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THEORY INTO ACTION...IN SCIENCE CURRICULUM DEVELOPMENT.

NATIONAL SCIENCE TEACHERS ASSN., WASHINGTON, D.C.

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A THEORETICAL FRAMEWORK AND GUIDELINES FOR SCIENCE CURRICULUM DEVELOPMENT ARE PRESENTED IN THIS VOLUME. THE BOOKLET CONSISTS OF THREE SECTIONS PLUS AN APPENDIX. IN THE FIRST SECTION A SCIENCE EDUCATOR PROPOSES A PLAN FOR SCIENCE TEACHING COMPATIBLE WITH THE NATURE OF SCIENCE, CULTURAL CHANGES, AND THE EXPANDING BODY OF KNOWLEDGE. THE CHOICE OF INSTRUCTIONAL MATERIALS FOR TEACHING CONCEPTUAL SCHEMES AND SCIENTIFIC SKILLS IS DISCUSSED. THE SECOND SECTION OF THE VOLUME IS A COMMITTEE REPORT CONTAINING A LIST OF SEVEN CONCEPTUAL SCHEMES OF SCIENCE AND A LIST OF FIVE MAJOR CONSTITUENTS OF THE SCIENTIFIC PROCESS. EACH LISTED ITEM IS DISCUSSED. PLANS AND SUGGESTIONS FOR A LOCAL ACTION PROGRAM TO FOSTER CURRICULUM DEVELOPMENT CONSTITUTE THE THIRD SECTION OF THE BOOKLET. THE ESSENTIAL COMPONENTS FOR A LOCAL ACTION PROGRAM ARE LISTED. TWELVE GUIDELINES FOR DEVELOPING A COORDINATED K-12 PROGRAM ARE ALSO LISTED AND DISCUSSED. THE APPENDIX INCLUDES THE NATIONAL SCIENCE TEACHERS ASSOCIATION POSITION ON CURRICULUM DEVELOPMENT IN SCIENCE AND A BIBLIOGRAPHY. THIS DOCUMENT IS ALSO AVAILABLE FROM THE NATIONAL SCIENCE TEACHERS ASSOCIATION, 1201 SIXTEENTH ST., N.W., WASHINGTON, D.C. 20036, FOR $1.50. THE STOCK NUMBER IS 471-14282. (RS)

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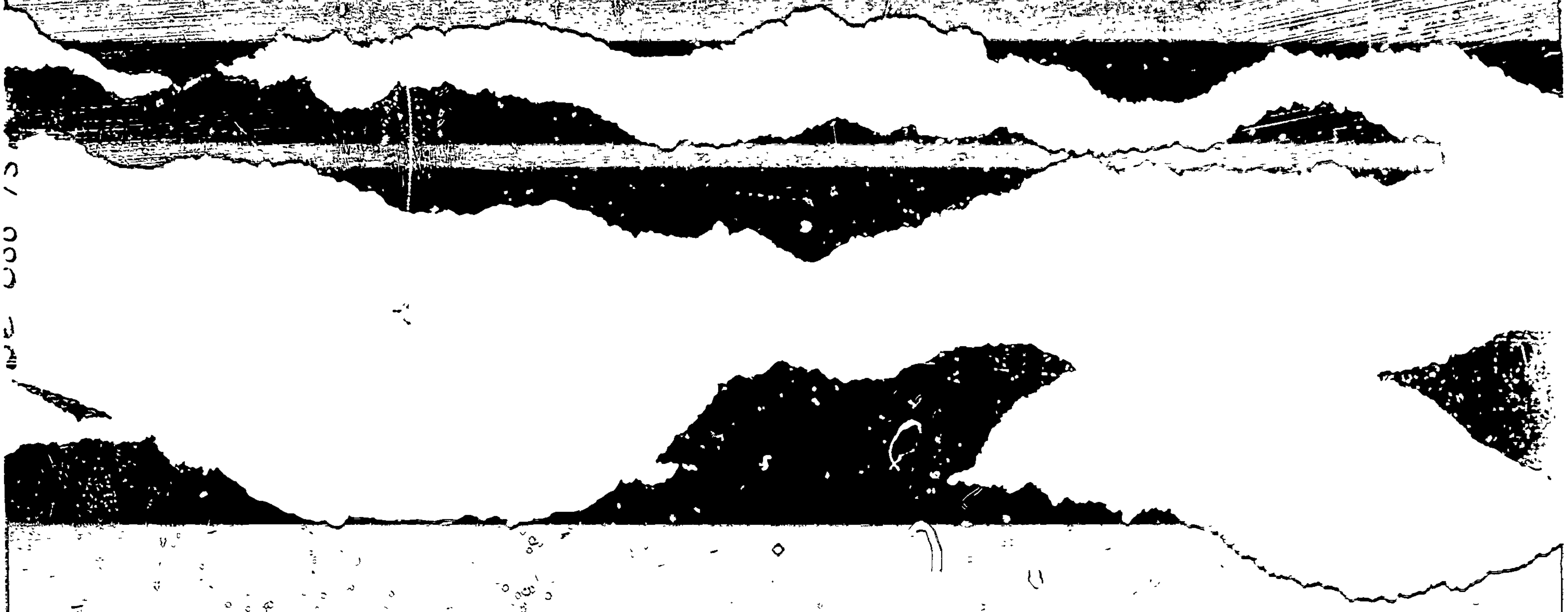

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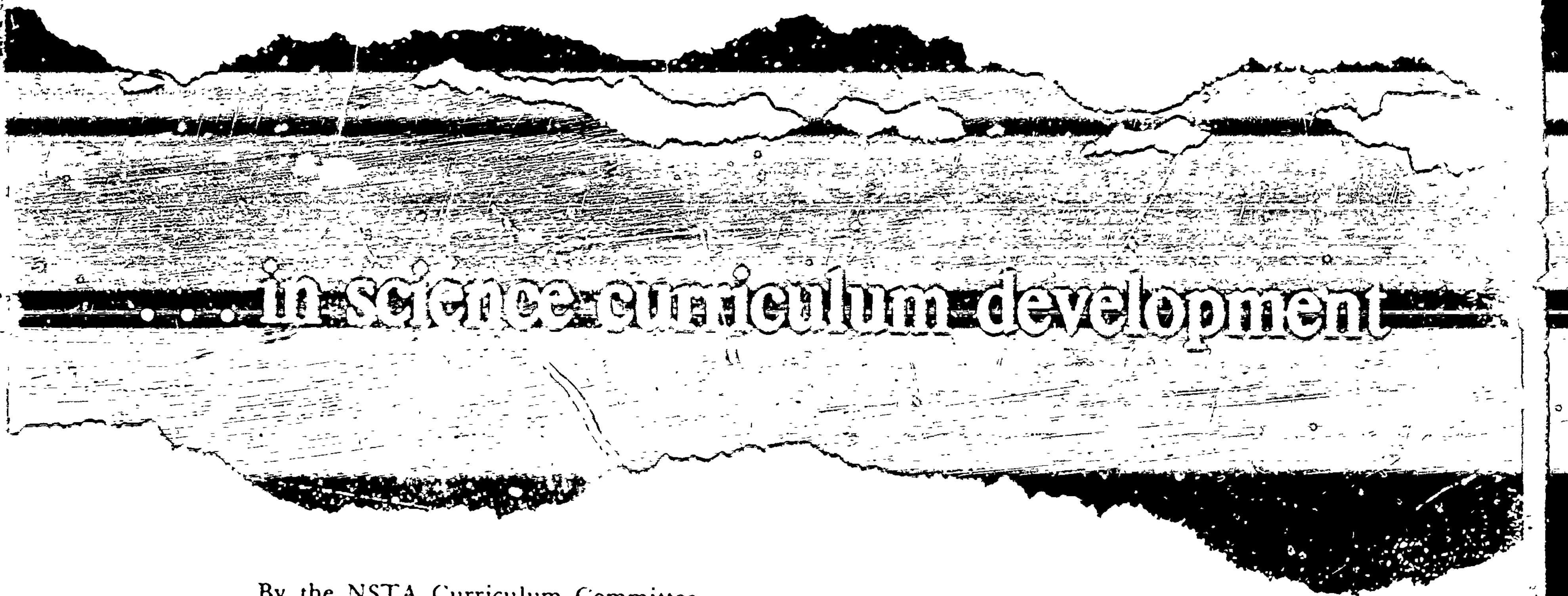

in science curriculum development

By the NSTA Curriculum Committee
and the Conference on Science Concepts called by NSTA

NATIONAL SCIENCE TEACHERS ASSOCIATION
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FOREWORD

The National Science Teachers Association has as its central purpose the advancement and improvement of the teaching of science at all educational levels. Implicit in this purpose are concern for the curriculum and concern that the Association provide some active leadership in helping to establish criteria for sound curriculum development.

The NSTA has not attempted, nor will it attempt, to build a single, K-12 curriculum. Its concern is with identifying the broad principles that can apply to any or all curriculum development efforts in science. It calls attention to the aspects or issues of science teaching and the most promising approaches in each area, and encourages the development of a coordinated curriculum, based on these, from kindergarten through grade 12 and beyond.

The Association carries out these activities in regard to curriculum through its Curriculum Committee, through special conferences and through other activities. This publication presents three phases of work along the above lines as planned by the NSTA Curriculum Committee.

Part I, "Toward a Theory of Science Education Consistent with Modern Science" by Paul DeHart Hurd, is twofold in purpose. First, it seeks to amplify and to continue the approach to curriculum efforts begun by the Curriculum Committee in its position statement of 1962, a copy of which appears in the Appendix. Second, it calls attention to key aspects or issues of science teaching and makes suggestions for the advancement of science teaching as it might be related to these key issues.

Part II, "Conceptual Schemes and the Process of Science," identifies a set of major conceptual schemes and major items in the process of science that can serve as the primary basis for science curriculum planning. It is anticipated that these schemes and processes will be of especial value in sequential course planning and in selecting course content for all levels of science education.

"Conceptual Schemes and the Process of Science" was prepared by a committee organized by NSTA. The names and titles of the committee members may be found in the Appendix. The committee, consisting of leaders in various areas of science and science education, convened at Washington, D. C., in November 1963. The general plan of the project was established by the committee as a whole, and the detailed drafts of the conceptual schemes and processes of science were left to the subcommittees. The final draft of the major items in the process of science differed very little from the original draft. The content and wording of the conceptual schemes were subjected to lively debate, and the final draft given herein represents the consensus of the majority of the committee members.

Part III suggests approaches to local action programs for teachers, educators, and curriculum workers at all levels. The intent is to inspire thinking and innovation, to be helpful in carrying out such activities, to be supportive of the best that is being prepared in course content and curriculum improvement, and to provide a unique and unifying approach.

The ideas in this publication are presented, not as a final plan of action, but as a basis for study and debate, and as providing criteria for assessing the need and direction in curriculum reform and curriculum building. NSTA offers these ideas to all concerned with curriculum development in all fields of science at all educational levels. May they serve their purpose well.

