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ABSTRACT

This guide provides a framework that may be used by local science curriculum developers to produce units of study, each representing a process of science applied to one of the conceptual schemes of science within one of the major categories of science. Examples of variants, (at ten levels of sophistication), of the 18 major concepts which result from applying the conceptual themes "diversity," "change," "continuity," "interaction," "organization," "limitations" to biology, physical sciences, and earth sciences are provided. The major topics within each of the ten levels are structure and function, biochemical reactions, genetics and evolution, ecology, matter, energy, force and the materials, processes and configurations of the earth and the universe. The major concepts and the following science processes are used to define the units of science: observing, classifying, inferring, predicting, measuring, communication, interpreting data, defining, formulating questions and hypothesis, experimenting, and formulating models. The nature of scientific enterprise, including the philosophy of science and the actions of scientists, is considered along with the cultural implications of science in its aesthetic, philosophical, economic, political, and sociological aspects so that curriculum builders can make appropriate choices about the content of their science units. This work was prepared under an ESEA Title III contract. (AL)

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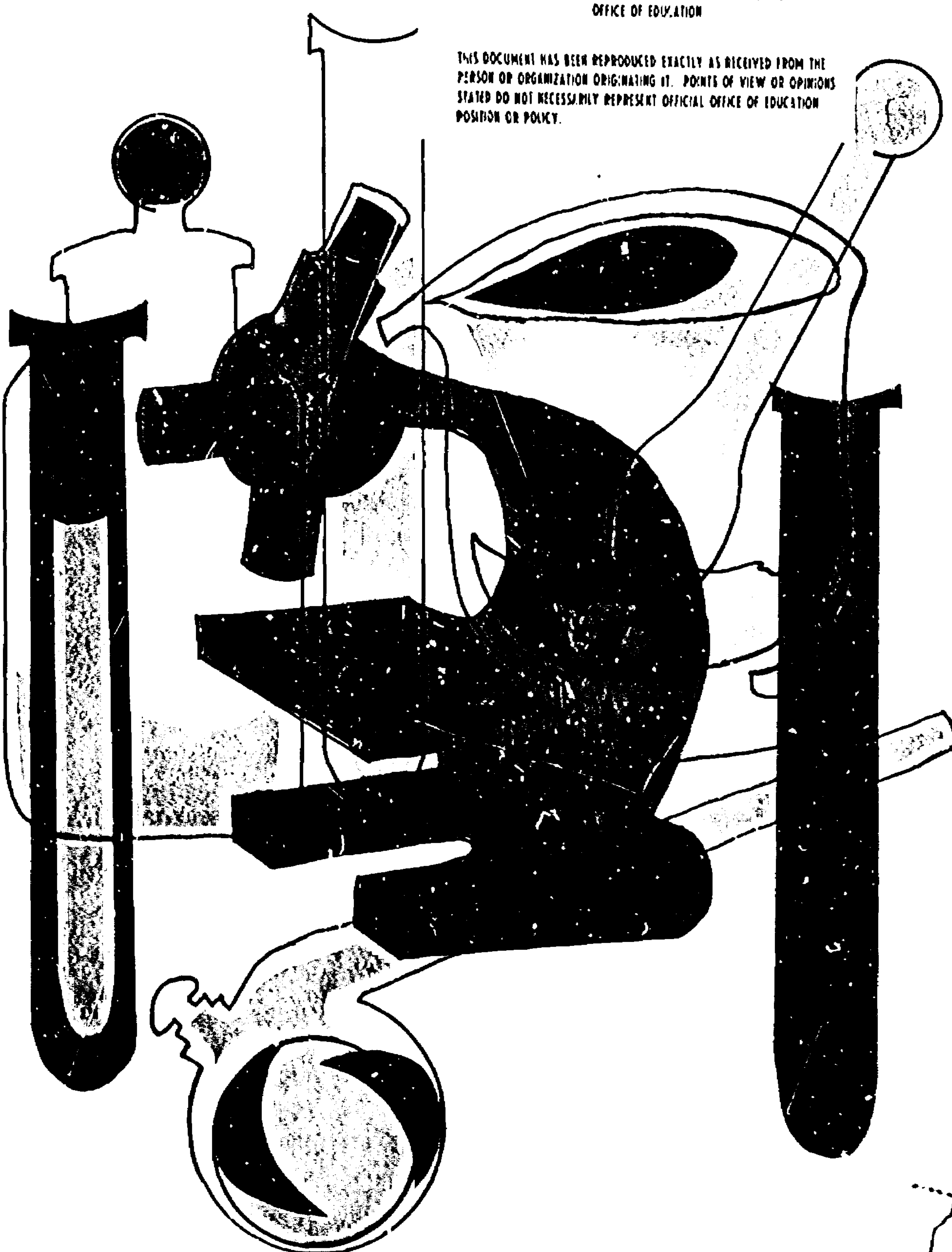
A GUIDE TO SCIENCE CURRICULUM DEVELOPMENT



WISCONSIN DEPARTMENT OF PUBLIC INSTRUCTION / WILLIAM C. KAHL / STATE SUPERINTENDENT

A Guide to Science Curriculum Development

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Wisconsin Department of Public Instruction William C. Kahl, State Superintendent

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Foreword

This Guide to Science Curriculum Development has been prepared to help implement a well-coordinated K-12 science program in Wisconsin schools. It is hoped that the Guide will be useful in determining the nature of the science curriculum at all grade levels.

The project resulted from the work of a committee composed of college science educators, scientists, high school science teachers and elementary teachers. Some of the people on the committees have had experience on writing committees for major curriculum projects. Others have been prominent in research in science education. Many have been instrumental in local curriculum projects and all the committee members have been very much involved in science education at some level.

The committee's efforts were directed toward the production of a framework to help local committees develop a guide to science curriculum. Due to the arbitrary nature of the decisions that were made in constructing this model, it is not intended that everyone who uses it should accept it verbatim. Rather, it is hoped that the Guide will be a beginning point from which local curriculum groups will be able to construct truly coordinated and integrated science programs.

There have been many hours devoted to the development of this Guide. The Department of Public Instruction is deeply grateful to the members of the committee for their efforts.

William C. Kahl
State Superintendent

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Introduction

Historically, science curriculum committees have faced a task that was too great in magnitude to be properly met with the resources that were available to them. This situation was no doubt considered when the development of national science curriculum projects, primarily under the sponsorship of the National Science Foundation, got underway. From the first project to the most recent there has been a developing trend to make the teaching of science a student-centered activity in which the processes of science have importance comparable to the knowledge of science. Although the results of these projects are far superior to those resources offered to curriculum builders in the past, critics still claim that science education does not relate to the lives of individuals and that K-12 coordination is still lacking in the science program.

A well coordinated science curriculum requires the integration of several aspects of science that are not easily interrelated. The technology of science, heavily emphasized early in the 20th century, is still important in the public schools but primarily because of a knowledge of the cultural and social implications of technology rather than a "how it works" kind of knowledge. The philosophy of science and its application to investigation may replace the emphasis upon the so-called scientific method as being important to the students' total understanding and appreciation of science. Science concepts, always emphasized, are still important to the framework around which the study of science may be built. The skills, or processes, of science are of increasing importance in a society where knowledge is developed at a far greater rate than ever before and where the responsibility for future learning rests with the individual.

