will have developed their patterns of thinking by the age of twelve. In these formative years, when minds are so receptive to new ideas, we believe it should be possible to develop a foundation in science that will remain a permanent part of the individual's intellectual life.

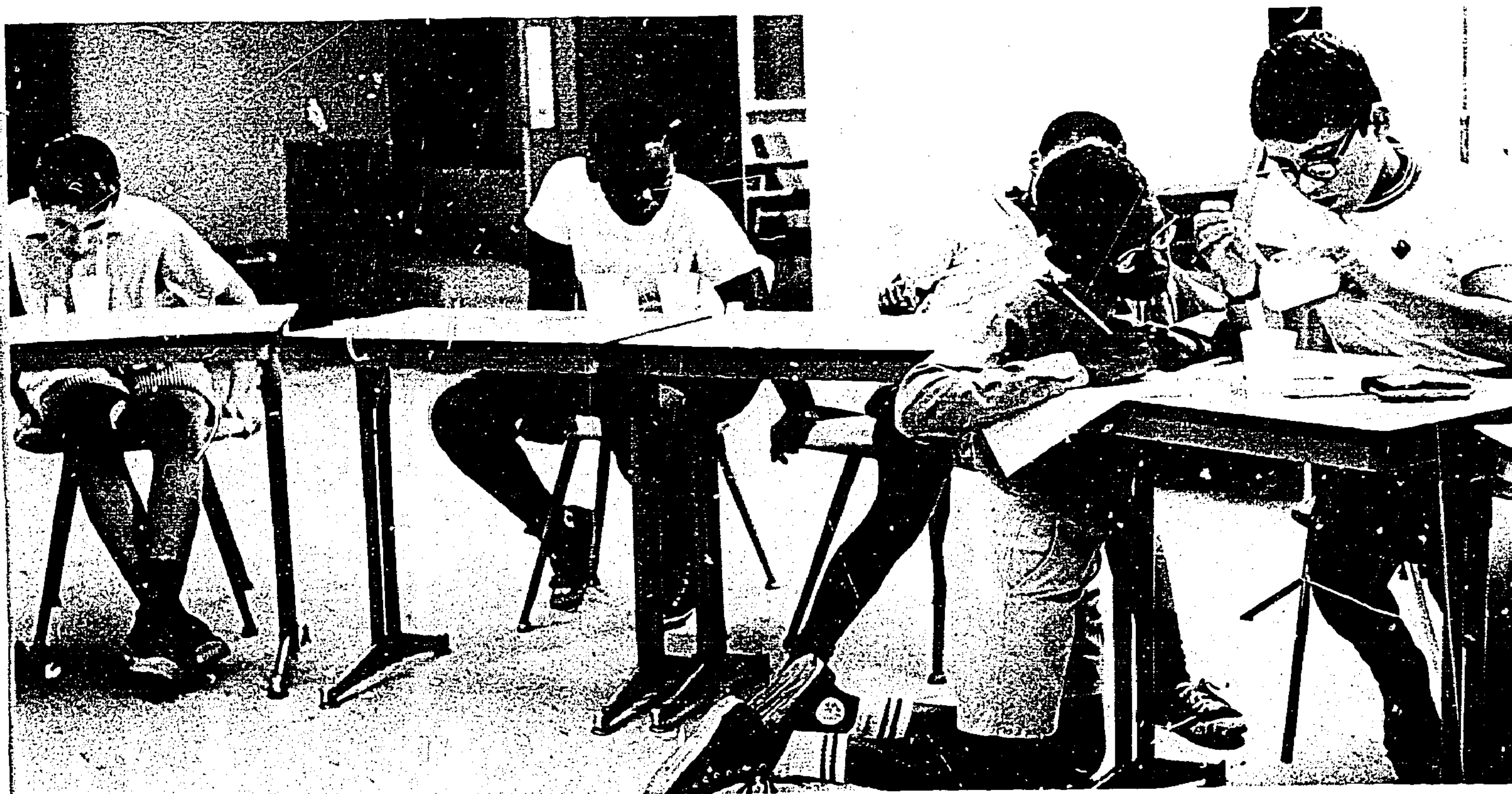
Within the last decade, several major projects have been initiated to develop elementary science materials. We believe that what is still lacking is a curriculum that shows promise of achieving the above goals. This is the primary purpose of the COPES program.

