DOCUMENT RESUME

ED 025 436 SE 006 033

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New Directions for Science Curriculum Development.
Educational Research Council of America, Cleveland, Ohio.
Pub Date 14 Jun 68
Note- 26p.
EDRS Price MF-$0.25 HC-$1.40
Descriptors- Bibliographies, *Curriculum Development, *Elementary School Science, General Education, Instruction, *Models, Objectives, *Scientific Literacy, *Secondary School Science

Proposed is an organizational plan for a K-12 science curriculum. The paper is organized into three parts. Part I proposes certain general objectives of instruction as a framework on which a K-12 science curriculum is to be built. The concepts of general education and scientific literacy are discussed in detail. Part II considers the "forces" tending to establish a unified or interdisciplinary structure for science in education. Part III deals with a model that attempts to relate the various elements of curriculum. The model is based on the premise that unified science is a valid and useful concept. The fundamental ideas or "conceptual schemes" of science are considered in the development of this model. A bibliography is appended. (BC)

NEW DIRECTIONS FOR SCIENCE CURRICULUM DEVELOPMENT

by

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ERC Papers in Science Education
Number 2
June 14, 1968

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THE SCIENCE PROGRAM
of the
Educational Research Council of America
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This paper is intended to propose a viable answer to the question, "What shall be the basis of a K-12 science curriculum?" The answer is organized into three parts in order of decreasing generality. Part I proposes certain general objectives of instruction. Part II proposes an interdisciplinary content structure for the curriculum. Part III proposes a specific plan for developing a science curriculum that is based on propositions developed in Parts I and II and on actual experience gained from previous efforts in the direction indicated.

PART I

The purpose of science instruction in grades K-12 is that of general education. As a result of experiencing a planned sequence of science instruction, the individual should achieve increasing levels of scientific literacy.

Not all individuals will, can, or should achieve exactly the same level of scientific literacy. However, each individual should have a clear opportunity to develop further scientific literacy at all levels of his intellectual development (i.e. at all grade levels K-12).

General education is that education which is not directed specifically toward acquiring a marketable skill or the first level of professional specialization. In other words, general education is not job oriented. General education aims to accomplish most of the ultimate goals of "liberal education," but to do so in a modern context that has direct relevance for the individual.

It should be noted, however, that general education in science would include, as an integral part, the uncovering of career possibilities in science. A significant proportion of the individuals in grades K-12 should eventually aspire to careers in science and science related fields.

Efforts to delineate "scientific literacy" have often been concurrent with identification of general objectives of science education. Haney has produced a series of six objectives[1] which have been modified slightly to give the following statements. These are proposed as the general objectives of science education:

1. The pupil should acquire knowledge which he can use to predict, understand, and control natural phenomena.
2. The pupil should grow in his ability to engage in the processes of science and to apply these processes in appropriate situations as he confronts them in his daily life.
3. The pupil should acquire the attitudes of scientists and learn to apply these attitudes appropriately in his daily experiences.
4. The pupil should come to understand the various interrelationships among

science, technology, and society and to perceive his personal involvement in these activities.

5. The pupil should learn and develop numerous useful psychomotor skills through the study of science.

6. The pupil should acquire a variety of interests in and enthusiasm for science.

It is proposed that these six general objectives of science education be the framework on which a K-12 science curriculum be built. The purpose of general education in science should be regarded as the foundation on which the framework rests. There are numerous reasons to substantiate this proposal. Several of these reasons are:

1. The six general objectives are permeated by a dimension of humanism through which science is linked inextricably to the life of each individual. Science is removed from the impersonal status of an activity conducted by strangers in sterile laboratories. Instead science is viewed as universal activity that has relevance for all aspects of human endeavor, at all ages and at all levels of intellectual sophistication.

2. Each of the six general objectives can be translated into behavioral objectives that would be appropriate for individuals at different age levels and at different levels of intellectual maturity. The full value of this feature can be appreciated only by one who has struggled to write behavioral objectives that derive from the unusual list of instructional objectives.