Donald G. Decker, *Chairman*
NSTA Curriculum Committee

Stanley E. Williamson, *President 1963-64*
National Science Teachers Association

Toward a Theory of Science Education Consistent with Modern Science

Paul DeHart Hurd
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A Service Document of the
NATIONAL SCIENCE TEACHERS ASSOCIATION

INTRODUCTION The purpose of this paper is twofold—to describe issues and to make suggestions for the advancement of science teaching. It provides a basis for discussion and debate; it does not pretend to supply answers to all questions that may be raised.

Science curriculum developments are influenced both by changes in society as well as by new developments in science. This means that the curriculum specialist in science needs to examine the writings and research in a wide range of fields: economics, sociology, public policy and manpower, as well as the current status of science. Each of these areas has relevance for the teaching of science.

The development of a literate citizenry in science does not result from the teaching in a single grade nor is it the product of any one course. It can be achieved with a carefully planned kindergarten through grade 12 (K-12) program in which there is a vertical as well as a grade-level coherence within the science curriculum. Curriculum improvement in science then, should be viewed from kindergarten through grade 12 and perhaps through the undergraduate years of college.

To begin a curriculum reform without first establishing at least a tentative basis for decisions is wasteful of time and effort and seldom produces significant improvements. A major problem in science education in American schools has been the lack of a viable theory of science teaching which could serve as a base for decision making. Consequently the schools can make no answer to their critics. The value of theory in education is that it frees the teacher and the researcher from the constraints of tradition and makes the development of new ideas more likely. It gives perspective to curriculum and instructional issues and provides a basis for making decisions.

Local action groups can make the best use of this document by first comparing it, issue by issue, with their own views on science teaching, noting what they can or cannot accept. Second, they should prepare a clear-cut formulation of acceptable purposes for an education in science, using this as a basis to assess the need and directions in curriculum reform. It should be expected that working groups will wish to change their viewpoints as progress is made in curriculum design and communication between members of the curriculum committee becomes clearer.

In formulating this statement, advantage has been taken of the ideas expressed in the modern science curriculum studies developed over the past decade. At the secondary school level, the works of the Biological Sciences Curriculum Study, the Chemical Bond Approach Project, the Chemical Education Material Study, the Earth Science Curriculum Project, the Junior High School Science Project (Princeton University), and the Physical Sciences Study Committee have been particularly enlightening. At the elementary school level, curriculum studies developed by the American Association for the Advancement of Science, the Educational Services Incorporated, the University of California, the University of Illinois, the Minne Math Science Project, the School Mathematics Study Group, and the United States Office of Education have provided new insights into science teaching.

SCIENCE TEACHING AND CULTURAL CHANGE

A rapidly changing society stimulated by advances in science demands an educational program designed to meet the challenge of change.

Schools exist to help young people know about and participate in the life of their time. In the past when cultural change and progress in science were slow, instruction in science could lag fifty years or more with little ill consequence for the individual or the nation. At the turn of this century, however, America began to move from an agrarian society to a scientific-technological society. Adjustments made in the science curricula reflected new technological developments but generally failed to reflect the advent of modern science. The impact of science on man's thinking, on social conditions, on economic development and on political action escaped widespread attention, even among highly educated nonscientists. In many ways the influence of science in shaping modern America is the unwritten history of the Twentieth Century.

By the close of World War II it was evident to nearly everyone that America had changed from an agrarian to a scientific-technological society, from rural to metropolitan communities, and that in a thousand related ways our pattern of life and philosophic values had changed. The demand for men and women trained for scientific and technological vocations more than doubled in a decade. But the science curriculum remained static, largely oriented to a culture that no longer existed, and taught from a content that had lost its scientific significance.

POINT OF VIEW

To escape the threat of obsolescence, education in the sciences must be based upon the kind of information that has survival value and upon strategies of inquiry that facilitate the adaptation of knowledge to new demands.

American schools need a science curriculum suited to recent advances in science and to a changing society. They require courses to prepare young people for change and progress and to help them meet the problems they will face during their lifetimes. A rapidly changing society stimulated by advances in science demands an educational program designed to meet the challenge of change.

Because our culture is characterized by change and progress, the greatest threat to either the individual or national security is obsolescence. This means that an education in the sciences must be based upon the kind of information that has survival value and upon strategies of inquiry that facilitate the adaptation of knowledge to new demands. This education must go beyond the immediate and include the future. What is more important, it should provide young people with the background and intellectual talents for shaping the future in a manner that assures the welfare of human beings and sustains progress. Progress is found not so much in tools and material resources as in the extension of intellectual capabilities of people and the viability of their knowledge. This suggests an education in the sciences that is oriented to lifelong learning, rational and independent thinking, and the acquisition of productive knowledge. A curriculum is needed that is oriented toward a period not yet lived, influenced by discoveries not yet made and beset with social problems not yet predicted. The need is for an education designed to meet change, to appreciate the processes of change, and to influence the direction of change.

The influence of science on national policy, on the thought of our times, on economic, social and political problems, and on the life of each person means that everyone needs an understanding of science. Men and women who do not have this background will be excluded from the intellectual life of the times and blindly buffeted by the forces that give direction and meaning to modern living. Without a grasp of science they will not be prepared to partake fully of the culture in which they are living.

GOALS OF SCIENCE TEACHING *Science teaching must result in scientifically literate citizens.*

Goals of education tend to be an expression of American values. They describe what the ideal American citizen should be like. As such they remain fairly stable over long periods of time. Our conception of the ideal does not change very rapidly. What changes are our ideas of how to achieve the ideals expressed through the goals. Unfortunately the connection between goals and the methods employed to reach them seldom is clear. We encounter very diverse kinds of curricula, all directed toward essentially the same ends. But we possess no satisfactory method for connecting the curriculum to abstract goals.

POINT OF VIEW *To state the goals of science education is to describe the cognitive skills expected in the student rather than the knowledge assumed essential to attaining these skills.*

Goals generally are stated in terms which are much too abstract to be useful as a guide in building a curriculum. It would be more to the point to break general goals down into smaller component steps that could be attained one after the other. Thus, for example, the general goal of producing independent inquirers might be achieved by first discovering what support skills should be learned and which ones should be learned first. Thus, the operative goals for a course would consist of precise statements of specific cognitive skills to be attained each year in science.

Talking about goals is a little like talking about building a bridge. We may know the concept of "bridge" just as we know the concept of "inquiry" but that, by itself, will not suffice to build a satisfactory bridge. We need to know where and for what purpose the bridge will be constructed. Similarly we need to examine the goal of "inquiry" to find out what kind of inquiry and the purposes for which we intend to use the inquiry skills. Once these general questions are answered, criteria or standards for curriculum design, teaching methods, and evaluative procedures may be established.

A statement of goals should describe what we mean by a scientifically literate person living in the last half of the Twentieth Century. A person literate in science knows something of the role of science in society and appreciates the cultural conditions under which science thrives. He also understands its conceptual inventions and its investigative procedures.

LEARNING SCIENCE *The strategies of learning must be related to the conditions that will lead to an understanding of the conceptual structures of science and of the modes of scientific inquiry.*

It is difficult at any time to formulate a satisfactory definition of learning, and it is particularly difficult if we wish to apply this definition specifically to the learning of science. Learning is sometimes defined as the relatively permanent behavior changes which result from experience. The goals of science teaching describe the desired behaviors. We can assume that some teaching procedures and learning materials are better than others for motivating inquiry and for developing an understanding of science concepts.

POINT OF VIEW *The educational setting and the choice of instructional materials are closely related to achieving the goals of science teaching.*

We must assume that the educational setting for attaining the goals of science teaching can be facilitated and that some instructional materials are more efficient than others for achieving goals. In the paragraphs that follow, a few learning principles relevant to science teaching will be identified and their significance for curriculum development and instruction will be illustrated.

One of the first tasks in teaching science is to teach the inquiry processes of science. Inquiry skills provide the learner with tools for independent learning. By means of extensive experience in inquiry the student learns to place objects and events in categories or classes. He discovers the utility of coding systems and becomes aware that systems of classification are not inherent in nature but are man-made. He establishes a conceptual framework. This conceptual framework, in turn, focuses his attention on other phenomena and helps him build new categories which are more comprehensive or more abstract. The conceptual structure ties past experience to the present and serves as a guide for the comprehension and assimilation of new facts and concepts. It serves as a basis for prediction of what will happen in a new problem or situation.

While the significant facts in science change at a bewildering rate, the conceptual structures are more stable. However, we need to recognize that conceptual frameworks also change. The problem is to produce learners with the concepts and modes of inquiry that will permit them to understand these changes.

The ability to form science concepts depends upon the learner's own background and the conditions under which he is taught. To insure in some measure the likelihood that a concept will be acquired, it must be presented and used in different contexts. In a well-organized course of study, concepts formed early in the year are used to develop new concepts that occur later. Concepts are most easily acquired when familiar and concrete perceptual materials are used. To enlarge the understanding of a concept requires that it be taught many times at different levels of abstraction.

Words facilitate the development of concepts only when the ideas they represent are understood. Verbalization without understanding is likely to hinder the learning of concepts. This is the danger of attempting to teach science concepts through definitions and names. The ability to verbalize a concept is not a guarantee that the learner can apply or relate the concept. Nevertheless, there is an interdependence of concept and language. It is difficult to form a concept without a language rich enough to express it.

How shall we teach the investigatory process that characterizes a researcher and marks the skilled learner? Research provides some suggestions. It is wasteful to teach facts divorced from a meaningful concept. When facts, which have meaning for the learner, are tied into a logically related conceptual pattern, retention is improved and insight is more likely to occur. After learning one pattern, a student tends to respond more systematically to the alternatives in a new situation. An understanding of conceptual structure and training in inquiry help him select what is pertinent in a new situation. The test of learning is the extent to which a student is able to use a conceptual pattern and associated inquiry skills in new contexts.

In any given situation, more than one explanation may seem to apply. There may be no good basis for choosing among alternatives until rather late in the decision-making or problem-solving process. Uncertainties exist during the interval in which the learner actively seeks and processes more data, examines other possible solutions, and finally makes a choice. Children have to be taught to consider alternatives and to recognize that answers must be sought in the environment of the problem, not primarily in the activities of the teacher. That is, they need to learn a pattern of delaying responses and of tolerating uncertainty until sufficient data are collected and alternative hypotheses are evaluated.

These procedures imply that the concepts which form the core of a course must be something more than questions for which students seek answers. Problem-solving is only one small part of scientific inquiry. We are seeking to develop a range of inquiry skills within the structure of a discipline which permits the student to increase his own efficiency in knowing.

The investigative strategies in science and the organization of scientific knowledge suggest valid and desirable principles of teaching. Stressing these procedures has the effect of minimizing authoritarian teaching and encouraging independent learning.