THE COPES PROGRAM

The ultimate goal of the COPES program is to develop an understanding of the nature of matter at various levels of sophistication. In the study of "the nature of matter" we include the entire breadth of science (both animate and inanimate)—an understanding of the structure of matter as well as its behavior.

We believe that having such a definite objective adds to the strength of a science curriculum, for it not only provides teachers and students with a clearly defined goal but also, perhaps more importantly, gives them a cohesive picture of science rather than a series of disjointed topics.

Each concept, each conceptual scheme in this approach, will be presented in a structured learning sequence with the purpose of contributing to this understanding. The order of the sequence will be in the form of a "spiral" development, in which, at each succeeding level



of sophistication, the students proceed from the most basic facts and concepts through the entire sequence as far as their maturity and learning capacity permit them to go in understanding the major conceptual schemes or those concepts necessary to this understanding.

We propose to use this approach with children from the time of their entrance into school. Presently, the production of a science curriculum from grades K to 6 would appear to be the first task, since the K-6 level represents the beginning of formal education and generally forms a single administrative unit that is more flexible than other segments of the academic structure and more amenable to innovation.

This is an ambitious and necessarily rigorous undertaking. One must first identify the conceptual schemes that will form the basis for such a curriculum. There then follows a weeding-out process, after which are left only the major and supporting concepts directly relevant to the broader schemes. Finally, one must work back to find the best sequence(s) in terms of the skills and knowledge necessary and in terms of children's psychological readiness to accept relevant and peripheral skills, ideas and their interrelationships. And one must try to identify the educative processes that lead most directly to this learning.

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THE CONCEPTUAL SCHEMES

Which conceptual schemes—which of the "great ideas" in science—should form the core of a conceptually oriented program in elementary science? There is probably no single choice of schemes that would fully express the views of all scientists and science educators. The breadth of the fields of interest and of science itself probably would result in many similar but not identical lists. After reviewing the efforts of two NSTA curriculum committees and following consultations with scientists and science educators, we have selected five conceptual schemes around which the COPES curriculum will be developed. The selection was based both upon what the scientists felt would be a meaningful and durable science program and upon the successful development of a logical and rational hierarchy of concepts for the first conceptual scheme, conservation of energy—rational because its structure is based not only on the sequential growth of ideas but also on the abilities of children to think in terms of abstractions as well as of concrete situations, to do model building or to exercise the required manipulative or mathematical skills.

A limitation of the pilot study was the attempt to develop one conceptual scheme (conservation of energy) in isolation from others. This was obviously less than ideal since science cannot be so rigidly segmented. In the full program this will no longer constitute a problem since all the schemes are to be developed concurrently and suitably interwoven with one another.

Following are the five conceptual schemes on which the full COPES curriculum will be based, with a brief description of each:

1. THE STRUCTURAL UNITS OF THE UNIVERSE

The notion that the universe is made up of various kinds of discrete units of matter is central to the formal pursuit of science. Whether these be the smallest subnuclear particles or the largest stars, whether a single living cell or a complex organism, it is the discreteness of matter that makes it feasible to study nature—to classify its structural units and establish a hierarchy among them. The structural units with which students have any direct experience, that is, large-scale matter, are composed of smaller units and these, in turn, of still smaller units. Atoms, molecules, crystals, cells, organisms, plants, animals, planets, stars, etc.—these are the structural forms in which matter is found. The more complex forms, or higher levels of organization, exhibit properties that are generally more than the simple sum of their parts. As for the fundamental "building blocks"

of matter, for the purpose of the COPES program these are taken to be atoms or, as more commonly encountered in nature, molecules.

2. INTERACTION AND CHANGE

Taken as a whole, the universe is constantly changing. This is evident at most levels of organization: stars, planets, geological formations, living things, etc., all change with time in perceptible ways. Some changes are readily observable, which means that they occur in relatively short periods of time. Certain chemical and nuclear reactions are examples of rapid changes. Others, such as most evolutionary or geological changes, involving very long periods of time, are not as evident and must be inferred from indirect evidence rather than from direct observation. Thus, the rate at which a given change occurs is a critical factor in detecting this change and assessing its magnitude and import.