3. Within the group of six general objectives, one can find explicit reference to objectives in cognitive, affective, and psychomotor domains. Other specific objectives fulfill current concerns that the processes of science be considered as content[2] and that social implications of, and for, science[3] become an integral part of the science curriculum. In short, the six general objectives, as stated, are relatively comprehensive.

PART II

Forces tending to establish a unified or interdisciplinary structure for science in education have been exerted from two principal sources for many years. The older and more persistent source is science as perceived by many (but not all) scientists. The newer source is education as perceived by science educators. The strength of the first source has been more or less constant through time.

Unity in Purpose

The present view of many scientists regarding the heuristic value of a unity of science concept for both educators and scientists is aptly expressed by Niels Bohr:

> Notwithstanding the admittedly practical necessity for most scientists to concentrate their efforts in special fields of research, science is, according to its aim of enlarging human understanding, essentially a unity. Although periods of fruitful exploration of new domains of experience may often naturally be accompanied by a temporary renunciation of the comprehension of our situation, history of science teaches us again and again how the extension of our knowledge may lead to the recognition of relations between formerly unconnected groups of phenomena, the harmonious synthesis of which demands a renewed revision of the presuppositions for the unambiguous application of even our most elementary concepts. This circumstance reminds us not only of the unity of all sciences aiming at a description of the external world but, above all, of the inseparability of epistemological and psychological analysis.[4]

Essentially, Bohr saw the unity of the various sciences in the purpose of science in its broadest context. An extreme expression of this point of view is that the purpose of all science is to develop one theory that can be used to account for all phenomena. In working toward this ultimate (and possibly unattainable) goal, scientists presently seek to formulate generalizations of increasingly comprehensive scope.

George Gaylord Simpson expressed a unity of science in purpose by writing, "The goal is a connected body of theory that might ultimately be completely general in the sense of applying to all material phenomena."[5]

Unity in Subject Matter

Other individuals have perceived the unity of science as being derived from the oneness of its subject matter. From this viewpoint, the various sciences have established barriers around groups of natural phenomena in highly arbitrary patterns. To point up the high degree of arbitrariness in grouping natural phenomena Ehrlich and Holm commented, "That peoples of other cultures order natural phenomena differently bothers most of us very little. For example, Eskimos have no generic term for water, but have a detailed and useful terminology describing the various kinds of frozen water. . ."[6]

This viewpoint based on the unity and interrelatedness of natural phenomena does not obviate the practical necessity for specific disciplines of science. Indeed, the nature of scientific research requires that narrow limits be set on the investigation immediately at hand.

The various separate disciplines have developed as research traditions. Within these traditions, rather narrow limits historically have been placed on the kinds of questions to be investigated and the techniques of investigation. However, in the past few decades there have been signs that historical boundaries between research traditions have been dissolving as more and more active research involves interdisciplinary thought. The specific areas of molecular biology, electronics, space, and psychophysics are only a few examples.

It is ". . .axiomatic that there is only one physical universe for all of us. . ."[7]

Unity in Methodology

A third basis from which unity of science can be derived is that of methodology. The basic procedures in inquiry for all sciences are similar. Holton feels that there are certain ". . .characteristics for good scientific work which successful investigators emphasize. . .(and these are). . .an intuitive feeling for nature, particularly for its quantitative aspects; the sensitivity for recognizing a favorable though unexpected turn of events; a common sense deepened through special training; a habit of using one's intelligence to the utmost; and a reliance first and last on observation and experiment."[8]

Unity in Concepts

A fourth basis from which unity of science can be argued is implicit in the observation that certain major concepts are used in many sciences. The number of concepts that can be categorized as basic is somewhat indeterminate, but is probably smaller than might be guessed intuitively when one considers the number, range, and apparent diversity of science disciplines and the natural phenomena which they treat.

In recent years, several efforts have been made by groups of scientists and science educators to extract and verbalize basic interdisciplinary concepts. None of the groups has claimed to have achieved the ultimate in such efforts though each has resulted in a notable product that has definite heuristic value. Perhaps it is not surprising that the independent efforts of each group have distilled essentially the same concepts from the body of the various sciences.