This **Guide to Science Curriculum Development** has been written as an essential aid to local science curriculum committees. It is intended to provide the framework into which actual classroom units and activities can be organized while still allowing for local option. This framework consists of four major aspects: 1) the conceptual structure, 2) the processes of science, 3) the nature of the scientific enterprise and 4) the cultural implications of science. The *Conceptual Structure* and the *Processes of Science* have been highly organized and interrelated. Although this development is quite arbitrary, it provides the mechanism by which a sequential development of the science curriculum can be produced by local curriculum committees. The *Nature of the Scientific Enterprise* and the *Cultural Implications of Science* can be applied to the formal structure of the other two aspects as the curriculum developer sees fit. These two aspects are an overriding influence in science education which must be emphasized at all times in order to meet the responsibility of relating science to the lives of individuals.

Rationale

. . . for a conceptual structure

The rationale for the development of a conceptual structure may be based largely upon the work of the National Science Teacher's Association Curriculum Committee, which produced the publication entitled "Theory Into Action." Morris H. Shamos, a member of that Committee, stated, "To make science education meaningful to the average man throughout his lifetime it must be based upon ideas which have survival value — not upon trivia." He defined science as a "continued search for first principles." Joseph D. Novak, another member of the NSTA Curriculum Committee, stated, "The task of science education becomes identification of major generalizations or concepts in science and methods of instruction most successful for imparting to students an understanding and appreciation of these concepts or intellectual achievements of science." The recognition of the importance of conceptual schemes led to criticism of the occasional overemphasis on process at the expense of conceptual structure. Novak stated, "There exists today in science curriculum projects an imbalance of opinion weighted heavily toward the pole that it is better to identify good science activities for pupils without confounding the work of any conscious effort to plan these activities with the intent that they may lead to understanding of specific major concepts. This point of view provides no restrictions on the curriculum workers except that the activities should be representative of science, a happy situation indeed." Shamos also criticized an aspect of the curriculum projects: "The so called discovery method which may be effective in guiding youngsters to discover for themselves some of the simpler laws of nature cannot possibly lead them to the major conceptual schemes without prior experience."

Such statements led the writers of **The Guide to Science Curriculum Development** to include a conceptual framework that may be taught parallel to the processes of science in an activity-centered curriculum. In producing this conceptual structure, important concept statements were categorized into six groups. Each group was then described by a single word identifier and a general statement was written to describe the content of each group. These statements became the six conceptual schemes upon which the conceptual structure is based. The six schemes were then related to the three major categories of science — biological, physical and earth science. This two-dimensional relationship resulted in the eighteen major concepts displayed on the first fold-out page in this publication.

. . . for the processes of science

It is easy to justify student activity as the means by which science should be taught. In 1960 Paul DeHart Hurd wrote, "Changing conceptions of the values and purposes of science teaching have tended toward an increasing emphasis upon laboratory work. The nature of the scientific enterprise is found in the methods by which problems are attacked. Therefore, more attention should be directed toward the processes or methods of seeking answers in the laboratory rather than putting so much stress on finding exact answers. More time should be spent by students in developing insight as to how data may be processed and predictions made from them." Joseph J. Schwab, in "The Teaching of Science As Inquiry," made the following statement: "In general, conversion of the laboratory from the dogmatic to the inquiring mood is achieved by making two changes. First, a substantial part of the laboratory work is made to lead rather than lag the classroom phase of science teaching. Second, the merely demonstrative function of the laboratory which serves the purpose of dogmatic curriculum is subordinated to two other functions." He goes on to explain that the two functions of the laboratory are "to provide a tangible experience of . . . the difficulty of acquiring data" and "to provide occasions for and invitations to the conduct of miniature but exemplary programs of inquiry." These and many other statements by qualified individuals establish the importance of an investigative laboratory experience for students as the means of implementing the science curriculum.

The American Association for the Advancement of Science project, "Science — A Process Approach," was an important resource in the development of this Guide. The AAAS project emphasized the sequential development of science-related behaviors as students advance through the elementary science program. The October 1965 issue of the AAAS Commission on Science Education **Newsletter**, described the course: "It is one experimental approach to meet the pressing need for research in science education. This team effort has, during the past three summers, brought together several hundred educators and scientists who have developed and tested materials directed toward introducing children at an early age to the processes of science. The subject matter is science of any content that is useful for the desired emphasis. It may be biology, geology, astronomy, mathematics, physics, chemistry, psychology or any of the other many sub-branches or combinations of these fields. The emphasis is not on the subject matter itself but on the general elements of process which characterizes the scientists' methods of analysis." Although the processes identified by the AAAS project were valuable in identifying the behaviors to be included in this Guide, the project offered no help in relating the processes to the conceptual structure. The fold-out page at the beginning of the second section of this Guide indicates the system by which this coordination between concepts and processes might be accomplished. The arbitrary nature of the decisions that go into developing such a system allows anyone using the system to make specific changes in the system to suit local needs.

. . . for the nature of the scientific enterprise

Inclusion of the nature of the scientific enterprise as a major portion of the science curriculum is based primarily upon the efforts of the Scientific Literacy Research Center at the University of Wisconsin. Research done at that Center has established that scientists view their enterprise in a different way from the lay person. This conclusion was formed from information gathered with a special survey instrument entitled "The Wisconsin Inventory of Science Processes." The items in this inventory include philosophy, assumptions and ethics of science. Information gathered from scientists from many parts of the country has been used to establish the nature of the scientific enterprise as it is presented here. A comparison of the responses of the scientists to the responses of high school graduates indicates that a discrepancy exists between these two groups' understanding of this aspect of science. This discrepancy establishes the need for educating children at all levels in the nature of science if scientific literacy is a worthwhile goal. Hopefully, curriculum builders will keep in mind that the processes carried out by students in their classroom activities differ from those carried out by research scientists, even though these activities may be somewhat related. The *Nature of the Scientific Enterprise* is presented in the Guide in such a way that it should be apparent to curriculum designers that there is no single scientific method, but that many activities can be combined in many ways to product scientific results.

. . . for the cultural implications of science

The relationship of science to society has been of concern to curriculum planners as long as science has been a part of the school program. This concern is growing in a period when science knowledge is being expanded at an increasing rate and when the culture of man is increasingly dependent upon science. Glenn T. Seaborg, Chairman of the United States Energy Commission, said at a meeting in Washington, D.C., in October, 1966, "The view of education not as knowledge but as power is essential to the viability of our democratic government and society. While citizens of a democracy are born free, they are not born wise. In a democracy it is a mission of the schools to make free men wise. The only man who is truly free to choose is the man who knows the choices. This mission — together with the growing importance of science and technology in shaping local, national and world problems — makes it imperative that our schools produce both public-spirited scientists and scientifically educated citizens." This is an example of references describing the need to relate the information and processes of science to the lives of individuals. For this reason, the *Cultural Implications of Science* are given special treatment in this recommendation for organizing the science curriculum.

The *Cultural Implications of Science* are developed around five general statements. These general statements are illustrated by events in the history of science. Quotations from various well-known people are included as direct examples. The narrative discussion is offered to help curriculum designers emphasize these important concepts in their science units. Although these conceptual statements could have been structured as the science concepts were structured, the committee decided against further complicating the framework. However, these ideas should pervade the planning of teaching activities.