Changes occur because of interactions among the structural units of matter, with the result that either the properties or arrangement of the units may be altered. Interactions among units of matter take place through fields of force, of which several basically different types can be distinguished but only two of these, gravity and electromagnetism (electric and magnetic forces), are normally experienced by the average individual. In fact, the electric force alone is sufficient to account for most of our experiences, including practically all chemical and biological changes.

The weakest force (gravitational) and the strongest (nuclear) play particularly interesting roles in effecting changes in the universe. The former is significant only for the largest structural units (planets, stars, etc.), while the latter applies only to the smallest (subnuclear) particles.

Thus the concept of force (interaction) as the "agent" of change plays a central role in science and in understanding the evolving universe.

3. THE CONSERVATION OF ENERGY

As one contemplates the concept of a changing universe it is comforting to find some properties of the universe that appear to be invariant. Such invariant properties are said to be "conserved," and the statements describing them are generally referred to as the "conservation laws."

The most fundamental of these laws are conservation of electric charge and conservation of energy. The latter is of special interest because it is so basic to all of science, finding numerous examples in both the physical and biological sciences. On the other hand, conservation of matter, if thought of as conservation of mass, while a useful concept in ordinary (low-energy) phenomena, is not valid for high-energy interactions. Instead, the principle of conservation of energy has been broadened to include mass as a form of energy, leading to the conservation of matter-energy.

The notion that the total amount of matter and energy in the universe remains constant is obviously a powerful conceptual idea, perhaps the most useful guiding principle in all of science. The more limited idea of conservation of energy alone, while not so inclusive, is found to hold so well for the (low-energy) interactions normally encountered by students (e.g., in energy conversion) as to constitute a highly significant conceptual scheme at the level to which the COPES program is addressed.

4. THE DEGRADATION OF ENERGY

Natural events tend to have a unidirectional character. That is, changes occur in such a way as to bring the universe closer to a final state in which it will have lost the ability to do any useful work. Thus, in the conversion of energy from one form to another, while the principle of energy conservation applies, part of the energy appears

in a form that cannot be fully harnessed to do mechanical work. This form is heat energy, by which is meant the (kinetic) energy of the assumed random motion of particles of matter.

The idea of particles moving at random is central to the kinetic-molecular theory, which has proved to be such an effective model for understanding gases, as well as the concepts of heat and temperature and the states of matter. In this sense degradation of energy means that every change in the universe occurs in such a way as to result in greater randomness; that is, matter tends to spread out or become less organized and energy to distribute itself more widely.

In more formal terms, the idea that changes occur in this fashion is expressed as the second law of thermodynamics. Thus, heat flows from a warmer to a colder body, but the reverse is not observed unless energy is supplied from an external source. The same general idea applies to all changes, e.g., even to those in living systems, which appear to result in higher states of organization. While the organism itself may become more ordered, it does so only at the expense of its environment, which becomes more disordered, the net result being an overall trend toward disorder (increased entropy), meaning that the total energy is degraded.

One cannot fully develop the idea of energy conservation in a meaningful way without also calling attention to the *direction* of energy changes, as embodied in the corollary conceptual scheme, degradation of energy.