A continuing conference of scientists and science educators at Ohio State University developed a list of 25 "big ideas" over a period of seven years starting in 1959. The big ideas are essentially concepts and include some that are derived from the process of science. These big ideas can be grouped in seven arbitrary clusters:

1 - Perception, Orderliness
2 - Hypothesis, Theory, Quantification Significance, Replication, Validation
3 - Energy-matter, Time-space, Fundamental entities
4 - Force, Change, Interaction, Rate, Equilibrium, Gradient
5 - Field
6 - System, Cycle, Resonance, Conversation, Organism
7 - Model, Scale[9]

The National Science Teachers Association has sponsored a committee that included scientists and science educators and which was charged with the task of formulating basic conceptual schemes of science. The product of the committee's efforts was a list of 12 statements - seven "conceptual schemes" and five "items from the process of science."[10] At the present the committee is in the process of revising the original statements.

CONCEPTUAL SCHEMES

I. All matter is composed of fundamental particles; these particles can be transferred into energy and vice versa.

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

III. The behavior of matter in the universe can be described on a statistical basis. For example, the behavior of individual atoms in a large group cannot be predicted; but the behavior of the group can be predicted according to the laws of chance.

IV. Units of matter interact. The bases of all ordinary interactions are electrical, magnetic, and gravitational forces.

V. If left to themselves, all interaction 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 occur. Nevertheless, the sum of energy and matter in the universe remains constant.

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

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

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.

The Michigan Science Curriculum Committee, composed of scientists and science educators, identified twelve "cross-cutting" ideas. These ideas ". . .or understanding of a cross-cutting nature, important for two or more fields of science. . .can be introduced. . .(early). . .and will continue to be valid in progressively more sophisticated fashion at each succeeding educational level."[11] The twelve ideas were not intended to be exhaustive of all science, but were to be exemplars. The twelve ideas were:

1. Measurement as an expression of relationship

2. Interdependence in the natural world

3. Interaction of heredity and environment

4. Dynamic equilibrium

5. Differential rates of processes

6. Tools, devices, and outside sources of energy as extensions of man's body and its capabilities

7. Change and variation

8. Normal curves and working factors

9. Gradients

10. Extrapolation and interpolation

11. Cycles and cyclic changes

12. Directional change in response to the challenge of the environment[12]

As has been noted, the groups that have identified big ideas, cross-cutting ideas, etc. have been composed of scientists and science educators. Their work is a bridge between the two main forces tending to establish a unified structure for science in education.

A Trend Toward Unified Science Education

The forces of education that have tended to produce a unified structure in education are evident from certain events of the past sixty years and, taken together, can be viewed as a trend toward unified science education.

The original intent of a general science at grade nine was that, "The first year science of the high school should be organized upon a broad basis involving fundamental principles of the various sciences and using materials from all. . ."[13]

In the early twenties, General Science courses departed from the original intent and deteriorated into several short courses in separate disciplines. Slosson recognized what was happening to General Science and attempted to redirect educators' efforts to recognize that, "General Science is not a crazy-quilt made up of patches torn from the various sciences. On the contrary, the various sciences consist of patches torn from the seamless robe of truth, which it is the object of General Science to present in its pristine unity, its natural integrity."[14]

In spite of the unity implicit in the original intent of General Science, in practice it was recognized as being ". . .no more integration than mixing water and sand forms a compound."[15]

In 1931, life enrichment objectives for science education were introduced[16] in accord with the "problems of life" trend in curriculum development. Attempts were made in this era to teach science in connection with social and personal problem areas. The science involved was not segregated into disciplines. This approach lost support due to the coincidental, as opposed to the planned, nature of the specific learnings attained.

Parallel with the problems of life approach was the development of Physical Science for the eleventh or twelfth grade. These courses attempted to integrate subject matter from chemistry, physics, astronomy, and geology. Research studies by Heidel[17] and Peterson[18] showed that the unified courses were at least as effective as traditional courses in teaching facts and principles. In fact, there were several indications that the unified courses were more effective.