The Guide's worth may be measured by its ability to interrelate the identified major aspects of science. This ability depends on the effectiveness of this publication in communicating the importance of coordination. It also depends on the ability of school districts to implement the ideas presented here. The **Guide to Science Curriculum Development** has been written to provide an organization of ideas to local curriculum committees or other groups or individuals responsible for developing actual teaching programs in enough detail to direct the day by day activities of the science teacher. It is intended that the organization presented here may be applied to all levels of the school program. Admittedly, at the upper end of the curriculum there will be definite problems in coordinating instruction of the special science areas. However, even at these upper levels, specialized courses can be organized according to this Guide to coordinate the special senior high school courses and the science instruction that preceded them.

Nature of Curriculum Guides

The usual science curriculum guide contains a description of the subject matter to be taught in the school system during some definite period of time along with suggested teaching-learning activities. In addition, a list of instructional materials, special references and other relevant information of help to teachers is usually included. Such guides are usually concerned with the teaching of science over several years' time in the school program, and ideally they cover the whole span from kindergarten through grade twelve. Almost always the teaching program for given grades is organized into units which are intended to be taught according to detailed suggestions. Each unit guide suggests the content to be studied and one or more ways in which this content may be organized. The desired cognitive, affective and psychomotor learning outcomes are listed along with the suggested activities and evaluative procedures. These curriculum guides usually consist of general statements concerning the overall plan for relating each teacher's work to the total school program. They suggest ways of developing various topics with greater depth and diversity than an individual with limited resources could normally plan.

Those who use the guides seldom find them ready-made teaching plans. Since the peculiarities of individual children, the makeup of classes and the personalities and abilities of teachers cannot be anticipated by the authors of such guides, the development of actual teaching plans is left to the teacher. It is the responsibility of individual teachers to use an accepted guide as intended in order to provide for the necessary coordination between the different levels of the program. The teacher is expected to be resourceful and creative in interpreting the contents of the guide and to constantly evaluate the effectiveness of the guide with possible revisions in mind.

How To Use This Guide

This Guide to Science Curriculum Development should not be confused with the detailed local curriculum guide. It has been prepared on the broadest possible scale in order to provide an interrelated organization of the *Conceptual Structure*, the *Processes of Science*, the *Nature of the Scientific Enterprise* and the *Cultural Implications of Science*. This kind of guide is referred to as a framework because of the broad nature of its organization. It is the responsibility of the local committee to build the details of the curriculum structure. To provide for the best possible program for each school district, curriculum development must continue to rest on responsible local leadership.

Although a detailed description of the intended application of a particular aspect of science to the overall curriculum is included in each of the four major sections of this Guide, an understanding of the curriculum model that was used to develop these ideas is important. The *Conceptual Structure* and the *Processes of Science* have been structured and interrelated in order to provide the necessary organization. The *Conceptual Structure* consists of six conceptual schemes which, when applied to the three major categories of science, are expanded to form the eighteen conceptual statements displayed on the first fold-out page in the Guide. These major concepts have been carefully developed through ten levels of variants or sub-concepts. Each level of variant is, according to the major concepts, made up of eighten sub-concepts. The variants are designed to lead the student through a sequential series of understandings which will eventually approach understanding of the major concept and, finally, the broad conceptual scheme. The *variant levels are in no way to be confused with grade levels* because in an early elementary program the rate at which concepts can be developed in the minds of children is much slower than the rate at which they can be developed in more mature students when increased time is devoted to teaching science. Each level of variants may be represented as one face of a rectangular solid as indicated in the figure on the following page. If the processes of science are applied as a third dimension to the two-dimensional array of conceptual statements, the rectangular solid will result. As can be seen from the figure, each of the small blocks formed will represent a process of science as applied to one of the concepts of science within one of the major categories of science. These blocks represent units of study in the science program.

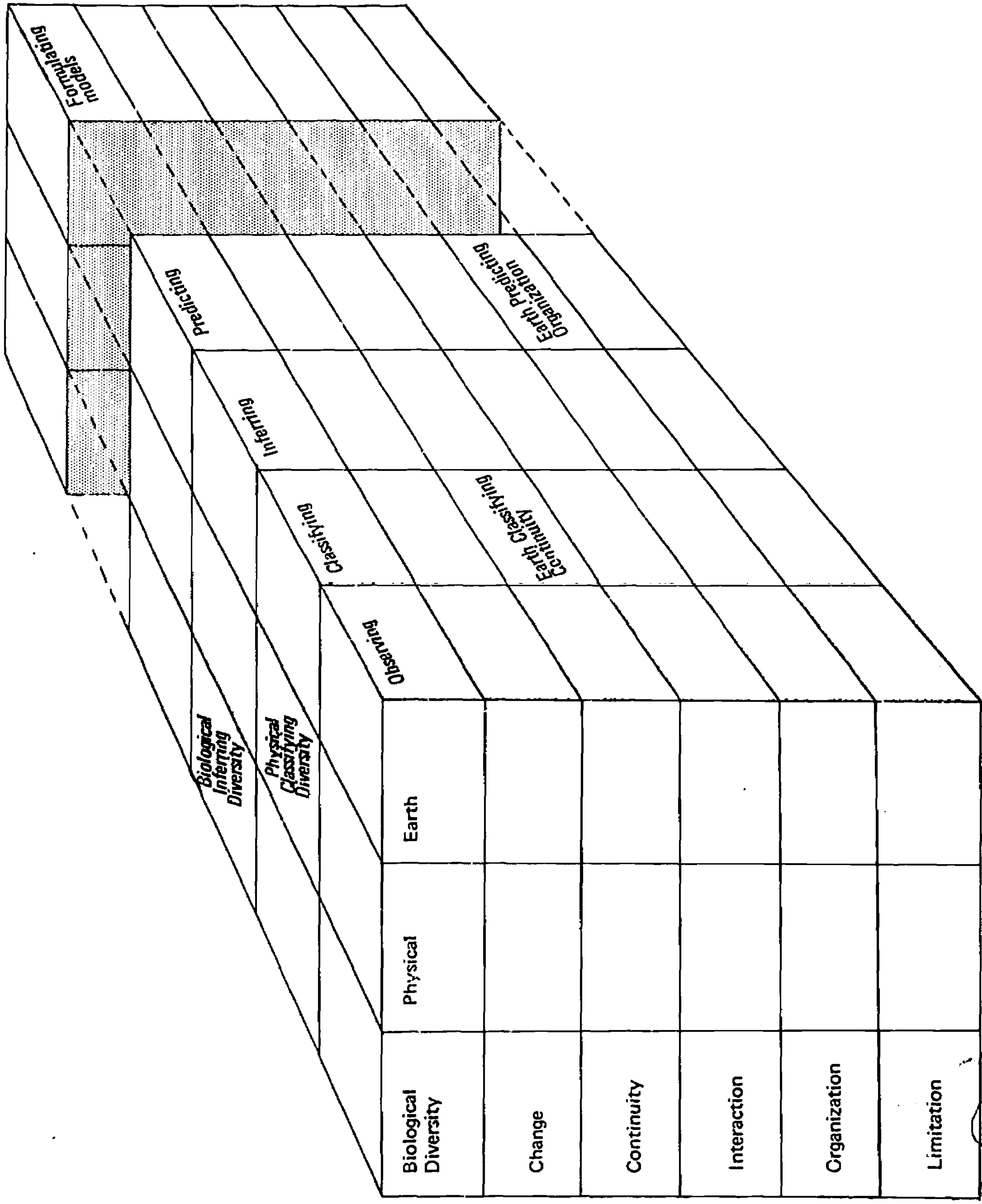
On first consideration this organization seems quite simple. But upon further inspection it is apparent that some of the blocks do not represent an organization of processes and concepts which can be logically developed into teaching units. However, since there are eleven processes which can be applied to eighteen sub-concepts at any of the ten levels, there will be a total of 198 blocks represented in the complete rectangular solid for any one level. It is here that the local committee can decide what actual instructional units will be designed. The local committee must also decide what teaching units will be developed in what grades and how continuity can best be provided from one grade level to the next. In determining the application of the *Processes* to the *Concepts*, the process sequences should be used and the relationship of the processes to the various levels as indicated on the second fold-out page should be considered.