5. THE STATISTICAL VIEW OF NATURE

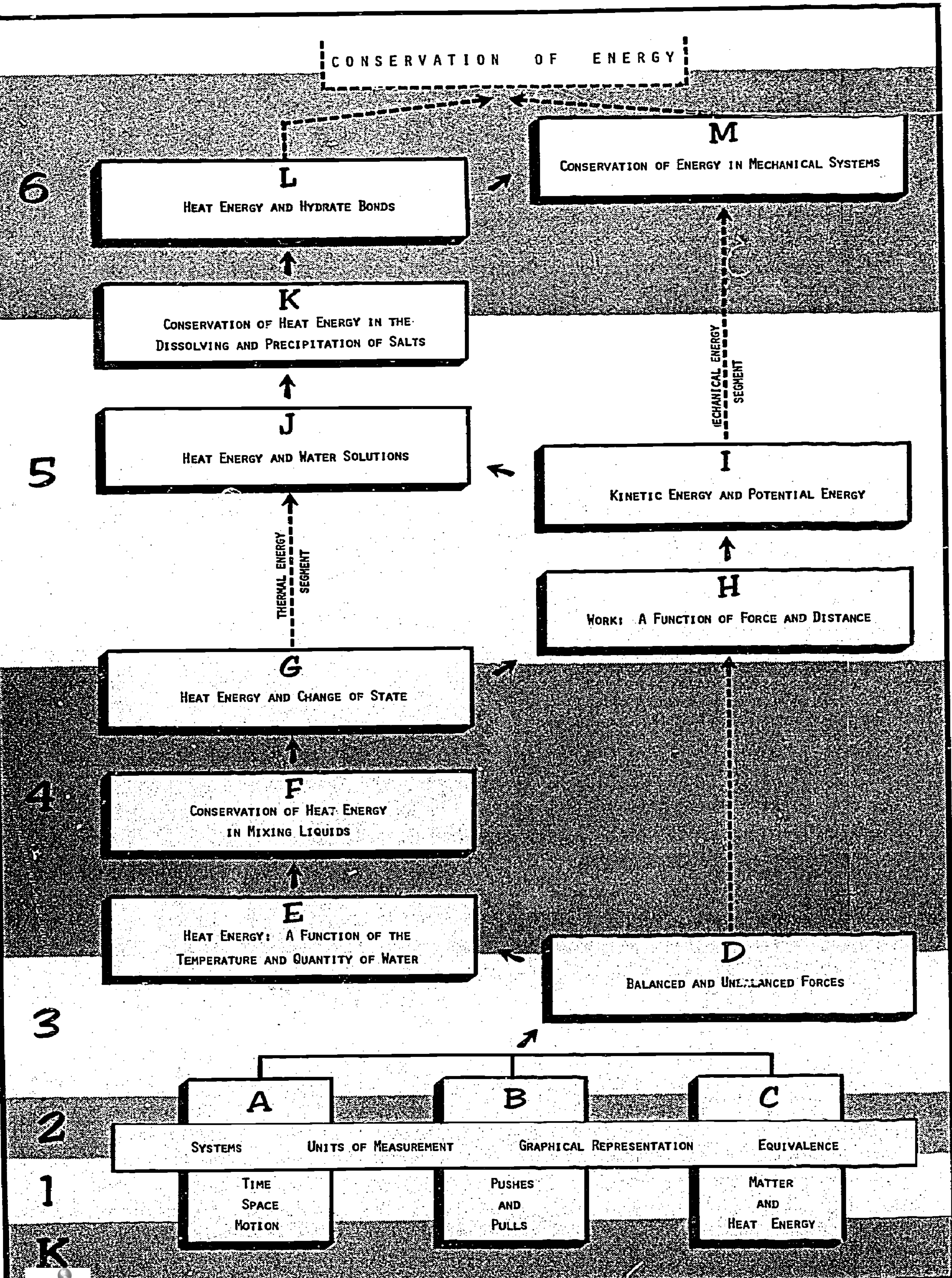
The modern view is that natural events can be predicted only on a statistical basis. Most of our experiences with nature involve large numbers, with the result that on the whole nature appears regular and predictable. Even the smallest sample of matter with which one normally comes into contact contains huge numbers of atoms or molecules, so large that one can readily predict the *average* behavior of the sample. This is analagous to a game of chance, where given a large number of events the overall outcome can be reliably predicted, although the result of a single event cannot be forecast. In fact, the same mathematical laws of probability that apply to games of chance appear to be successful in helping one predict the statistical behavior of natural phenomena.

When one studies individual or small numbers of events, the random character of natural phenomena becomes evident. Radioactivity is one such phenomenon where behavior can be predicted only on a statistical basis. Another is the transmission of genetic characteristics to successive generations of living things, as described by the Mendelian laws. Still another is the Brownian motion of small (microscopic) particles. Examples are limited, since randomness is apparent only when dealing with small numbers, which one does not often encounter in nature.

Yet the idea that on a submicroscopic level all phenomena are random, and that nature is predictable only by the play of large numbers, is obviously a basic and important conceptual scheme. The challenge is to convince students that one can reasonably generalize to this conclusion from the few concrete examples that are available.

CONSERVATION OF ENERGY— AN EXAMPLE

How does one develop an understanding of this powerful conceptual idea among elementary school children? Energy itself is an abstract concept. There is no precise description of it except to say that the change in energy of a system is a measure of the physical work done on or by that system. Nevertheless, we wish to convince young children that the total energy of the universe remains constant, that is, in any given process the energy is conserved in one form or another. If one considers mechanical energy alone, it is not very easy to be convinced of this; for instance, a bouncing ball never returns to the same height. It is only when heat is considered as a form of energy that the conservation idea becomes at all plausible.