In 1956, the Physical Science Study Committee picked up the war-interrupted idea of integrating science disciplines for instructional purposes. The intent of the committee to produce a physical science course uniting chemistry and physics was aborted due to unresolved disagreements between physicists and chemists on the committee.

Since 1960, several programs that apply the unified science approach to instruction in the secondary school (17, 18, 19, 20) have been developed. Some of these have been compared to conventional courses and the relative effectiveness in teaching common objectives has been assessed (19, 21, 22, 23). In each of these studies, the effectiveness of the unified science course has been equal to, or better than, the traditional course structure.

The trend clearly is toward ". . .the next phase in the evolution of secondary school science programs, designed to meet the needs of <u>all</u> the students, as a movement toward courses that seek to integrate the whole of science."[24] The dynamic nature of the trend to, ". . .unified science education embodies the concept of continuing curricular evolution."[25]

The trend to unified science education in the secondary school is reinforced by a similar trend in college level science courses especially those that are specifically intended for general education. Fuller[26] has reported that 421 institutions of higher learning out of a total of 994 responding to a survey offered one or more courses combining two or more of the sciences for non-science majors.

Possibly more surprising is his finding that 75 institutions offered multidisciplinary courses for science majors.

In summary, specialization is necessary to further the research traditions of specific scientific disciplines. However, "the natural world does not operate in compartments, fragments, or specializations and the more specialized a particular individual becomes, the more certain it is that his knowledge will be too limited to understand all the factors operating in a particular situation."[27]

It seems appropriate that science curriculum development at this time be based on a unified view of science. This is especially true for all grade levels at which general education in science is the primary purpose in teaching science.

PART III

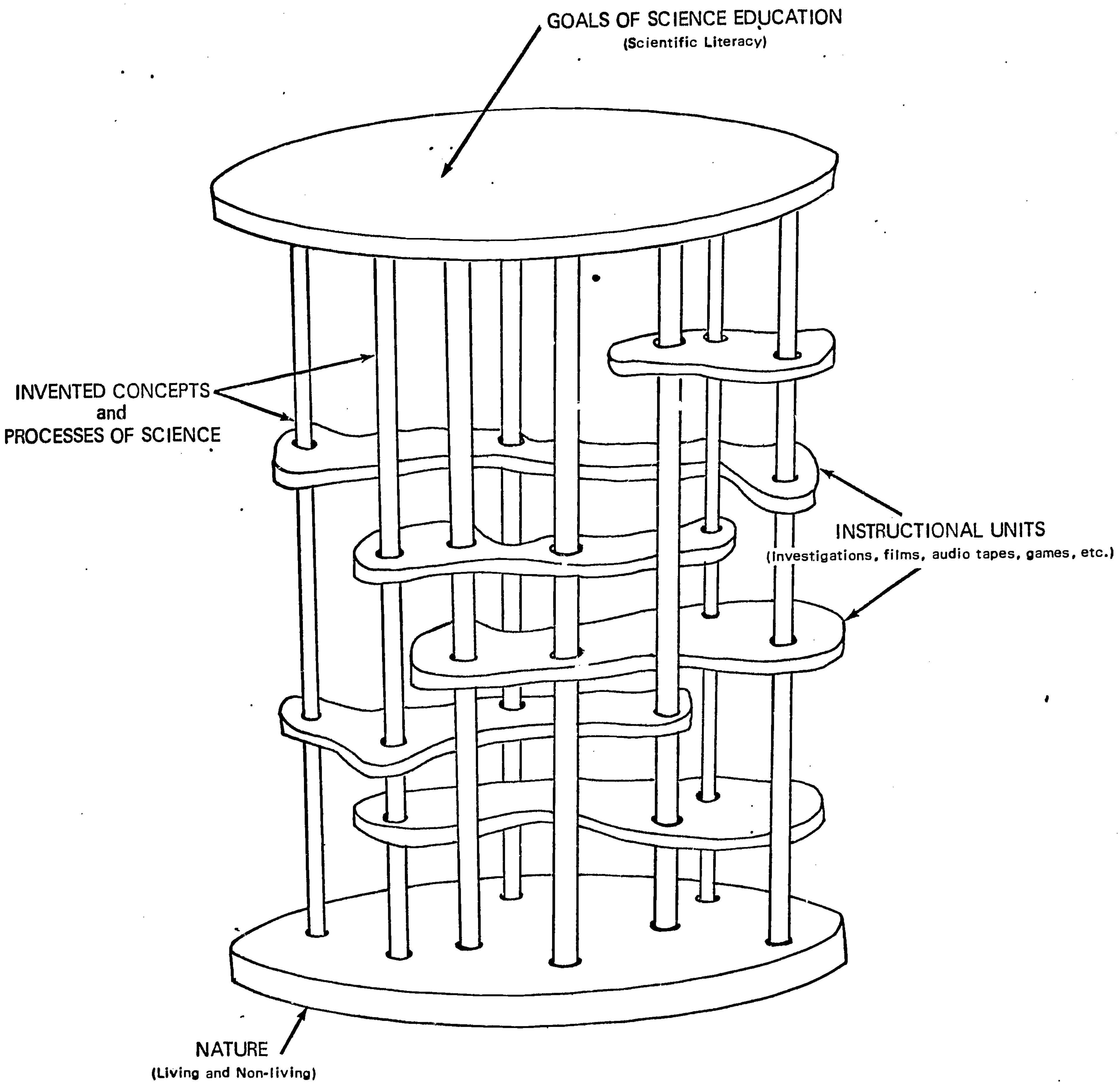
Once a rationale for a unified or interdisciplinary approach to science curriculum has been established, the next logical step is the development of a model that will relate the various elements of an actual curriculum. As a model, it should have all the attributes of a scientific model. Its heuristic value should be of primary importance, although it should represent the relationships among the components of a science curriculum fairly accurately.