SELECTING THE CONTENT OF THE CURRICULUM *Because science and the cultural scene are in a continuous process of change, the content of science courses must be constantly re-evaluated and, if necessary, revised to reflect major shifts in thinking and new interpretations of phenomena.*

Science is a systematic and connected arrangement of knowledge within a logical structure of theory. Science is also a *process* of forming such a structure. Much of the effort in science is directed toward seeking new knowledge. There is also a certain lack of durability in this knowledge and scientists are dedicated to keeping this so. The significance of facts and concepts is constantly shifting within the scientific discipline. New ideas and theories cause the meaning of present knowledge to change. Correction and refinement are always operating to modify scientific information. And in science there is always more to be discovered and new relationships to be described.

Although the information phase of science is tenuous and overwhelming in amount, there are a small number of theories, laws, principles, and inquiry processes which provide the basis for interpreting a great variety of phenomena.

POINT OF VIEW *To develop a comprehensive science program that will achieve the goals of science teaching, the curriculum maker must extract the essence of scientific knowledge and define the significant concepts in terms of their usefulness for understanding the structure of science.*

Criteria for the selection of curriculum materials should be consistent with the purposes of science teaching and consistent with the structure of science. The task of the curriculum-maker is to extract the essence of scientific knowledge and define the significant concepts in terms of their usefulness for understanding the structure of science. This is a process that begins with the "big picture" of science, not with bits of information, bodies of facts, or concepts in isolation. Thus it is the conceptual schemes and the inquiry processes that provide the framework for curriculum design and for developing courses at each grade level. By this approach we can reasonably expect to develop a comprehensive science program that presents a valid image of a science and will achieve the goals of science teaching.

Criteria for the selection of curriculum materials should be consistent with the purposes of teaching science and consistent with the structure of science. **1.** The knowledge must be familiar to the scholar in the discipline and useful in advancing the learner's understanding of science **2.** The content should serve the future as well as the present; therefore the selection of content should focus on the conceptual aspects of knowledge. **3.** Every field of science has a basis in experimental and investigative processes. To know science is to know its methods of inquiry. **4.** There are connections between the sciences themselves and between the sciences and other subjects. The content for courses needs to be selected to take full advantage of these relationships and to provide wherever possible a logical integration of knowledge. Transdisciplinary skills, intra- and interdisciplinary understanding should rank high as instructional aims. 5. Only a small fraction of the basic knowledge of science can be selected for teaching in a K-12 program; consequently special attention should be given to including those concepts that are most likely to promote the welfare of mankind as well as the advancement of science. This must also include the knowledge that will enable individuals to participate in the intellectual and cultural life of a scientific age.

ORGANIZING THE SCIENCE CURRICULUM FOR LEARNING

Organization of the science curriculum demands a dominant cognitive pattern.

A science curriculum is a systematic organization of instructional materials designed to achieve the purposes of science teaching with maximum efficiency. The science curriculum developer begins his task by considering the nature of the knowledge he is to work with and what is involved in learning this field of knowledge. Because we are interested in how the pupil gains knowledge and understanding, the implication of cognitive processes for curriculum development must be considered. There are other aspects to curriculum planning, but these are the major considerations.

POINT OF VIEW

To assure that at every point there will be a readiness for more advanced learning, the curriculum continuum needs to be planned to provide for increasingly complex inquiry skills as well as for growth in the meaning of the conceptual schemes.

The patterning and integrating of information is essential for developing knowledge, suggesting that the logical schematization peculiar to the nature of science should be used in organizing the science curriculum. The materials chosen to form the curriculum should be organized in a manner that requires the learner continually to reorganize, synthesize, and use his knowledge.

A comprehensive curriculum should have unity resulting from a coherent structure and continuity. This suggests that learning should take place in a context which relates to previous knowledge and supplies a foundation for what is to come. The curriculum continuum needs to be planned to provide for increasingly complex inquiry skills as well as for growth in the meaning of significant concepts. This helps to assure that at every point there will be a readiness for more advanced learning. Good curriculum organization establishes its own continuity by making the next steps in learning seem reasonable.

Construction of a science curriculum should not be done in isolation from other parts of the school curriculum. In addition to modes of thought which can be useful in other subjects, there are transcurricular skills such as measuring, coding, observing, and inferring. These skills, rather than information, are the most fertile connections between subjects.

The organizational basis for designing a science curriculum is derived from the nature of science and from the intellectual development of the learner. Conceptual schemes and inquiry processes provide the integrative basis which serves to give both coherence and continuity to the curriculum. Within this framework it is then possible to select information that represents the current status of the discipline and will be most likely to move the learner toward the goals of science teaching.

THE TEACHING OF SCIENCE *A newly conceived curriculum prescribes a style of teaching consistent with the goals of instruction and with the nature of the discipline.*

The success of a new curriculum greatly depends upon how it will be taught. A curriculum reform is as much a matter of improving instruction as it is a re-evaluation of course content. A newly conceived curriculum prescribes a style of teaching consistent with the goals of instruction and the nature of the discipline.

POINT OF VIEW *To encourage independent learning in science, teaching practices should be related to the inquiry aspects of science, to its investigative strategies, and to the structure of scientific knowledge.*

A theory of instruction that is particularly suited to the teaching of science is crucial to modern curriculum development. This theory needs to have a broad base and should include the following aspects of instruction: 1. *The nature of science:* its structure, its processes of inquiry and its conceptual schemes. 2. *The nature of the learner:* his motives, cognitive style, emotional background, and intellectual potential. 3. *The nature of the teacher:* his cognitive style, ability to communicate, control pattern, educational philosophy, and understanding of science. 4. *The nature of learning:* its processes, contexts, conditions, and purposes. 5. *The nature of the curriculum:* its organization, sequence, and its substantive, attitudinal, and procedural dimensions. 6. *The nature of the social structure:* social and cultural forces with their demands and incentives.

Instruction links curriculum with teaching goals. While we have recognized instruction as the role of the teacher, we have not fully recognized it as a function of the student. What the pupil does, determines in some measure what the teacher does, for both pupil and teacher are influenced by the texture of the teaching and learning environment. There is also an interplay between instructional activities and the materials of instruction and both of these in turn are influenced by the discipline.

LABORATORY WORK IN SCIENCE TEACHING *Laboratory and field work are central to the teaching of science.*

Learning from work in the laboratory and field is central to the teaching of science. It is here that the student relates concepts, theories, experiments, and observations as a means of exploring ideas. While technical skill and precision are important outcomes of the laboratory, it is the meaning they have for the interpretation of data that is more significant.

POINT OF VIEW *To achieve its greatest educational value, work in the laboratory must provide opportunities for the student to interpret observations and data.*

The laboratory is a place to explore ideas, test theories, and raise questions. Here, meaning is given to observations and data. The data from an experiment remain inert facts until rational thinking makes something more of them. It is at this point that work in the laboratory has its greatest educational value.

Experiments, at whatever grade level, should have a dimension in the investigative aspects of science and provide a variety of experiences with scientific inquiry. Experiments solely for the purpose of gathering data, even though the data are carefully described and summarized, represent merely a preliminary step for understanding science. To collect experimental data is not enough. The student must learn to formulate statements based on data and to test these statements against theory. The conclusion to an experiment is found in the interpretation of data, and it is this interpretation that generates new questions, stimulates further inquiry, helps to solve problems, and leads to the refinement of theories.

A few of the elements of scientific inquiry that need to be systematically introduced throughout science laboratory work are: **1.** The variety, characteristics, and limitations of experimental designs **2.** The relationship between experimental options and the nature of the data obtained **3.** The relationships between observed data, experimental results, and the inferences based on the data and results **4.** The tools of measurement and their influence on experimental accuracy **5.** The use of data in generating hypotheses and defining questions and, conversely, the use of hypotheses to guide data collection **6.** The use of theories and models in interpreting data and in making predictions **7.** The analyzing, ordering, and displaying of data in precise and valid ways.

Laboratory work should be seen as a means of relating science concepts, inquiry processes, observation, and experimentation. The child's first experiences with science, even in the primary school, should involve aspects of experimental inquiry. He should learn how to observe with all of his senses, how to measure, classify, use numbers, communicate, and practice similar subdisciplinary skills. As he progresses through school he should have opportunitites to use these knowledge skills to further his understanding of science concepts.

Laboratory experiences need to be planned in both horizontal and vertical sequences, thus providing for progressive learning within as well as across problems. A good laboratory program at any grade level is not a series of "one shot" activities. Some laboratory experiences form substructures for others. The proper sequencing of experiments makes it possible for the pupil to use earlier learning to attack increasingly complex problems.

There are other factors associated with making the best use of laboratory procedures in schools. These include communicating the results of experiments, pacing inquiry skills in science with those in mathematics, and providing for a wider use of mental experiments. We need to recognize that the value of an experiment lies more in the means it presents for exploring the unknown than in the verification of the known.

CONCLUDING REMARKS It would be rash to suggest that a new curriculum in science has been developed, but it is clear that new viewpoints have emerged. The purpose of this section of "Theory Into Action" has been to present a logical plan for science teaching that is consistent with the structure of science and a modern view of science education.

Not all phases of science teaching have been discussed. There is need for more research and experimentation on some of the proposals. For others, the answers must emerge from one's own rational analysis of the problems. The need for a new approach to science teaching is no longer a matter for debate; it is the nature of the new curriculum that is not clear. The issues and viewpoints presented here are intended to focus discussion and provide a pivot for local action.

CONCEPTUAL SCHEMES

•

MAJOR ITEMS IN THE PROCESS OF SCIENCE

NSTA Conference of Scientists
Randall M. Whaley, Chairman

•

Subcommittee on Conceptual Schemes
of the NSTA Curriculum Committee
Joseph D. Novak, Subcommittee Chairman

INTRODUCTION The unprecedented importance of science requires intensive study of efficient methods for transmitting to our children the principal intellectual achievements of science, together with some understanding of how these achievements were, and are being, obtained.

We submit that the principal achievements of science can be identified as the "major conceptual schemes" or "big ideas" that serve to summarize areas of inquiry, together with an understanding of the process by which scientific knowledge may be obtained.