CONSERVATION OF ENERGY
M
CONSERVATION OF ENERGY IN MECHANICAL SYSTEMS
6
L
HEAT ENERGY AND HYDRATE BONDS
K
CONSERVATION OF HEAT ENERGY IN THE DISSOLVING AND PRECIPITATION OF SALTS
ECHANICAL ENERGY SEGMENT
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J
HEAT ENERGY AND WATER SOLUTIONS
I
KINETIC ENERGY AND POTENTIAL ENERGY
THERMAL ENERGY SEGMENT
H
WORK: A FUNCTION OF FORCE AND DISTANCE
G
HEAT ENERGY AND CHANGE OF STATE
4
F
CONSERVATION OF HEAT ENERGY IN MIXING LIQUIDS
E
HEAT ENERGY: A FUNCTION OF THE TEMPERATURE AND QUANTITY OF WATER
D
BALANCED AND UNBALANCED FORCES
3
A
B
C
2
SYSTEMS
UNITS OF MEASUREMENT
GRAPHICAL REPRESENTATION
EQUIVALENCE
1
TIME SPACE MOTION
PUSHES AND PULLS
MATTER AND HEAT ENERGY
K

The accompanying scope and sequence chart outlines the logical development of ideas and experiences used in the COPES approach to the conservation of energy. Grade levels at which a particular section of activities was found to be most appropriate are indicated on the left. The title of each section indicates the principal focus of its learning activities. At the K-6 level, two main threads in the conservation of energy sequence appeared most adaptable to the overall scheme—that is, conservation of thermal (heat) energy and conservation of mechanical energy—eventually followed by the interconversion of these two forms. The rationale for the order of the sequence depends first on the selection of activities that provide the best and most meaningful (to children) examples of conservation of thermal and mechanical energy. The total structure of the sequence then reflects those major and supporting concepts and skills needed to cope with and fully understand the culminating activities. Before entering the major threads of the sequence, K-2 children would have had experience with activities designed to develop those skills and concepts needed for developing the major ideas starting at section D. We envisage that the broad base of K-2, so-called "presequence," activities will serve as the foundation for all five conceptual schemes.

As the sequence proceeds from one major "conservation" activity to another, additional concepts are developed to provide a logical "lead-in" to the higher order, more sophisticated concepts. The classical example of conservation, the Galilean pendulum, was considered as one of the final activities toward which the sequence would be aimed. Originally it was believed that since children enjoy pushing and pulling objects, this might be an appropriate avenue of approach to developing the idea of conservation of energy. Although the concept of force can be adequately developed, the concept of work or mechanical energy appears much too abstract for the young child in the early stages of the sequence.

It was found, however, that the concept of thermal (heat) energy has more meaning for the young child, hence it was decided to begin the sequence by developing activities focused on conservation of thermal energy rather than mechanical energy. Three major examples confirming conservation of thermal energy were used because they were felt to be meaningful at the K-6 level. In hierarchical order they are (1) heat energy is conserved when samples of a liquid are mixed (section F); (2) the heat energy absorbed to dissolve a salt in water will be released when the salt precipitates (section K); and (3) the heat energy required to break the bonds of hydration will be released when the bonds reform (section L). The intermediate sections of the thermal energy thread must then provide the bridging concepts. For instance, before working with concepts of solution, the idea of the difference in energy between the liquid state and its solid has to be considered. Thus, a section of activities is devoted to the relationship between heat energy and change of state. When pursuing activities in section F, where the temperature of a mixture of water samples can be accurately predicted on the assumption that heat energy is conserved, the child must first develop the concept that the heat energy in a sample of matter (liquid water, for example) depends not only on its temperature but also on its quantity.

Similarly, the structure of the mechanical energy thread is determined by the more elementary concepts needed to appreciate the conservation of energy in a swinging pendulum. Starting with simple concepts of force, leading into the concept of work, the more abstract concept of the energy of moving bodies (kinetic energy) is then developed. This is followed by the concept of potential energy as measured by the work done on an object or the "potential work" the object can do. The child is then ready to analyze the energy relationships in the pendulum, an almost ideal machine. Since he has been accounting for heat energy in the thermal thread, he again attempts to account for the small "losses" of mechanical energy in the pendulum. His familiarity with heat energy can be used to develop the concept of conversion of mechanical energy to heat by friction as the source of the "loss." Thus, energy in the system apparently has been conserved. His search for an explanation of the losses helps the child to develop a feeling for, and confidence in, this great conceptual scheme—conservation of energy.