Because this three-dimensional model is already quite complex, no structure of the *Nature of the Scientific Enterprise* or the *Cultural Implications of Science* has been developed. Since these aspects of the science curriculum are conceptual in nature, structures could be provided. However, this would multiply the complexity and make the overall organization less apparent to teachers and students. For this reason the responsibility for appropriately including these important concepts in the blocks of the rectangular solid is left with the local curriculum committee. These ideas should not be underemphasized — they are very important to the overall objectives of science education. Here more than anywhere else, difficulty may occur in attempting to effectively implement the science curriculum.

In curriculum development at the local level, a variety of questions must be answered before the final form of the curriculum can be determined. These questions should be carefully listed and answered before proceeding with the details of the curriculum structure. The following are examples of questions which may be considered:

- What are the resources in personnel, time, money, equipment and facilities which may be allocated to the development and implementation of a new science curriculum?
- Should science be taught as a specialized series of courses or should it be integrated into one continuous program?
- Should science be taught in the elementary school by specially trained teachers or should it be taught only in the self-contained classroom?
- Is the K-12 coordinated science curriculum of enough importance to warrant re-training teachers and re-equipping the schools?
- How much emphasis can logically be put upon science at the various levels in the school program?
- Can a commitment be made to continue working on the curriculum until it is implemented and can a further commitment be made to continually work at revising the curriculum?
- What is the relevance of science education to children, teachers, administrators and parents in the local school district?
- How can balance be provided between the four major aspects of the science curriculum?
- How can provision be made for coordinating the science curriculum from the elementary program to the junior high school program to the senior high school program?

These and many more questions are important to decision making, a major part of curriculum development. If such questions go unanswered, a committee's attempts will be stalled. However, once the questions are answered and a priority for activities established, work may begin and continue over as long a period as necessary to gradually and efficiently bring about the kind of science teaching program desired for many years by science educators.


Formulating models
Predicting
Inferring
Classifying
Observing
Earth Predicting Organization
Earth Classifying Continuity
Biological Inferring Diversity
Physical Classifying Diversity
Earth
Physical
Biological Diversity
Change
Continuity
Interaction
Organization
Limitation

Use of This Guide by Individuals

The curriculum recommendations offered in this Guide may have value to individuals not directly involved in curriculum development. Since many teachers at both the elementary and secondary levels are in districts that do not have a well-developed science curriculum, individual teachers may find this curriculum model helpful in evaluating their science teaching. The individual might carry out the following kinds of activities related to the Guide

- *Use the Guide to evaluate his own understanding of science.*
- Use the Guide to determine whether or not he is presenting a well-balanced teaching program in terms of the four major aspects of science
- Use the Guide as a framework for planning and organizing his own teaching units within his area of responsibility in the science curriculum
- Use the Guide to evaluate his own teaching methods related to student-centered activities
- Use the process sequences of the Guide to establish behavioral objectives for laboratory activities
- Use the Guide to develop tests for evaluating achievement in the major aspects of science
- Use the Guide to evaluate appropriateness and effectiveness of teaching materials presently being used or being considered for use
- Use the Guide to devise means of individualizing instruction
- Use the Guide as a means of influencing other teachers to work toward a coordinated science program

Although these and other activities can be carried out by individual teachers making use of the Guide, it is not recommended that individuals attempt to bring about curriculum change by themselves. Hopefully, this Guide will influence teachers on a district-wide basis to consider the problems they face in science education and to work cooperatively in solving them.