What are the major conceptual schemes that have been devised by scientists? There are many ways that one can "package" the achievements of science. Our objective has been to describe major conceptual schemes that *will be useful in science curriculum planning*. This restriction, we trust, will serve to facilitate curriculum planning, rather than to confound it. Such planning, we hasten to add, should be accompanied by counsel from able scientists, highly trained science teachers, and experienced curriculum workers. *The schemes are thought of as being useful in building the entire curriculum, not as topics for individual units or courses.*

To supply what has been referred to as the "structure of science"[1] for curriculum planning, the following criteria for definition of conceptual schemes have been used by our Committee: **1.** The big idea or scheme represents an area in science that has become firmly established in the scientific community and is basic to the progress of research. **2.** Each scheme represents a system of facts, principles, and concepts which hopefully can be organized into a sound learning sequence from simple (capable of being taught to very young children) to complex (the level at which "current problems" are being researched)

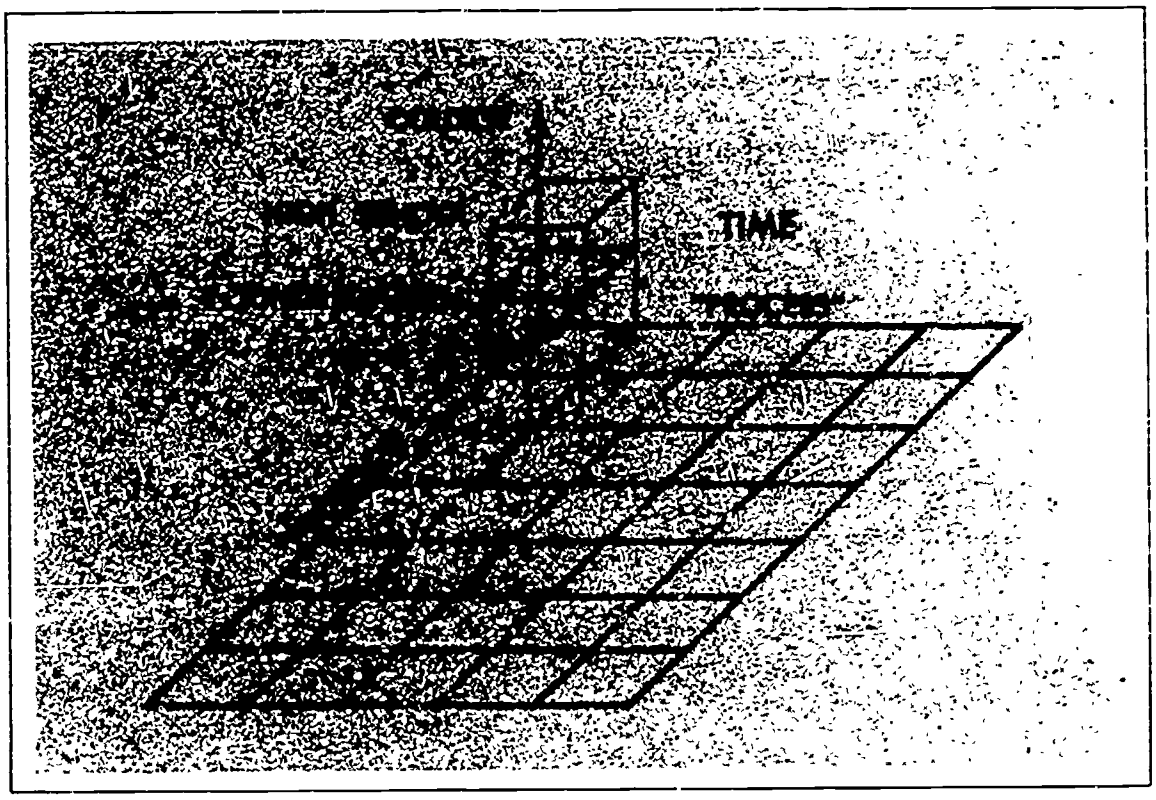
It might be interesting, if possible, to include all of science under one grand conceptual scheme. This would be of little value, however, for science curriculum planning. Another possibility is to attempt a "packaging" of the most important facts and principles of science that would result in 6 to 10 major ideas or schemes. This number of "packages" would permit careful consideration of possible experiences to be provided to students at each grade level to extend their understanding of some or all of the schemes; and yet, the packages would not be so all-encompassing as to provide little or no guidance to the science curriculum planner. In the end, the committee agreed upon twelve statements, seven describing conceptual schemes and five, the process of science.

The Concept Conference participants also found other points of agreement which they used in selecting and formulating conceptual schemes useful in the science curriculum. These agreements included: **1.** The elementary and secondary school science programs should be planned to include *all* students. No fundamental difference in objectives should exist for various student groups, although pace of instruction and illustrative examples might differ for "slower" and "accelerated" groups. **2.** A heavy emphasis should be placed on the nature

[1] Jerome S. Bruner. *The Process of Education*. Harvard University Press, Cambridge, Massachusetts, 1961.

of science or the *process* by which new knowledge is obtained. 3. Instruction should be planned to develop understanding of basic ideas of science concomitant with an appreciation of the methods of science; these two aspects should not be treated independently. 4. Some knowledge is more important than other knowledge. Most science courses have been dwelling on knowledge that is relatively trivial today.

The following representation indicates the three-dimensional character of curriculum planning. Children's experiences must be planned over time, so as to develop understanding of the major intellectual *products* of science (the major concepts) and *process* (methods of science). The following figure illustrates this representation.



Though it is not possible to illustrate the interdependence of the various conceptual schemes on the figure, this aspect must not be overlooked. Because of the close relationship among the concepts of science, the division of the left axis is arbitrary, and a small or relatively large number of conceptual schemes or "products" could be included. The three-dimensional matrix would be, in fact, one large corpus—*science*, or at least the portion of science to which a student might be exposed.

We offer the following statement of conceptual schemes, therefore, in the hope that these schemes will help provide a unifying concept for curriculum planning and criteria of relevance and importance in consideration of content for particular units or courses. We offer these schemes, also, in the belief that they provide stimulation for both breadth and depth in the understanding of science as a great intellectual adventure.

PRELIMINARY STATEMENT Scientific facts consist of a collection of observations or point readings on some scale. These point readings are ordinarily of little value unless they provide the basis for making scientific laws. As scientists study observations they creatively develop tentative explanations of causes of the order which they have observed in nature. These tentative explanations, called *theories*, are subject to continual study and revision. A part of what is commonly called the *process* of science includes the interaction involved in making new observations, fitting them into the existing framework of theories and laws, and revising the theories and laws when necessary, which often leads to further observation and further revision.

Some of these laws and theories have become so fundamental to the structure of the scientific enterprise that scientists are generally reluctant to modify or discard them. Sometimes these theories and laws become so thoroughly accepted that the average scientist "believes" them and seldom, if ever, considers the possibility that they may not be correct. On the other hand, without common acceptance of many of these ideas, science itself would become a meaningless accumulation of uncertainties that would be of little value for teaching science.

In the list of conceptual schemes that follows, scientists have attempted to select the theories and laws important for understanding science as we know it and organize them into a unified framework for studying science. Every law has its exceptions or its uncertainties, and every theory is subject to question. Sometimes, these exceptions and uncertainties must be minimized, else the student might become disconcerted, confused, and hindered in achieving an understanding of what we know as science. Later these limitations should be examined as the student's understanding progresses.

These uncertainties in science should be presented clearly and frequently to students, but we should not obscure the fact that many of our present theories have come from others that are now unacceptable. Without these imperfect ideas as starting points, progress in science would be impossible. For example, quantum mechanics has inconsistencies, but is nonetheless the basis for most of our modern physics. We know that Boyle's Law does not represent a complete description of the behavior of gases, yet it is a useful generalization which cannot be cast aside.

The conceptual schemes are not intended to be the final statement of authority, nor to be the only ones that might be useful. Waves and the wave nature of matter, for example, could furnish the basis for another scheme of equal importance. Those presented provide possible bases around which a curriculum might be organized and reflect the most commonly accepted and basic ideas of contemporary scientists.

The process of science has no discernible rules. It is a creative human enterprise which no two scientists perform in precisely the same way. Its practice demands utmost honesty, freedom from prejudice, and a willingness to conform to observed facts.

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VII

MAJOR ITEMS IN THE PROCESS OF SCIENCE

I Science proceeds on the assumption, based on centuries of experience, that the universe is not capricious.

II Scientific knowledge is based on observations of samples of matter that are accessible to public investigation in contrast to purely private inspection.

III Science proceeds in a piecemeal manner, even though it also aims at achieving a systematic and comprehensive understanding of various sectors or aspects of nature.

IV Science is not, and will probably never be, a finished enterprise, and there remains very much more to be discovered about how things in the universe behave and how they are interrelated.

V Measurement is an important feature of most branches of modern science because the formulation as well as the establishment of laws are facilitated through the development of quantitative distinctions.

CONCEPTUAL SCHEMES

I

All matter is composed of units called fundamental particles: under certain conditions these particles can be transformed into energy and vice versa.

The chief identifying properties of a particle are its mass, electric charge, spin, and magnetic and angular moments. These properties, as well as parity (symmetry properties), and other characteristics that can be treated statistically, are useful in describing the behavior of the particle when it interacts with other particles.

The major "building blocks" of matter are the atoms, which in turn contain various combinations of neutrons, protons, and electrons. These are relatively stable particles, which exist in the free state for appreciable times. The proton and electron appear to be stable; the free neutron is radioactive, with a half-life of about 15 minutes. In addition, a number of other apparently independent particles are now known. These, however, are quite different from the three—neutrons, protons, and electrons—listed above. Two, the photon and neutrino, have zero rest mass, which means that they are created and absorbed in atomic or nuclear reactions but do not exist at rest. While they are in motion, their effective mass is that given by the mass-energy equivalence of the Special Theory of Relativity. Others, such as the mesons and some of the baryons, are radioactive with extremely short lifetimes (of the order of a microsecond or less) and ultimately decay into more stable particles (electrons, protons, and neutrons). Finally, for every particle there appears to be an antiparticle (e.g., electron and positron) which is its "mirror image" in the sense that its properties are inverted and which annihilates its counterpart when the two meet, producing energy (photons). Particles and their antiparticles can coexist only for extremely short periods of time, and, therefore, are not found together in nature. The inverse process is also known: under certain conditions photons materialize particle-antiparticle pairs.

All of these particles are involved in the structure of living as well as nonliving matter. Unstable particles produce important physiological changes, and stable particles can form the building blocks of which living as well as non-living matter is constructed.

Which of these particles are most fundamental remains an open question. As far as the gross structure of matter is concerned, only four of the particles are used in describing the structure and non-nuclear energy changes within an atom: the electron, proton, neutron, and photon.