The proposed model for a K-12 science curriculum is shown in Figure 1. The physical elements of the model are: base, rods, segments, and crown. Each of these elements corresponds to a component of the science curriculum.

The base of the model represents all natural phenomena that are part of public experience and which, therefore, lend themselves to scientific study. The crown represents the general objectives of science education. The vertical rods represent the "big ideas" or major concepts that permeate all science. These are the vertical threads of continuity for the total curriculum in science. The horizontal segments represent instructional units or modules. The actual number of modules shown in the model is only symbolic. In the actual curriculum, between four to twelve modules would likely be needed for each grade level.

The assembled model shows relationships among the components of the curriculum. A dimension of time and the sequential nature of the curriculum is implicit in the model and should be perceived as progressing from the base upwards.

Most of the elements of the curriculum model have been discussed in previous sections of this paper though not in specific context of the model. The central portion of the model is occupied by the vertical rods or big ideas of science. A tentative list of 25 specific big ideas was presented in Part II. The list should be reviewed and possibly expanded by identifying appropriate big ideas that can be derived from the interrelationships of science and society. Others that are derived from technology might be added appropriately. However, care must be taken that the



Prepared by Dr. Victor M. Showalter, Research Associate ERCA. Labels modified by Dr. Ted F. Andrews. June, 1968.

ideas so identified are of basic value. There is some value in minimizing the number of big ideas that form the core of the curriculum.

It should be noted that the big ideas can represent both concepts, as usually defined, and processes. Frequently a distinction is made between concepts and processes as the former is regarded as being part of the "content" of science.

In recent years there has been a growing feeling that the distinction between process and content should be dropped, especially in the business of curriculum development. "We argue for a conceptualization of process as the life-blood of content and for a point of view which holds that (process and content) cannot be a dichotomy."[28]

As is apparent from the model, the function of the instructional units or modules (segments) in the curriculum is to provide a medium that interrelates two or more big ideas. Depending on the invention and placement of specific instructional units, the same big idea can be related to a variety of other big ideas and can be treated at an increasingly sophisticated intellectual level and through a variety of instructional modes and strategies as one progresses upward through the model.

The instructional units can differ from each other in several ways. The length of instructional units can differ as indicated by the thickness of segments in the model. The combination of specific big ideas that are related in an instructional unit can differ both in kind and number.