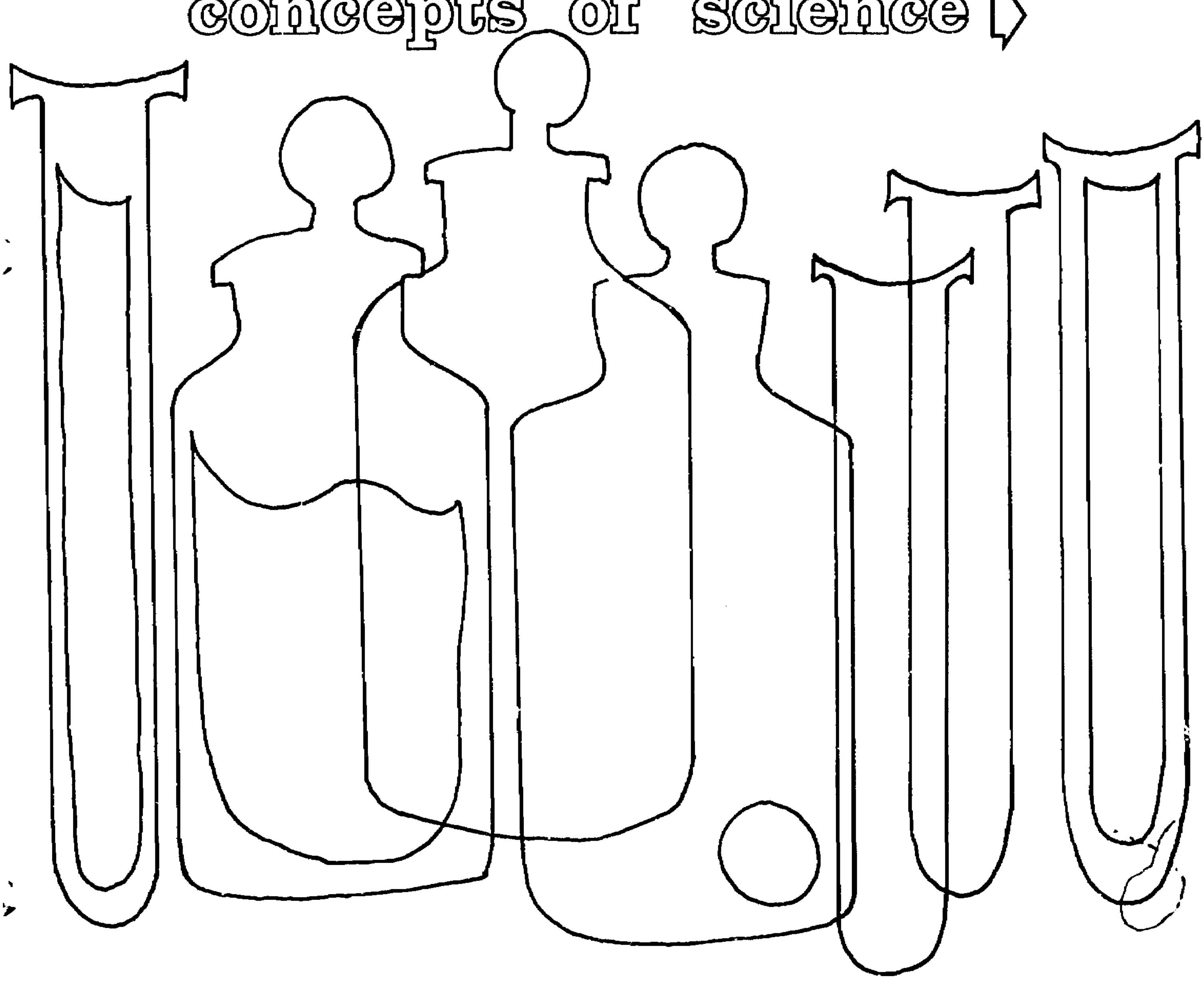
Preservice and Inservice Education

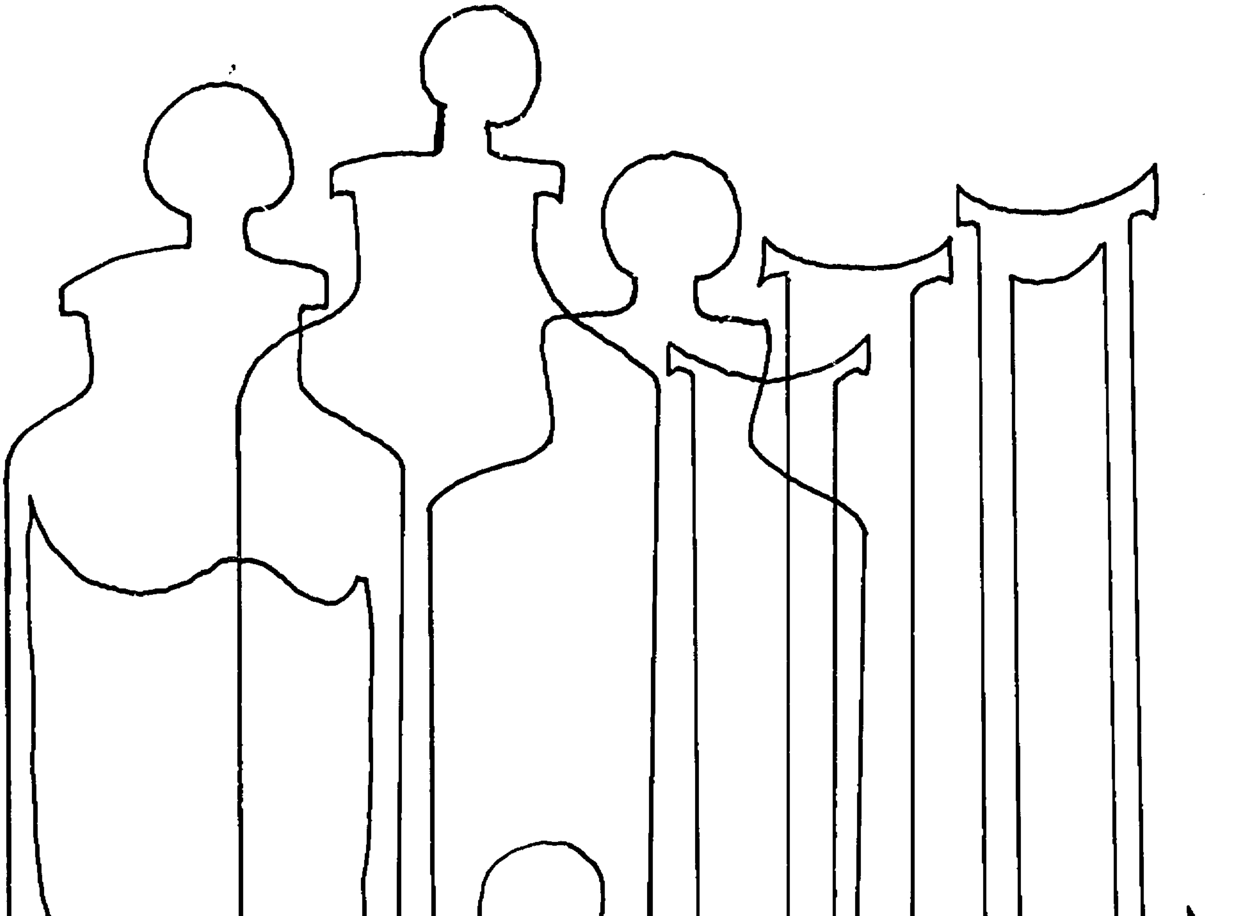
Because this Guide does not necessarily follow the kind of science teaching program in existence in many school districts, there may be a discrepancy between the knowledge and ability of teachers presently working in the field and those needed in the future to implement this kind of curriculum model. To help solve this problem, the **Guide to Science Curriculum Development** can be used in preparing activities for the preservice and inservice education of science teachers. Activities such as the following might be used in such programs:

- Survey the Guide in order to establish the nature of the curriculum model which is presented
- Define and clarify the meaning of science in the school program and establish objectives for teaching science
- Evaluate conceptual schemes as a means for providing vertical organization in a science curriculum; in particular, evaluate the six conceptual schemes presented in the Guide
- Relate the processes of science, as they are presented, to actual teaching methods.
- Develop strategies for arriving at concepts through application of the processes
- Work with teachers to help them evaluate their own understanding of the conceptual schemes and related concepts
- Provide opportunities for teachers to develop their own process skills by actually doing laboratory activities related to the Guide
- Evaluate teachers' understanding of the nature of the scientific enterprise and provide instruction where improvement is needed
- Establish the importance of the cultural implications of science to the actual process of teaching science
- Use the curriculum model as presented in the Guide to develop prototype units involving the four major aspects
- Develop a series of units in which a major concept is developed through several levels
- Develop units which provide for the investigation of the major categories of science

Efforts in preservice and inservice education should be related to the best current practices in education. Teachers must have knowledge of the nature of the learner at different age levels and be able to apply this knowledge to the teaching process. Overall, the teacher must be made aware of his correct role in the classroom and in the total school program. He must also realize the student's role as an active participant in all activities if effective learning is to be accomplished.