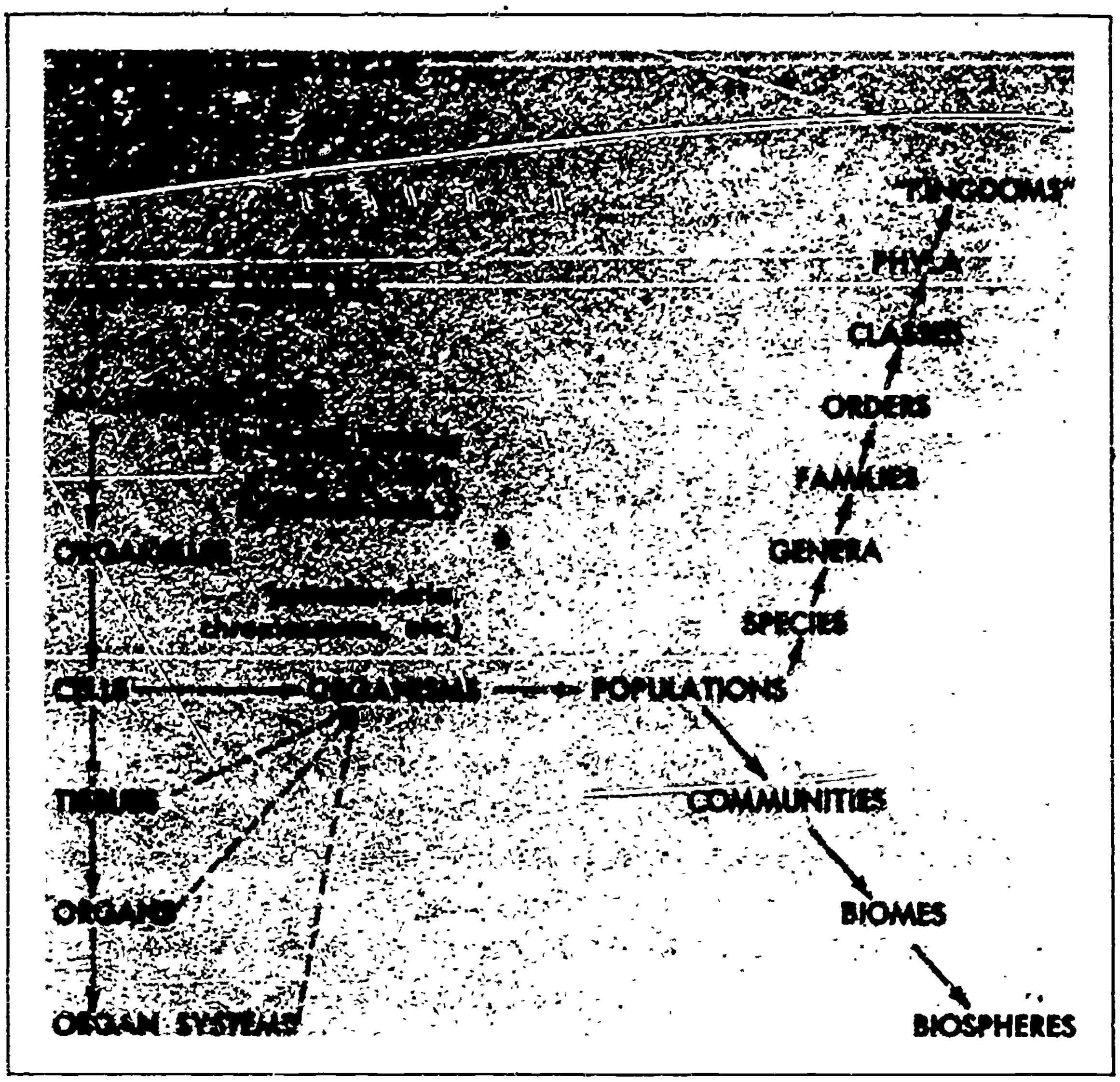
II

Matter exists in the form of units which can be classified into hierarchies of organizational levels.

The material units of the universe can be classified into sequences of structural categories, or *levels of organization*, such that several joined units of any one level form a single unit of the next level. For example, if protons, neutrons, and electrons are regarded as units of the level of fundamental particles, then certain combinations of these units form a single unit of a "higher" or more inclusive level, namely, an atom. In their turn, certain combinations of atoms form a single unit of a still higher level, for example, a molecule composed of more than one atom. Extended series of this kind represent hierarchies; that is, with very few exceptions, a unit of any one level includes units of all lower levels as components and is itself a component within a unit of all higher levels. Therefore, any given level contains fewer units than any lower level; and each such unit may also be said to be more "complex" than any units of lower levels. Thus, the hierarchy of levels describes a hierarchy of *numbers* of units and of *complexities* of units. Moreover, the levels also describe a hierarchy of *properties*, since any unit encompasses the properties of all lower-level units as well as additional properties of its own.

Several types of hierarchies may be constructed. All share the same lowest levels, for all material components of the universe consist of the same types of units. These common lowest levels are, in sequence of increasing complexity: fundamental particles ——→ atoms ——→ molecules or ions. Above the level of molecules or ions, hierarchies may be different according to the particular portion of the universe they are intended to describe. For example, the physical world can be described by the following hierarchy: Molecules and ions and fundamental particles ——→ aggregates of molecules or ions (sand grains, TV sets, mountain ranges, oceans) ——→ heavenly bodies (planets, moons, comets, stars) ——→ solar systems ——→ galaxies ——→ galactic aggregates ——→ universe.

The biological world can be described in an analogous manner by the following sequences:



Note that the *complexity* of a unit does not necessarily give a clue to its *size*. For example, a stone and a mountain have the same level of complexity, i.e., that of an aggregate of molecules or ions. Note also, that, by virtue of different internal *arrangements* of their component parts, the units of any level have different internal and external structures, or forms. However, though there may be considerable diversity in external forms, e.g., the diversity among animal forms, there is also a fundamental unity in that the properties contained at any organization level, such as the organism, are basically the same.

III

The behavior of matter in the universe can be described on a statistical basis.

Description and prediction of the behavior of matter requires the use of the most effective tools available to the scientist. Among these are thermodynamics, statistical mechanics, and intuitive reasoning. Thermodynamics is that branch of science dealing with heat and energy which describes the possible and the impossible and permits the prediction of what may happen and what may not happen. There is no proof for the laws of thermodynamics except that they have been shown to be valid in every test. Statistical mechanics refers to the methods of statistically extending the deduced behavior of a small number of particles to describe or predict the average behavior of all particles in a system. The use of either of these tools requires application of the mathematics of probability and of the theory and application of limits (calculus).

Radioactivity is an example of a property of matter which follows the laws of probability and which can be described on a statistical basis. Atoms of elements such as uranium, thorium, and carbon[14] spontaneously disintegrate by the emission of particles. In any large group of such atoms it can be predicted that a certain number will disintegrate in some unit of time. However, it is not possible to predict when any given atom will disintegrate.

Another behavior of matter which can be predicted on a statistical basis is the transmission of characteristics from parents to offspring among living things. The laws of inheritance were first clearly established by Mendel. On the basis of the Mendelian laws, it is possible to predict the distribution of characteristics among a significant population of offspring. However, it is not possible to predict all the characteristics which will appear in a single offspring.

IV

Units of matter interact. The bases of all ordinary interactions are electromagnetic, gravitational, and nuclear forces.

Two of the forces, in terms of which all ordinary phenomena must be explained, arise from electromagnetic or gravitational fields. Both are inverse square law forces, the first having been described originally by Coulomb and the other by Newton. It is possible that a close link exists between these forces; the discovery of this link is the goal of the Unified Field Theory. A third type, called "nuclear force," is invoked to explain the binding of nucleons. However, since one's normal experience is with atoms and aggregates of atoms, the nuclear force need not be considered in most situations.

Chemical bonding in both physical and biological systems involves electromagnetic forces. The motions of planets and satellites are explained in terms of gravitational force. Other phenomena may also be explained in terms of these fundamental forces.

Though the behavior of all matter in the universe is probably determined by electromagnetic, gravitational, and nuclear forces, the behavior of higher organizational units of living matter cannot be interpreted on this basis at this time. It is more fruitful to study the behavior of genetic material in terms of coded information and energy transformations required to utilize this information in cell synthetic processes. Similarly, the behavior of a worm or human being can be predicted best in terms of exchanges of energy and information between the organism and its environment.

V

All interacting units of matter tend toward equilibrium states in which the energy content (enthalpy) is a minimum and the energy distribution (entropy) is most random. In the process of attaining equilibrium, energy transformations or matter transformations or matter-energy transformations occur. Nevertheless, the sum of energy and matter in the universe remains constant.

Man's experience has shown that two great principles apply without exception to every macroscopic process occurring in the universe. These two fundamental principles are embodied in the statements of the first and second laws of thermodynamics.

The first law is a statement of the principle of conservation of energy, i.e., matter and energy are conserved or the sum of matter and energy in the universe remains constant. Interactions in nature result in transformations of energy from one form to another, such as heat to light or electrical energy to kinetic energy. In some processes, such as in nuclear reactions, large matter-energy transformations sometimes occur. A typical chemical reaction involves changes both in the composition of matter and in chemical potential energy. At the same time light, heat, electricity, or other forms of energy may either be taken from or given to the surroundings. However, the net gain or loss of matter and energy for the whole system is invariably zero.

In accordance with the second law of thermodynamics, heat will flow from a warmer body to a colder body, raising the temperature of the latter, but the reverse flow of heat without external aid has never been observed. The direction of changes in matter are such that greater randomness may occur in a system, but the reverse is not observed unless energy is supplied. For example, molecules of sugar will be distributed at random throughout a cup of coffee, but if the coffee is evaporated, these molecules would not be expected to reform a sugar cube.

Complex molecules may disorganize into simpler components, but the reverse does not take place unless considerable free (or available) energy is available. Living systems are characterized by their utilization of free energy to form organized structures (from complex molecules to societies). Nevertheless, disorganization of matter must take place somewhere, for living systems to function. The total of changes results in greater disorder in the universe. These and all other observations indicate that all natural processes are unidirectional in character and tend to bring the universe ever nearer to a state of equilibrium, in which it will have lost its ability to do any work. The degree to which the state of equilibrium is approached is itself a measure of the passage of time.

In living systems a relatively constant organization may be maintained, e.g., the charge on a cell membrane or the sugar level in the blood, but this requires the expenditure of energy with disorganization and "death" resulting if organism, or community, fails to utilize energy appropriately.

The driving force leading all systems to equilibrium is the tendency toward minimum potential energy or maximum randomness of molecular arrangement. The most disordered state has the greatest probability.

VI

One of the forms of energy is the motion of units of matter. Such motion is responsible for heat and temperature and for the states of matter: solid, liquid, and gaseous.

The kinetic-molecular theory of matter is one of the most powerful conceptual tools that exists in modern science. It provides a simple mechanical model for the pressure exerted by a gas, for the concepts of heat and temperature, and for the three principal states of matter (solid, liquid, and gas). A moving mass has kinetic energy by reason of its motion, this energy being equal to the work done in setting the mass into motion. The kinetic theory was developed by direct analogy with the concept of dynamic energy in the case of large-scale objects. The basic assumptions of the theory are quite simple: first, that matter is composed of small, discrete units which we call "molecules" and, second, that these molecules are in constant motion.