There seem to be two major types of instructional units that can be invented. Type I is based on a natural phenomenon or related group of phenomena toward which several disciplines have contributed some measure of understanding. Examples of Type I are titled, "The Sun," "The Ultimate Fate of Solar Energy," "The Rise and Fall of the Phlogiston Theory," "Space Travel," "Pollution," etc.

Type II instructional units are based on the big ideas themselves and, in effect, are expansions of the big ideas. Examples of Type II units are titled, "Equilibrium," "Model," "Quantification," "Theory Building," etc.

In both Type I and Type II units, specific content will need to be selected from that which is appropriate and available. In all the examples cited, more material is available for potential use than could or should possibly be used. Guidelines for selecting specific material to be used should be based on the potential interest for the student, a reasonable prerequisite of intellectual development by the student, adaptability to school facilities, and potential contribution of the unit to achieving instructional objectives.

Goodlad perceived that continuing future ". . .encouragement should be given to projects designed to. . .experiment with materials and techniques that challenge and hold the interests of students with widely varying motives, abilities, and past educational attainment."[29]

Another feature of the model is that it lends itself to continuing curriculum development. Instructional modules can be replaced or, within limits, rearranged. Should one or more of the big ideas become obsolete, it can be removed, replaced, or modified in the light of new knowledge. If new big ideas are identified, they can be added.

In effect, the structure of the proposed instructional materials is modular. Each module should consist of a complete package of instructional materials built around a theme which is based on the big ideas of science. The subject matter of each module should be multidisciplinary by traditional standards.

Each module, or instructional package, should utilize a diversity of instructional modes. Thus, students would be exposed to several kinds of learning experience in each module. Ideally, the instructional materials might provide parallel activities that could correspond to the intellectual styles of different students.

Special emphasis should be placed on the development of student study skills and attitudes that will foster ability to continue learning after leaving school. This means that there should be a sharp decrease in the importance accorded to a textbook. The individual student must learn to use other resources that will be more typical of those available to him after he leaves school.

The instructional modules for any given school year, for any class group (assumed to number 24-30), should be manageable by one teacher. The potential values of team teaching an interdisciplinary science course have <u>not</u> been established clearly. In fact, there is some evidence to favor the one-teacher approach. "One of the discoveries of the past decade is that students make better achievement under one instructor than under a group of specialists each discussing his own specialization."[27]

The modular nature of the proposed curriculum structure will enable it to evolve continually. Changes in the instructional materials and the curriculum can be made in response to:

1 - New knowledge in science that will continue to be gained at a rate at least equal to that of the past decade.
2 - New knowledge in the fields of learning and teaching.
3 - New technological developments.
4 - New perceptions of problems and interests that will arise from the dynamic nature of society.

Several questions for which there are no universal answers at the present need to be answered, at least tentatively, because of the direct implications that they have on the format of the proposed science program. Ideally, these questions eventually need more or less "permanent" answers of the kind that would be forthcoming from formalized research.

1. Is the specific sequence of instructional units crucial to the learnings that they engender? There is a logical compulsion to argue for a best sequence of learning experiences. However, this logic is built on an adult point of view and may be of less real importance than it is currently assigned.

2. What are the relative values of individual instruction as opposed to group instruction? Is one mode of instruction sufficiently superior to obviate the other, or is there some optimum proportion of the two?

3. Are there certain "styles" of teaching that are of optimum effectiveness in science education? Are certain individual students more likely to "resonate" with one style than another? If so, is it feasible to establish a parallel track curriculum based on preferred style rather than past academic achievement?

4. Is personal initiation of inquiry and study as great a motivating factor as recent studies seem to indicate? If so, what ways can be devised to adapt this approach to regular classroom instruction? It may well be that a certain proportion of each school year's work in science should be devoted to the pursuit of a truly individual investigation.

5. What instruments can be devised to measure the attainment of long-range goals of

science instruction? The scope of assessment should go beyond the work of a single year and, ideally, be the basis of continuing evaluation and diagnosis.

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