concepts of science





Major Concepts

	Biological	Physical	Earth
Diversity	Living things live in a diversity of forms and environments. Various structural, functional and behavioral patterns have been identified.	Matter and energy exist in many forms and combinations which exhibit a variety of properties. All forms of matter have some properties in common.	The earth and other bodies of the universe exhibit a variety of form, composition and organization of matter and energy.
Change	Organisms change through time. New species arise and others become extinct through interaction of genetic and environmental factors. As a result of these changes, organisms may be adapted to their environments.	Changes in the organization of matter are accompanied by energy changes. Such changes result from the application of forces.	The earth, planets, stars and other bodies of the universe change continuously within themselves and in their relationships with other bodies.
Continuity	The characteristics of living things are transmitted from generation to generation through a "genetic code" by either the fusion of specific cells or the division of cells.	The physical quantities used to describe matter and energy and their relationships exhibit constancy. These quantities may be used in understanding and predicting natural processes.	Evidence of change in the universe and observation of the present characteristics of the universe may be used in interpreting its past and predicting its future.
Interaction	Living things and the parts of living things interact with their environments. The environment consists of both living and nonliving matter and may be external or internal to the organism.	The interactions of matter result in electro-magnetic, gravitational and nuclear forces. Energy may be transmitted through the application of these forces.	There are interactions between the bodies in the universe and their structural units which produce exchanges and interchanges of matter and energy.
Organization	Complementarity exists between the structure and the function of an organism or its parts — molecules, cells, tissues and organs.	Matter exists as units which may be classified into hierarchies of organizational levels.	The earth is part of a universe which is organized into a complex of dynamic matter - energy systems.
Limitation	The behavior of an organism is limited by the environmental conditions it requires and by its particular heredity. Interactions within the biosphere are limited by the energy available.	The general and special properties of matter limit its interactions. In matter - energy changes there is a tendency toward equilibrium with random distribution of energy.	The nature of the earth and the universe is consistent with the nature of matter and energy. Progressive changes in the bodies of the universe reflect the tendency toward equilibrium.

Concepts of Science

Science is an activity which has as its goal the formulation and understanding of a complete model of the universe. This goal will probably never be reached, but as long as the activity continues the existing model will continue to be expanded and refined to include new observations. It will no doubt grow in sophistication, but probably not in complexity, since simplicity is one of the criteria accepted by scientists in their efforts to describe a systematic universe.

Attempting to understand interrelationships in one's environment is a primary activity of the human mind. Therefore, the conceptual model of the universe as developed by scientists has a certain importance for all students regardless of their motivations and regardless of the limitations placed upon their view of the universe.

Actually, it is not justifiable to say that scientists have developed a recognizable model of the universe. No one person, or group of people, has been able to take all of the concepts which have reasonable credibility and fit them into a single conceptual structure which is completely satisfactory to everyone. Since knowledge of the nature of the universe is developed a little at a time with no way of identifying a special niche for each new concept, it becomes the task of the science student to fit accepted concepts into the conceptual structure that is most satisfactory to him. This does not mean that the conceptual model is completely arbitrary; it does mean that equally valid attempts to describe the conceptual structure of science might be quite different.

In order to provide science curriculum writers with a framework within which science learning experiences can be developed, a structure of science concepts has been produced. This structure should be regarded as being versatile enough to permit change to meet special requirements without losing its overall organization.

The organization of the framework is based upon six *major conceptual schemes*. For purposes of simplification and easy reference, each of these schemes has been assigned a one word identifier which will be used in referring to the total idea.

Diversity — The vast number of natural phenomena whch can be observed display a wide variety of similarities and differences.

Change — Our environment, living and nonliving, microscopic and macroscopic, is constantly undergoing change.

Continuity — There is constancy in cause-and-effect relationships which precludes any abrupt reversal in natural phenomena

Interaction — The interactions of matter in an environment and the resulting exchange of energy determine the nature of the environment.

Organization — Systematic relationships exist in natural phenomena. Systems within systems comprise the universe.

Limitation — Natural phenomena are limited by the fundamental nature of matter and energy. There is an overall tendency toward random distribution of energy and a corresponding tendency toward equilibrium in an environment.

Because of the traditional breakdown of science into special categories, the six *major conceptual schemes* have been stated in terms of *biological science, physical science* and *earth science.* The resulting eighteen *major concepts* are displayed on the fold-out page. These statements will have primary importance to those who will use this structure to develop teaching units. *All of the concept variants on the following pages are intended to lead to the development of the major concepts* which in turn will contribute to the *major conceptual schemes.* It is important in the utilization of this framework that this relationship of ideas be kept in mind at all times.

Those who are interested in making content comparisons with other science curriculum materials will find an emphasis on certain important topics. In biological science special attention is given to *structure and function, biochemical reactions, genetics and evolution* and *ecology.* In physical science *matter, energy* and *force* are major topics. Earth science is structured around the *earth* and the *universe* and emphasizes *materials, processes* and *configuration.* Throughout all three science areas there is indirect and direct reference to the *particle nature of matter.*

The ten levels for which the variants are expressed are an attempt to provide examples of the major concepts at different levels of sophistication. The number ten is arbitrary. *These levels are not to be compared to grades or years.* In presenting the processes of science "Level O" is added to indicate that this aspect of science education can logically begin in the elementary grades before an emphasis is placed upon concept development. It is entirely possible that one concept level may provide the content for two grades as they are usually recognized. It is equally possible that in grades where more time is devoted to science, a single grade or year might be devoted to more than one concept level. Local decisions must determine how extensively science will be pursued at a given grade level.

LEVEL I
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	Living things are either plant or animal. They differ in structure, in function and in habitat.	Matter is described in terms of its properties, which can be detected with the senses. Through comparison of these properties, similarities and differences in matter can be discovered.	There is variety in the natural materials of the earth. There are identifiable similarities and differences in these materials.
Change	The appearance and activities of living things vary with the seasons.	Changes in the speed or direction of motion of matter result only from the application of forces.	Wind and water are agents of change which act on the earth's surface.
Continuity	Living things reproduce their own kind.	Matter can be changed in position, motion, shape and other conditions and still retain its identity. Such changes do not change the quantity of matter.	Events on earth often occur with dependable regularity. Day and night and the seasons occur now as they have for centuries.
Interaction	Green plants use energy from the sun, water and air from their surroundings to produce food. Animals get food from plants or from other animals.	Force is the result of the interaction of matter. Force is only detected by the effects it has on matter.	Without energy from the sun, the earth would become a cold, dark, lifeless body.
Organization	Like or similar living things tend to live in similar surroundings.	Most observable substances exist as aggregates of different forms and kinds of matter.	The earth's surface is made up of the atmosphere, the seas and the solid land. The atmosphere has no definite outer boundary.
Limitation	The ability of living things to adapt to changes in their environment is very limited.	The position and motion of matter on earth are always affected by the force due to gravitation.	The earth and other observable bodies in the universe are approximately spherical.

LEVEL II
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	Living things are interrelated with the living and non-living factors in their environment. Each has specific environmental requirements in which it survives best.	When energy is added to or taken from matter, some of the properties of the matter are changed. Energy can be detected by the senses only as a result of changes in matter.	There are differences and similarities in the form and composition of the earth, moon and sun.
Change	As living things grow and age they change in form and activity. Some also change in habitat.	Whenever a force acts on an object to change its position or motion, energy is exchanged.	The earth, moon and sun are continuously changing position with respect to each other. No one of these three bodies can be considered to be at rest with respect to the other two.
Continuity	Living things exhibit behaviors which are hereditary.	Energy is related to matter in many ways. The total amount of energy remains unchanged in changing from one relationship to another.	The motion of the earth and moon are predictable. The relative positions of the earth, moon and sun may be determined for any future time.
Interaction	Similar physical environments result in similar biological communities.	Many forces may act upon an object at the same time. However, all of the forces combine to produce only one effect as though only one force were acting.	Observation of apparent relative motions of other bodies may be used to interpret the motions of the earth.
Organization	The processes by which plants and animals live can often be inferred from observing their external structures.	The properties of a material depend on the properties and organization of the constituent parts of the material.	The earth's crust is composed of a few basic materials organized in many ways.
Limitation	Oxygen and water are essential to most known forms of life.	An object moving through its environment tends to give up energy to its surroundings until it comes to rest.	The bodies of the solar system have nearly constant motion.