In a gas, this molecular motion exerts a pressure by transferring momentum in elastic collisions with the walls of the container. Although the motions of gas molecules are random, their numbers are so large in a typical sample as to give the effect of a steady pressure. The thermal energy (heat content) of a sample of matter is interpreted as being the result of its molecular motions; it is proportional, in fact, to the total kinetic energy of the molecules. The absolute temperature of a given sample, on the other hand, is proportional to the average kinetic energy of its molecules. (This is not strictly true for solids but is a reasonably good first approximation.) It is thus possible to have an object at a given temperature with greater *heat content* than another at a higher temperature; the difference is simply one of average vs. total kinetic energy.

The states of matter are also related to the motions of molecules on the basis of kinetic theory. The chief difference among the three states of matter lies in the strength of the intermolecular forces. These forces are particularly strong in solids and liquids, and relatively weak in gases. Since temperature is the measure of the average kinetic energy of the molecules in a sample of gas, it follows that as heat energy is added to the sample, its molecular motion increases, thereby increasing the average distance between molecules. Not all the energy goes into increasing the translational motion of the molecules; part goes into vibrational motion and part into rotational motion. The translational kinetic energy, however, largely determines the temperature of the sample.

Change of state (melting or vaporization) occurs when the added energy is great enough to overcome the attractive forces among neighboring molecules; the added energy goes into increased *potential energy* of the molecules as work is done to separate them from one another.

The motion of particles, or units of matter, plays a major role in a wide range of phenomena. The entire field of current electricity (electrodynamics) is based upon the motion of charged particles. Diffusion phenomena in gases and liquids, and across permeable membranes, are accounted for in terms of kinetic theory; the motion of ions, which plays so important a role in the biochemistry of living systems, involves both kinetic theory and electric field theory. Chemical kinetics, the study of the velocity and mechanism with which chemical reactions occur, depends upon the motions of molecules and ions. The oscillation of electric charges in a radio antenna gives rise to electromagnetic radiation. Differential heating and cooling of groups of molecules in the atmosphere gives rise to winds, and other changes in molecular kinetic energy account for most of the phenomena we class under weather. These are but a few examples of the various ways that the motion of units of matter is used to account for the organization and behavior of physical and biological systems.

VII

All matter exists in time and space and, since interactions occur among its units, matter is subject in some degree to changes with time. Such changes may occur at various rates and in various patterns.

Interactions among and within units of matter may produce changes in form, properties, or position.

The planets, natural satellites, stars, galaxies, and galactic systems are subject to transformations in substance, form, and position. These involve interactions which produce interchanges of matter and energy, exchanges of energy, and the systematic motion of celestial bodies in a gravitational field of universal dimensions. Movements of the earth and moon serve as convenient bases for time units such as day, week, month, and year.

Materials of the solid earth are constantly undergoing transformations from one form to another. The common rock types represent changes in the form and organization of the matter of which they are composed. In most instances, changes from one rock type to another also involve changes in volume, shape, and position of the material. The movement of molten rock material to the earth's surface and the transportation of sediment to the sea by rivers are familiar examples of changes in position. In contrast to the relatively slow geological changes, nuclear particles may undergo extremely rapid changes.

All life processes involve interactions whereby nonliving matter becomes involved in processes and forms characteristic of living matter and eventually returns to the nonliving state. These interactions inevitably require time and may require, or result in, changes in position.

Several general relationships among plants and among animals indicate that living matter has undergone systematic changes over a long interval of time. **1.** Any classification of plants or animals results in a branching system of groups. **2.** Similarities between related but biologically distinct groups suggest a common ancestry. **3.** Changes occur in groups of plants or animals as the result of natural and artificial environmental factors over short periods of time. **4.** Fossils found in rocks of successive geological periods demonstrate a sequence of faunas and floras requiring systematic variations with time.

Organic evolution is one of the grandest manifestations of the temporal changes in matter as conditioned by the physical and chemical environments at or near the earth's surface.

MAJOR ITEMS IN THE PROCESS OF SCIENCE

Prepared by Ernest Nagel

I

Science proceeds on the assumption, based on centuries of experience, that the universe is not capricious.

Phenomena observed to occur under certain conditions in one sample of matter, occur under the same conditions in other similar samples of matter. However, it is usually not immediately obvious in which respects different samples must be similar or which conditions are relevant for the occurrence of a phenomenon. Hence, extensive investigations must frequently be undertaken to settle these questions.

The so-called "Laws of Nature" that are the conclusions of scientific inquiry are, in general, assumed to hold under explicitly stated "ideal" or limiting conditions. When laws of nature are formulated in this way they are not faithful descriptions of what actually happens. Nevertheless, the strategy of formulating laws in this manner makes it possible to state in a relatively simple fashion highly complex patterns of relations between occurrences in nature and is one of the most fruitful procedures of modern science.

II

Scientific knowledge is based on observations of samples of matter that are accessible to public investigation in contrast to purely private inspection.

The conclusions which may emerge from a scientific inquiry require support by evidence obtained through carefully directed observation or experiment. Such evidence must either be replicable in principle, or must be capable of being independently confirmed through competent investigations.

Moreover, although the empirical evidence for a scientific claim never has the force of a *formal demonstration* in logic or mathematics, it must have some degree of *probative* weight. In particular, if the evidence is to have any merit at all, it must embody in some measure the idea of *control*—for example, the claim that a phenomenon occurs under certain observable conditions is worth little, if anything, unless the evidence provides reasons for believing that the phenomenon does not occur in the absence of those conditions.

III

Science proceeds in a piecemeal manner, even though it also aims at achieving a systematic and comprehensive understanding of various sectors or aspects of nature.

Scientific inquiries are not addressed to some one, all-inclusive problem but rather to an endless number of different specific problems. The adequacy of any conclusion that may emerge from a given inquiry must be evaluated by reference to the problem for the sake of which the inquiry was instituted. Major advances in science often result from the occurrence of serendipitous events during the "piecemeal" approach to scientific exploration. In general such occurrences have no impact on knowledge advance unless the observer or experimenter has a "prepared mind" capable of recognizing the occurrence as important.

IV

Science is not, and will probably never be, a finished enterprise, and there remains very much more to be discovered about how things in the universe behave and how they are interrelated.

Since many, if not all, of the conclusions of the sciences logically imply a vast number of further statements, the factual worth of any one conclusion cannot, in general, be settled by a single observation or experiment, for if a conclusion is to be credible is must be confirmed by a variety of empirical data.

Moreover, the resolution of one problem may lead to the pursuit of further questions and often depends on answers given to previously examined questions. Science is an ongoing and cumulative enterprise, in which the answers to one set of specific problems may acquire great importance because of the light those answers throw on a large class of other problems.

V

Measurement is an important feature of most branches of modern science because the formulation as well as the establishment of laws are facilitated through the development of quantitative distinctions.

The rationale for the introduction of quantitative methods (or measurement) is not to accumulate precise data for their own sake but to make possible more rigorous and systematic checks of assumed relations of dependence.

Planning a Local Action Program for Implementing Curriculum Development in Science

Subcommittee on Local Action Programs
of the NSTA Curriculum Committee
Richard W. Schulz, Subcommittee Chairman

PLANNING A LOCAL ACTION PROGRAM FOR IMPLEMENTING CURRICULUM DEVELOPMENT IN SCIENCE

An important function of a professional association is to provide leadership in areas served by the organization. The association should be concerned not only with new ideas that might lead to improvement but also with the implementation of these ideas.

The previous parts of this publication have presented the philosophy and theories of science education of the Association. NSTA has taken a position on curriculum development that hinges on two unifying threads: 1. *Science curriculum for our schools must be seen and developed in the total sequence of kindergarten through grade twelve (K-12), or beyond.* 2. *The conceptual schemes and the process of science should be at the focal point of any science curriculum; they apply to any of the sciences and allow for growth and change in science.*

How can we implement these ideas in a way that will be useful to each member of the Association and to each school system or group of educators concerned with science? It is the Association's view that action by those who will be planning and carrying out a particular program is the soundest base for an effective program. Thoughtful consideration and well-planned action will help individuals and school systems become increasingly knowledgeable about today's ferment in science teaching and increasingly perceptive and secure in building a strong science curriculum for the community. Therefore, the following suggestions for planning a local action program are designed to help provide purpose and direction for local self-improvement programs.

Elements of such a program include:

- Interest in improving progression and sequence of science education
- A forward-looking philosophy of science education
- Professional and lay personnel willing to devote time to the project
- A workable plan for carrying out the project

The task of improving a science curriculum is primarily one of selecting and organizing ideas and materials so that they will produce a sequential program, well articulated from step to step throughout the school program. It is in this sense, rather than in that of writing material for a specific course, that the term curriculum development is used in this publication. Progress has already been real and significant within the layers of curriculum at the instructional levels on which attention has been focused. This work should be neither repeated nor ignored, but a relationship must be established among these efforts, gaps must be identified and closed, and fragmentation avoided. These things a local action program can help to accomplish. It can help to bring order to a fluid and sometimes confused situation. It can consider such questions as sequence and content of courses, grade placements, programs for learners of varying levels of ability, different teaching styles, and relations between science and other subject areas, such as mathematics and social science.

ASSUMPTIONS The following assumptions by the NSTA are presented as basic to the development of a local action program for implementing a continuing curriculum development in science: **1.** The ultimate responsibility, professional and financial, for curriculum development is that of the local school district, yet the curriculum must represent a broad view and avoid localism, whether it be geographic, economic, or social. **2.** No single action program can be equally effective for curriculum improvement efforts in all or even a majority of the school districts of the nation. Action programs can be more effective if planned for individual school units. **3.** The unique contribution of the NSTA to the organization of science curriculum lies in the area of vertical structure, that is, emphasis on a continuing program from kindergarten through grade 12 and beyond. **4.** The curriculum must provide opportunity for the development of scientific literacy for all students. **5.** Because of the changing nature and content of science, a science curriculum must look to the future, and curriculum development must be a continuous process.

Because each school district will have its own individual problems and goals, local action programs should be individually tailored to meet the specific needs of that situation. However, there are some components that should appear in almost any local action program. These components are included in the following outline *although the sequence may be varied* to meet local needs.

ESSENTIAL COMPONENTS FOR A LOCAL ACTION PROGRAM **1.** *Preplanning session* — Determine preliminary strategy, including identification of suggested goals, scope, and estimated costs. **2.** *Preliminary organization*—Appoint steering committee; set tentative goals; determine scope; suggest timetable; develop tentative procedures; prepare budget estimate. **3.** *Opening conference*—Examine recommendations of steering committee; define goals; adopt working procedure. **4.** *Enlistment of community support.* **5.** *Inservice education.* **6.** *Curriculum development.* **7.** *Implementation and evaluation.* **8.** *Continuing revision and evaluation.*

A local action program includes both philosophy and procedures. The NSTA service document, "Toward a Theory of Science Education," and the "Conceptual Schemes and the Process of Science" in the preceding sections of this publication present part of this philosophy. The following guidelines are based on this philosophy and point a way toward effective action in curriculum building.