THE COPES CURRICULUM

The full COPES curriculum will be a structured program, with the concepts organized in a logical hierarchy. All five of the conceptual schemes will be developed concurrently. Positioning of a concept within a particular scheme will be determined on the following bases: its contribution as an introductory idea, its suitability for active exploration at a given age level and its relative sophistication as a component of the scheme.

It is anticipated that the K-2 portion of the curriculum will be composed of sets of introductory concepts contributing to an understanding of such topics as: Pushes and Pulls, Time-Space-Motion, Matter, Energy and Randomness. There is no intention of treating any topic

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at one grade level only. Rather, increasingly sophisticated activities related to each topic will be included in the sequence for each of these three years. For example, *Melting—A Change of State*, is designed as a kindergarten activity to build introductory concepts concerning matter. This is followed by studying *When Solids Dissolve* in the first grade and *A Close Look at Crystals* in the second grade.

Those concepts intended to develop the five conceptual schemes will be spread through grades 3-6. In some instances, a concept will be related almost exclusively to a single conceptual scheme, but many concepts will be related to two or more schemes. As in the case of the sets of introductory concepts, no one scheme will be designated for teaching at any one grade level. Rather, it is anticipated that children will be learning concepts related to each of the five conceptual schemes in every one of the four upper grades. The conservation of energy pilot sequence described earlier illustrates the continuous development of concepts related to one of the conceptual schemes.

The COPES curriculum is action centered. Almost all activities will require that explorations of a nonreading nature be carried out by individuals or by small groups of students. For this reason, there will be opportunity for continuous development in grades K-6 of such skills as estimating, experimenting, interpreting, measuring, observing, ordering, predicting and recording. We believe that such active exploration on the part of children is imperative if they are to learn, rather than memorize, concepts selected to build faith in the conceptual schemes of science.

Whenever consideration is given to the objectives of science teaching, questions are frequently raised regarding the relation of process or skill objectives to content or concept objectives. To demonstrate how the skills, among those mentioned above, are brought into action by children in dealing with designated phenomena to produce desired concepts, a tabular format (*see* page 15) is used to indicate the objectives for each COPES activity.

Two kinds of assessment materials have been prepared for use within each grade. Appropriate sections of these are to be used at the conclusion of each group of activities dealing with a specific topic. The large-group screening assessments serve to identify children who have not come up to the teacher's expectations. The individual reteaching suggestions are to be used with children who appear to need additional experiences with selected phenomena before going ahead. Thus the assessment materials become an integral part of the teaching-learning processes in COPES.

Activity: Ordering Objects in Terms of Size

Teaching Objectives

Skills	*Phenomena*	*Concept Goals*
Observing	groups of different sized objects	to reinforce the property of dimension, such as length, area, volume
Measuring	the rise of water level in a container as different sized objects are placed in it	
Interpreting	the above measurements	to associate the amount of displaced water with the size of the immersed object

From the beginning COPES has been viewed as a basic elementary science program. It deals almost exclusively with basic science to the exclusion of technological applications. Since COPES involves children in firsthand investigations, no materials, other than worksheets and screening assessments, have been written for children. Reading is not emphasized as a way of finding out. This is not to discredit reading or applied science. There are a number of good elementary science textbook series being used in schools. There are also many good trade books in science for children. Applied science is dealt with in both sources of reading materials. The teaching materials in COPES are being prepared to take up no more than 80 percent of the time usually allotted to science in the elementary school. It is therefore suggested that COPES be used as the core of the elementary science program and supplemented with materials such as referred to above in schools desiring to do so.

The teacher is the key to the success of any science program. COPES is no exception. If anything, the teacher assumes a more critical role in COPES than in most other science programs. There are no textbooks for children. All learning activities must be initiated and judiciously directed by the teacher. There are no prepared kits of materials. The teacher or her helper must assemble the materials. She must also reproduce copies of worksheets and assessment materials for her children. COPES is a highly teacher-dependent elementary science program. It should not be undertaken by teachers who lack strong commitment to the teaching of elementary school science.