LEVEL III
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	Living things are specially adapted to their environment. There are varying degrees of specialization of structures for particular functions.	Matter may be classified according to exhibited properties under a given set of conditions.	Geologic features with similar forms and composition are assumed to have similar histories.
Change	When physical environments change, those species which can no longer fulfill their needs become extinct in that environment.	When the forces applied to matter are changed, some of the properties of the matter may be changed.	Major changes in the earth's crust usually occur over long periods of time, but occasional violent changes occur in short time intervals.
Continuity	The process of reproduction is primary among the processes in which all living things are involved.	There are general properties which describe all matter. There are other special properties which identify kinds of matter. The same kinds of matter are found throughout time and space.	Natural changes in the composition and structure of the materials of the earth occur very slowly.
Interaction	Organisms are found living together in relationships which are mutually beneficial, mutually detrimental or beneficial to one at the expense of the other.	Forces result from apparent direct contact of matter or from interaction of matter through a distance. Forces have magnitude and direction.	The structure of the materials of the earth are determined by the conditions under which the materials exist. Structure changes as conditions change.
Organization	Living things exist within ecosystems in which each is adapted to its living and non-living environs.	Many forms of solid matter have a crystaline structure. The shape of a crystal is characteristic of the matter of which it is composed.	The varied distribution of the natural materials of the earth determines the characteristics of the earth's surface.
Limitation	The activities of living things are directed toward a very few basic life processes.	Special properties of matter are limited by the conditions to which matter is subjected.	The properties of earth materials are determined by the nature of the materials and the conditions under which the materials are formed.

LEVEL IV
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	Many systems could be developed for classifying plants and animals. A system based upon structure and function is the accepted classificational system.	Energy added to matter may cause a temperature increase. The increase for a given amount of energy is dependent upon the amount and kind of matter.	Climate depends upon latitude and topographic features.
Change	Living things have changed in form, appearance and complexity over time. New characteristics are due to genetic accidents.	Changes in the motion of particles within a body of matter are indicated by temperature changes. The temperature of matter can change if energy is exchanged between matter and its environment.	The short term cyclic changes on the earth are primarily due to changes in the relative positions of the earth, moon and sun.
Continuity	Cells, the living units in all life forms, contain the genetic substance that carries inherited traits from one generation to the next.	Energy tends to move from a region of higher temperature to a region of lower temperature.	The fossil record provides clues to the sequence of events in the geologic history of the earth.
Interaction	Biological communities tend toward a balanced condition. This balance can be shifted by the introduction of new species, the disappearance of old species or a change in the non-living environment.	Matter attracts matter. When only two objects are involved, the force of attraction acts with equal magnitude on both objects along a line between their centers.	The topography of the earth's crust is the result of the interaction of the atmosphere, the hydrosphere and the lithosphere.
Organization	The parts of plants and animals are dependent on other parts and can neither function nor exist alone.	Matter may be described in terms of particles and energy.	The earth and other planets move around the sun. The moon moves around the earth.
Limitation	The activity of any organism is limited by its inherited characteristics.	An object placed in a new environment will exchange heat until it reaches the point where it is gaining energy at the same rate that it is losing energy. At this point its temperature will be the same as its surroundings.	The hydrologic cycle results in a never ending erosion of the earth's surface.

LEVEL V
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	There are many ways in which plants and animals reproduce their own kind. All of these reproductive processes may be classified as either sexual or asexual.	Most matter may be classified as solid, liquid or gas. Some forms do not clearly fit any of these categories.	Form and composition are indications of the environment in which minerals were formed. Under different conditions the same materials may form different minerals.
Change	If a new inheritable characteristic appears which has adaptive value, the chances of survival of the species improves.	In a change of phase energy is gained or lost by matter without a corresponding change in temperature.	Gravity, energy from the sun and diastrophism are primary factors causing the earth's surface to change.
Continuity	Reproduction may occur by a variety of asexual means. When reproduction is asexual, the offspring resembles the parent very closely.	In a simple change of phase there is no change in the amount of matter present.	Composition, structure, orientation and relationships between strata of rocks can be used to interpret the earth's history.
Interaction	Competition for dominance in a biological community results in a climax community which succeeds all others and is most stable.	The amount of matter in any given unit can be determined by measuring the force of attraction between that unit and the earth.	The atmosphere is always moving. Gains and losses in heat cause local vertical movement. Rotation of the earth causes massive horizontal movement.
Organization	Organisms may vary from simple to complex. Complexity is a matter of degree of specialization and interrelation of the parts of the organism.	The phase in which matter exists depends upon the structure of the matter and the energy of the individual particles.	The earth and other planets move in the same direction around the sun in roughly the same plane.
Limitation	The physical environment limits the life forms which can exist within it.	The phase of a given material is determined by the temperature and pressure of its surroundings. In a given environment a material can have only one stable phase.	The period of revolution of the planets varies directly with their distance from the sun

LEVEL VI
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	All plants may be put into two subdivisions: those which have flowers and those which do not. All animals may be put into two subdivisions: those which have dorsal spinal cords and those which do not. These subdivisions are convenient but arbitrary.	Although energy appears in many forms, it must always exist as energy due to the position of matter in a force field, as energy due to motion of matter or as radiant energy.	The atmosphere, lithosphere and hydrosphere have no exact boundaries. The properties of matter within these categories vary widely.
Change	Evolution is the result of chance changes in the inherited characteristics of an individual of a species which makes the individual better able to adapt to a changing environment than was the parent or its predecessor.	Changes in the position and motion of particles of all sizes which bring about different relationships between particles without changing the composition of matter are called physical changes.	Many earth changes are repeated periodically in cycles. Other changes occur without regularity and are often irreversible.
Continuity	Sexual reproduction requires the union of two special cells called gametes. Usually the gametes are produced by separate parents.	When radiant energy is absorbed by matter or when energy radiates from matter, the amount of energy before and after the change is the same.	The events of the ice ages have been inferred from geological features produced at that time which are the same as features being produced by glaciers in the present era.
Interaction	The internal organs of complex plants and animals have specific functions. The functioning of each organ affects and is affected by the functioning of other organs.	Force is necessary to change either the speed or direction of a moving object.	At high latitudes, the amount of energy available is the primary factor in determining climate. At mid-latitude, the amount of water available is the primary factor in determining climate.
Organization	Survival of living organisms is dependent upon the complementary functioning of their organs.	Gases, liquids and most solids appear to be continuous, but the nature of interactions of matter indicates that all matter consists of discrete particles.	Energy and matter tend to be concentrated in the same spaces in the universe.
Limitation	Growth, activity and even survival of living things are limited by the availability of energy.	The rate at which energy can be exchanged between a given mass and its environment is limited by the special properties of the mass.	The earth receives energy from space at nearly the same rate that it loses energy to space.