GUIDELINES FOR THE DEVELOPMENT OF A COORDINATED SCIENCE CURRICULUM THROUGH A LOCAL ACTION PROGRAM

Guideline No. 1: The Local Action Program, at all stages of development, should be a coordinated effort, including administrators, teachers, scientists, and competent laymen.

Curriculum development is not a simple process. Development of a superior program will tax the abilities of many members of the entire community. Participants must be carefully chosen, and each must understand his role.

Individuals selected to assist in curriculum development must have:

- An understanding of the objectives of education and a commitment to their implementation
- A sincere interest in improving the educational program for the school or the school system
- Willingness and ability to devote the time necessary to the project
- Sufficient flexibility in thinking to permit the give-and-take essential to the development of a good curriculum.

Following are the groups involved and their responsibilities:

School administrators

- Initiate, encourage, and support curriculum development activities
- Reassign work loads to provide time for committee work and experimental projects
- Arrange financing, coordination, and promotion of the program

Classroom teachers

- Develop, evaluate, and use new curriculum materials experimentally (This requires patience, dedication, and imagination.)
- Recognize that worthwhile progress in curriculum development is a slow and demanding process

Scientists

- Work with teachers to learn the capabilities and limitations of children and youth
- Provide counsel on the accuracy of curriculum materials
- Assist teachers in understanding how scientists think and work

Civic, social, and scientific groups

- Devote time and effort through membership on action committees
- Contribute suggestions for the improvement and development of the curriculum
- Provide continuing moral support

Guideline No. 2: An intensive study of existing research and resource materials should be undertaken to identify worthwhile suggestions for action at all stages of the local action program.

There are many sources of background information and fertile ideas fc curriculum development. The bibliography in the Appendix lists some of these sources. Valuable background will also be found in:

- The STEPS program developed by the U. S. Office of Education
- Published curriculum materials, which include those of the Biological Sciences Curriculum Study (BSCS), the Physical Science Study Committee (PSSC), the Chemical Bond Approach project (CBA), and the Chemical Education Material Study (CHEMS)

- Unpublished experimental projects now under way
- Curriculum materials from other local and state curriculum programs
- Community resources of many kinds

Committee members and consultants affiliated with the local action program should be able to add materials that are especially pertinent in the local situation.

A general word of warning may be in order here: The study of resource material is primarily for background information and should not "set" the pattern of thinking so early in the program that good ideas which do not conform to the pattern may be lost.

Guideline No. 3: The curriculum should be developed on at least a K-12 basis. It should be laboratory centered and flexible, yet comprehensive.

The laboratory, as the term is used in science teaching, is the place where observations are made and experiments are conducted. This may be in the school building, outdoors, or in the home. Both scientists and educators have insisted for many years that scientific inquiry and laboratory-centered instruction are *essential components* of every desirable science program. An important problem facing the planning group will be to arrange for appropriate and adequate laboratory work at every grade level.

Several excellent courses have been developed by groups of scientists and teachers working on a nationwide scale. Excellent as these courses are in themselves, as a group they contain considerable duplication and overlapping. The authors have expressed various points of view, and in many of the courses they have included far more material than can be taught in a single year of study. Before these materials can be used at their maximum effectiveness, it will be necessary to integrate them into a sequential program, selecting for inclusion such of the materials as meet the criteria and needs of the program.

The planners need also to be aware that weaknesses in teacher preparation may be revealed as the curriculum is developed, and they will find it necessary to think beyond grade 12 to consider the effect on college courses of the new and more advanced science courses in high schools and to plan for continuing adult education for laymen.

Guideline No. 4: Curriculum development should be carried out by persons selected for their knowledge of science, their ability in curriculum planning, their facility for critical thinking, and their dedication to the use of inquiry in teaching science.

The lack of imagination and quality in a course of study or in a curriculum may be traced to the lack of these characteristics in the persons responsible for its development. Therefore, it is of the greatest importance that persons with the qualities mentioned in the guideline be brought into the program. If persons lack these qualities, they should be encouraged to develop them. Many districts might profitably spend a year or more in identifying potential leaders and encouraging the development of leadership among teachers before embarking on a program of curriculum development. Administrators should recognize that the identification and selection of personnel is one of the first considerations in planning a local action program.

Teachers with leadership potential can be found in every district. They may not have achieved their greatest potential because of overcrowded classrooms, overloaded schedules, or lack of encouragement from school administrators. A district cannot hope to achieve success in curriculum development until its potential leaders are identified, encouraged to develop their capabilities, and given an opportunity to exercise leadership.

The curriculum must be planned with representation of all of the points of view suggested in the guideline if it is to be sound in content, workable in the administrative framework of the school, and effective in the classroom.

Guideline No. 5: The curriculum should be organized around broad principles in science and should provide opportunity for all students to gain some understanding of the scientific process.

The conceptual schemes and processes presented in this document set forth the broad principles around which a sequential curriculum can be developed. The ultimate goal, of course, is scientific literacy for oncoming generations.

Such conceptual schemes and processes have two outstanding advantages as the backbone of a science curriculum. They can encompass future growth and change in science itself, and they offer a broad outline of science to which the future nonscientist can relate the scientific information that will reach him in his daily life.

The goal of developing scientific literacy and understanding of science on the part of all students is an extremely important part of curriculum development. It will require considerable attention to the needs of the slower student as well as planning for students who will become scientists, professional persons, or leaders in other areas of society. Ample provision for study of educational research on teaching and learning techniques for various ability and interest levels should be included in the plans for the local action program.

Guideline No. 6: The relative importance of science in the curriculum and its relationship to other subjects should be considered at all stages of planning.

Science, mathematics, the language arts, and the social sciences are inextricably related in actual practice. Yet they have been arbitrarily separated in the school curriculum, to the detriment of all. The many relationships that exist need to be explored and strengthened so that students will begin early to see and to utilize the relationships that are becoming increasingly apparent between science and other aspects of life. For example, the historical and social implications of science are extremely important, but have been seriously neglected. An understanding of the social implications of scientific and technological developments is a major factor of scientific literacy, but it can only be developed from habits of thinking that link science with other aspects of life.

Curriculum planners must keep in mind that science is not the only important subject in the curriculum. Planners in each curriculum area share a common responsibility to eliminate unnecessary content and repetition and to develop a program that is both effective and practical.

Guideline No. 7: Teachers should be thoroughly familiar with the principles and practices of scientific inquiry and their use in classroom and laboratory situations.

Experience has shown that many curriculum development programs have been undertaken by teachers who were quite unfamiliar with the philosophy and procedures inherent in scientific inquiry. Since the teacher should be involved in planning the curriculum and will certainly be the person to carry out the curriculum plans, he must be familiar with the goals of the curriculum development program, must be in sympathy with them, and capable of carrying them out.

Most school districts wishing to initiate a local action program of curriculum development would do well to consider the possibility of enlisting selected teachers in an experimental program to demonstrate the effectiveness of introducing scientific inquiry into the classroom and laboratory. Once teachers have experienced the challenge of teaching an inquiry-centered program, the majority of them will become ardent supporters of this method of instruction. Without this conviction and experience, they are not capable of developing and teaching a curriculum that is oriented to the principles and practices of scientific inquiry.

Guideline No. 8: The local action program should include continuing inservice education with adequate provision for discussion among participants as well as for feedback of information to administrators.

A local action program in itself presupposes some changes in course content, philosophy, and methods of teaching. Certainly, increasing attention will be given to the inquiry process of learning as well as to articulation between the grade levels and courses included in the curriculum. It is only realistic, therefore, that plans for an ongoing program of inservice education should be built into the local action program. Such an inservice program will prepare beginning teachers to teach the techniques of scientific inquiry as well as benefit those who will be shifting to this technique. With knowledge expanding so rapidly, there will also be a need for inservice programs to keep teachers up to date with new developments in science.

Guideline No. 9: New materials should be used experimentally before they are incorporated into the curriculum.

Introductory, experimental use of new materials before they are finally accepted for the curriculum provides an opportunity to try a variety of materials and approaches in the situation where they will be used. The most effective can be retained for the new curriculum.

Another very considerable advantage concerns teacher acceptance of new materials. A teacher who is hesitant about, or opposed to, undertaking new procedures and techniques may be bolstered by the idea that the new methods are "experimental" and will be retained only if they are successful. The greatest psychological advantage, however, is that experimental use offers teachers an opportunity to take an active part in the selection of the techniques and procedures that are to be included in the new curriculum.

Guideline No. 10: Evaluation should be planned to begin with the earliest steps in the program and should continue throughout its development.

Evaluation involves much more than the measurement of achievement in the classroom. It should include the appraisal of the effectiveness of each phase of the local action program, as well as teacher and pupil behavior in the classroom. Report sheets, checklists, oral suggestions, and the results of discussion groups should supplement the more formal methods of evaluation commonly used in school systems. Provision for obtaining evaluations of these types, as well as for improving subject-matter testing, should be built into the program. The results of evaluation may indicate a need for changes in plans for inservice education as well as in the curriculum itself.

Guideline No. 11: Curriculum planning is a continuing process. Plans should reflect the need for continuing evaluation and revision. They should not be terminal.

Science, technology, and education are progressing so rapidly that it is essential to provide for continuing revision in the curriculum. It is impossible to predict what science will be like when today's first-grade student graduates from high school. Another factor affecting the adequacy of the curriculum is the continuing change in pupil background and knowledge. As students are introduced to new materials and methods of inquiry, they will need different and more sophisticated approaches in later grades. This in itself will make continuing curriculum revisions mandatory.

Guideline No. 12: A local action program should receive adequate financial, as well as moral, support from the community.

If we accept the premise that the ultimate responsibility for curriculum development lies in the local district, it follows that the responsibility for obtaining adequate financing for the program must lie there as well.

Local groups may look to foundations and other granting agencies for experimental and pilot projects. But even these must provide for continuing financing at the local level if the projects are to continue at the end of a limited period of time. Foundations cannot make grants to all of the thousands of districts that wish to consider problems of curriculum develo

In many areas, the local taxpayer may not be able to bear the entire cost of a curriculum development program. The alternatives, then, are to find volunteer help, curtail the program, or to find outside sources of funds. There are sources that are sometimes neglected in the search for the big grant. For example, some agencies will provide matching funds for science equipment and many other types of curriculum improvement. Local industries and civic agencies will often help support a program if convinced that the project is sound and worth while.

DEVELOPING A LOCAL PLAN OF ACTION

Each community, school system, or group contemplating a local action program for science curriculum development will be in a unique situation and must, in the end, develop its own program pattern. Each group must assess the needs and resources of its community and plan a program of curriculum development that will be flexible, that will provide for revision when needed, and yet offer a definite and workable plan of action.

The NSTA will welcome reports of local action programs and will hope to serve as a clearinghouse of ideas for curriculum development programs. The Association will be glad to encourage and assist in the development of local action programs, within the limitations of its staff and budget. If your district is planning a local action program, the NSTA would like to be informed of your plans and progress. The Association will place you on its mailing list to receive information about further developments in local action programs, if you so request.

Appendix

The National Science Teachers Association has devoted five years to examination of its beliefs about the science curriculum. Officers, the Board of Directors, Committees, and the members have moved carefully, step by step, toward the formulation of this Position Statement.

In 1958 and in 1959, the Association held special conferences to study selected problems in elementary school science and high school science. These resulted in the two publications: *It's Time for Better Elementary School Science* and *Planning for Excellence in High School Science*. In 1959, also, through sessions at regional meetings and the National Convention at Kansas City, Missouri, the implications of a K-12 curriculum were studied.

During 1960, the NSTA Curriculum Committee prepared a basic outline for the Association's work in reference to curriculum development. This paper, together with suggestions of the Board of Directors and various reviewing groups, was further refined as a guide to Association activities in 1961. During this same year, working papers, including one on curriculum, were prepared for discussion at the 1962 National Convention in San Francisco, California, with the objective of obtaining resolutions for the membership to discuss.

Drawing extensively on this background, the Curriculum Committee developed this Position Statement. It has been approved by the Board of Directors and is published herein so that all who are interested and look to NSTA for guidance may know what the Association's beliefs are on curriculum development in science. The Committee and the Board offer this statement as one that embodies the fundamental concepts of a good science program, reflects the climate of the times, is forward-looking, and can serve as a guide to new and continuing programs in science. In recognition that the importance of this Position Statement lies in its implementation, action programs which will include publications and leadership conferences are being planned.

The Curriculum Committee of NSTA invites all educators to think critically and analytically about this Position Statement. Your opinions regarding the ideas expressed here and your suggestions for implementing them in local school systems will be most welcome. Please direct communications to Marjorie Gardner, Assistant Executive Secretary, NSTA, 1201 Sixteenth Street, N.W., Washington 6, D. C.

DONALD G. DECKER, *Chairman*
NSTA Curriculum Committee

THE NSTA POSITION ON CURRICULUM DEVELOPMENT IN SCIENCE

IN the period since World War II, a number of important changes have occurred in science education. There has been a growing awareness by the general public of the decisive roles played by science and technology in modern society. The climate is conducive to extensive experimentation and change in this area of education. For the most part, changes are occurring in secondary schools and colleges, notably through the revisions of high school science courses on a national scale. In addition, considerable financial support has also been provided to improve laboratory and research facilities in the nation's high schools and colleges.

Several new course improvement programs have been developed, largely with financial aid from the National Science Foundation. The Physical Science Study Committee, the Biological Sciences Curriculum Study, the Chemical Bond Approach Committee, and the Chemical Education Material Study are now well known. A basic premise of each of these groups is that science instruction in most schools is out-of-date and fails to present an understanding of the objectives and methods of scientific inquiry. Programs in the elementary schools and junior high schools manifest the same obsolescence.

In such an atmosphere professional groups and individuals look to their national organizations for guidance. Many school administrators and teachers are willing to explore new curricular and methodological suggestions, but find themselves on the horns of an educational dilemma. On the one hand, there is an honest desire for extensive curriculum changes but, on the other, there is no clear image of the ideal science curriculum. This is particularly true in the elementary and junior high schools, where science is not normally divided into separate disciplines and has, therefore, not been the object of much attention by scientific groups. To develop a one-year course in any one of the separate science disciplines, where for the most part some agreement on content is found among professional scientists, is far easier than to devise an integrated science curriculum that is more than a collection of isolated units selected from the various disciplines. Yet, there is a growing conviction among educators that it is in the elementary grades that the greatest impact can be made in promoting general understanding of the nature of science.

The National Science Teachers Association has a responsibility to be concerned with matters relating to the school science curriculum. The membership has on various occasions affirmed concern in this respect, most recently through (1) the report of the 1962 San Francisco Convention Resolutions Committee and (2) the 1962 report of the Policies Committee. Both urged the Association to assume a leading role in science curriculum development.

The Nature of Science

If NSTA is to further the development of sound science curricula, the Association must clarify the sense in which the term "science" will be used.

Science is the activity through which best explanations are sought for the observed facts of nature. These explanations are expressed as theories or statements which conform to general standards of reliability imposed upon them by the scientific community and which are characterized by economy of thought and expression. In this sense the great conceptual schemes such as the conservation of energy, the kinetic theory of heat, the atomic theory of matter, and the biochemical theory of heredity should be at the focal point of any science curriculum, rather than the individual concepts or the facts about our environment.

There are three aspects of the scientific enterprise. The first consists largely in the observation and description of nature, and is sometimes called *natural history*. It presently comprises the major part of any elementary science curriculum, as well as many high school and introductory college courses in science. In a sense, one might regard this type of knowledge as the first phase of scientific inquiry. It includes not only the more obvious phenomena of our environment but, also, the relationships among these that may be revealed by simple experiments.

The second aspect of the scientific enterprise, *science*, begins with the first—with observation, with descriptive statements, with simple, causal relationships derived from experiment. But it is important in science education to realize that the essence of science lies not so much in seeking out the detailed structure of nature as in trying to understand it. As an example, one might point to Boyle's Law (or the gas laws, generally). This relationship is easily demonstrated; in fact, students may be guided to the "discovery" of this law for themselves. And, as is generally the case in a science curriculum, one can find innumerable practical examples involving the application of Boyle's Law. Instead, what one should look for is the *why* of Boyle's observation—that is, for reasonable explanations. What basic conceptual scheme provides for understanding the behavior of gases? The answer, of course, lies in the kinetic theory of gases. Hence, to speak of the behavior of gases without introducing the kinetic theory in a meaningful fashion marks the difference between a natural history approach and a science approach.

As for the third aspect of the scientific enterprise, *technology*, the distinction between this activity and what we call science is probably more evident than that between natural history and science, where the boundary is not nearly as sharp. While science is an intellectual quest for understanding of natural phenomena, technology is a practical effort to use and control these phenomena. Technology yields the tangible products of science.

All three aspects of the scientific enterprise must be a part of the science curriculum:

1. Descriptive science or natural history, because it provides the basis for scientific inquiry and plays so prominent a role in a child's conventional experience;
2. Science proper, because of its intellectual challenge, which should be a primary goal of scientific education; and
3. Technology, because it serves so well to illustrate the practical application of scientific principles and because of its impact on modern society.

It is clearly impractical to include each of these categories in the same degree at all levels. It is important, however, for students to understand the distinction among these activities which, collectively, make up what is commonly termed "science." Indeed, if little more is accomplished than to clarify in students' minds the nature of the scientific enterprise, a major advance will have been made in science education.

The Role of Mathematics

One cannot speak realistically of a sound science curriculum without considering the important role played by mathematics. Just as science itself could not have developed to its present stage without mathematics, so it is unrealistic to think that the true character of science can be portrayed without mathematical reasoning. Mathematics is the language by which one describes the order in nature and which, in turn, leads to a clearer understanding of that order. Those sciences which rely heavily on mathematical demonstration have been most successful in structuring man's experience. Efforts in science curriculum development should be accompanied by corresponding developments in mathematics, and the two must be closely correlated at all levels.

The Goals of Science Education

Various objectives have been cited in the past as constituting the goals of science education. For the most part, these objectives relate to some utilitarian purpose or to a review of a wide spectrum of facts about nature. But science is more than a collection of facts, and teaching science requires more than presentation of information about the natural world.

If science education is important for all students, it must be for reasons other than the utility of science alone. It is always tempting, of course, to point to an end product. But by trying to rationalize the value of science education primarily in terms of what applied science or technology can accomplish, the goals of such education are placed on tenuous ground.

The primary goals of science education should be intellectual. What is required is student involvement in an exploration of important ideas of science. The mental stimulation and satisfaction of exploring one's environment, learning about its past and probable future, examining man's role in the scheme of things, discovering one's own talents and interests—these are reasons enough for the study of science, just as they are for the study of most disciplines. Science is one of man's major intellectual accomplishments, a product of the mind which can be enjoyed —not for its material fruits alone but for the sense which it provides of the order in our universe.

The Role of NSTA in Curriculum Development

The central purpose of the National Science Teachers Association is the improvement of science instruction at all educational levels. Commitment to this purpose requires NSTA to be concerned not only with curriculum development in terms of course content and learning experiences but, also, with instructional materials and methods, facilities and equipment, and teacher education.

The National Science Teachers Association takes the position that to be fully adequate the school science program:

1. Must start as early as kindergarten or first grade;
2. Must be articulated from one level to the next through grade twelve, or higher;

3. Must encompass a full range of the contemporary knowledge and ideas which scientists employ;
4. Must result in understanding the nature of the scientific enterprise through direct student involvement in the processes of scientific inquiry;
5. Must involve the best that is known about child growth and development and the psychology of learning; and
6. Must be supported by first-rate staff, facilities, and instructional materials.

With regard to evaluation, the Association believes that this process should be closely tied to the stated objectives of a given curriculum. But goals should be stated independently of the problem of evaluation, and methods should then be sought to test the attainment of these goals. Where the evaluation of a given set of goals turns out to be difficult, this should not be taken as indicating a weakness in the goals but, rather, as a weakness in our knowledge of evaluation.

The National Science Teachers Association asserts its position that no single program can or should be designed for use in all or even a majority of the school districts of the nation. The Association believes in multiple efforts in curriculum development and will encourage and assist efforts involving creative and diverse approaches by many groups and agencies—local, regional, and national. Because of the need for leadership and guidance in the development of science curricula, the Association will strive to keep the total picture of science education in focus, to seek to identify the over-arching themes in science, to clarify the goals, and to establish criteria for sound curriculum development in science.

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BIBLIOGRAPHY A group that is planning a program of action should become informed of current thinking and progress. This bibliography suggests some of the highlights that should be studied before charting a course of action.

The three-volume report of the NEA Project on Instructional Programs of the Public Schools makes an excellent starting point for professional reading. The philosophy and outlook of some leading American science educators may be found in the 59th Yearbook of the National Society for the Study of Education, *Rethinking Science Education.* Bruner's *The Process of Education* is an excellent treatment of the topic by a psychologist. A summary of the most recent research in science is presented in the June 1961 and June 1964 issues of the *Review of Educational Research.*

One of the more important aspects of any curriculum improvement program is the testing program. Both teachers and students are extremely sensitive to test results. If a curriculum improvement program is to succeed, it will be necessary to get teachers to ask the types of questions on their tests that will evaluate the achievement of the stated objectives of the program. The publications of the Educational Testing Service merit careful study for their value in improving the testing program.

The publications of the National Science Teachers Association will provide many helpful suggestions for planning a curriculum improvement program. The list of U. S. Office of Education science publications will provide another rich source of helpful materials. It is suggested that each local school add many of these titles to its professional libraries. Thorough study of some of these publications should precede even preliminary planning for a program of curriculum development.

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