LEVEL VII
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	In spite of the great variation in living things, all plants and animals carry out the processes of respiration, excretion and reproduction.	Elements are the simplest forms of matter. Elements can be combined into more complex forms of matter which can again be broken down into the same basic elements.	The same chemical elements found on earth are found in varying proportion throughout the universe.
Change	All forms of life show characteristics which are common to other forms. This evidence indicates that large groups of life forms have common ancestral backgrounds.	Changes which take place between particles within molecules or within crystals of matter are called chemical changes. Chemical changes always involve energy exchange.	The sun is constantly undergoing violent changes which affect the earth and other planets. Some of these changes are periodic.
Continuity	Characteristic traits are inherited by offspring from the parent generation in definite predictable patterns.	In chemical changes matter and energy are conserved. In addition, the number of atoms of each element involved remains the same.	Evidence indicates that although the earth's magnetic and gravitational fields have fluctuated, they have always been present.
Interaction	In sexual reproduction the genetic characteristics of one parent may dominate those of the other.	Electrostatic and magnetic forces, like gravitational force, act as force fields. Unlike gravitational force, these forces can repel as well as attract.	The earth and moon move together as a balanced mechanical system. This same kind of system in more or less complex relationships accounts for motion throughout the universe.
Organization	Molecules, cells and tissues are constantly replaced in living things without changing the characteristics of the organisms.	The organization of the particles within atoms, molecules and crystals determines the special properties of matter.	The solar system is made up of the sun, the planets, satellites and other bodies moving with periodic motion in a balanced system.
Limitation	Simple behavior is the result of the ability of organs to function or not function under a given set of conditions.	Spontaneous chemical reactions release energy into the environment. Such reactions can only be reversed by application of an external supply of energy.	The limitations on the interactions of matter and energy which apply on earth also are assumed to apply throughout the universe.

LEVEL VIII
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	Plants and animals which differ greatly in external appearance and behavior may have similar structure and functions of their internal organs.	All matter has electrical properties. The distribution of charges and the ability to conduct charge are important special properties of matter.	Although the motions of the bodies of the universe are varied, they are usually systematic and predictable.
Change	The direction of evolutionary change is influenced by the physical as well as the biological environment. The nature of the environment and the changes within it act to select the individual which will survive.	Aggregates of matter are usually electrically neutral. In order to cause an electrical imbalance, electrical forces must be applied and energy absorbed.	The distribution of matter and energy on earth as well as in the entire universe is constantly changing.
Continuity	Paired chromosomes in normal cells have corresponding genes which determine inherited characteristics. One or more pairs of genes which occur in each cell determine each trait of the organism.	In all energy-matter interactions the total amount of electrical charge is conserved.	The general motions of the solar system and many of the characteristics of the planets have remained unchanged since the origin of the solar system.
Interaction	In a multicellular organism there is interaction between the cells which is mutually beneficial to the cells and to the entire organism.	Chemical changes are the result of electrostatic forces acting upon the electrically charged particles within atoms and molecules. Energy is exchanged when particles move due to these forces.	The solar system is characterized by systematic and interrelated motions. Any interruption of this system would be followed by readjustment to bring about a new balance.
Organization	Specialized cells in living things are modified to perform special functions.	Matter is composed of particles with uniform electrical charges. Externally the forces due to these charges are not usually noticed, but internally these forces determine the structure of matter.	The mechanics of the solar system may be explained by mathematical quantities.
Limitation	Carbohydrates produced by photosynthesis in green plants are directly or indirectly the source of energy for all living things.	Electrica charges can only move from one point to another when the difference of potential between the points is adequate to overcome the resistance. In this change the charges lose energy to their surroundings.	All bodies in the universe react to gravitational attraction. The nature of gravitational fields determines paths of objects moving within them.

LEVEL IX
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	All of the cells of an individual organism have the same basic components. Cells may also have special structures which are adapted to the functions which the cell performs.	The effects caused by radiant energy are dependent upon wave length.	All stars have some common features, but differ in mass, volume, luminosity, stability and other features.
Change	When an individual develops characteristics which differ from its parent generation, the change is due to a difference in the chemical composition of the genetic substance of the cells.	The wave length of radiant energy can be changed by changing the density of the medium through which the energy passes. The frequency of radiant energy can only be changed if it is absorbed by matter and re-radiated.	The energy emitted by the sun, as well as by other stars, is a product of nuclear changes which are taking place.
Continuity	Probability can be used to predict patterns of heredity.	Momentum, which depends upon both mass and velocity, is conserved in any physical interaction of matter.	The energy output of the sun is continuous with only minor variation in intensity.
Interaction	Chemical activity within a cell is affected by the internal and external environment of the cell.	A given mass can only lose or gain momentum by interacting with other masses.	Evidence indicates that gravity and radiation pressure act together to cause interstellar matter to condense into star systems.
Organization	Chemical reactions in living things are controlled by enzymes produced in specific cells or tissues.	The organization of electrically charged particles in any kind of matter determines the ability of that matter to emit and absorb radiant energy.	The Milky Way Galaxy is a complex of interrelated star systems in varying stages of stellar evolution.
Limitation	All cells in an organism have the same inheritance factors. Specialization is due to chemical limiting of some of these factors.	The velocity of radiant energy in a vacuum is the upper limit of relativistic velocity in the physical universe.	The luminosity and color of a star are dependent upon its temperature.

LEVEL X
CONCEPT VARIANTS

	Biological	Physical	Earth
Diversity	Differences in the internal and external characteristics of plants and animals are recorded in the chemical composition of the genetic material of cells. This unique composition is passed on to offspring in reproduction.	Most of the physical characteristics of matter can be explained in terms of forces of attraction and repulsion acting upon basic particles and in terms of energy per particle.	The galaxies of the universe exhibit a variety of forms, compositions and organizations.
Change	Characteristic changes during the life cycle of an organism are due to changes in the production of enzymes within the specialized cells of the organism.	Most naturally occurring changes involve so many cause and effect relationships that they can only be predicted on a statistical basis.	Stars and galaxies evolve through a series of stages which are irreversible.
Continuity	A homeostatic state exists within the systems and sub-systems of any successful organism.	In nuclear interactions changes may occur in which the amount of energy or matter may vary, but the sum of both remains the same. In such nuclear reactions the number of nucleons remains unchanged.	Although the exact nature of the universe cannot be determined, present evidence indicates that the universe is systematic.
Interaction	The characteristics of an organism are determined by a complex system of chemical checks and balances within specialized cells.	Gravitational, electrostatic, magnetic and nuclear forces are due to interaction of matter within fields of influence which exist around masses, electric charges, magnetic poles or nucleons.	The observation that all galaxies are moving away from the Milky Way at velocities proportional to their distances from it indicates that all galaxies in the universe may be interrelated.
Organization	The synthesis of protein material in living tissue is controlled by chemical compounds which dictate the amino acid patterns which can occur.	Under certain conditions matter and energy will exhibit both particle and wave characteristics.	Matter in the universe exists in a hierarchy of organizational systems from atoms to galaxies.
Limitation	Behavior is limited by environmental conditioning.	The larger nuclei tend to be unstable and therefore radioactive. Natural radioactivity limits the maximum size of the nuclei and therefore limits the number of naturally occurring elements.	Observations of the universe are limited by the distances separating stars and galaxies and by the maximum relativistic velocity.

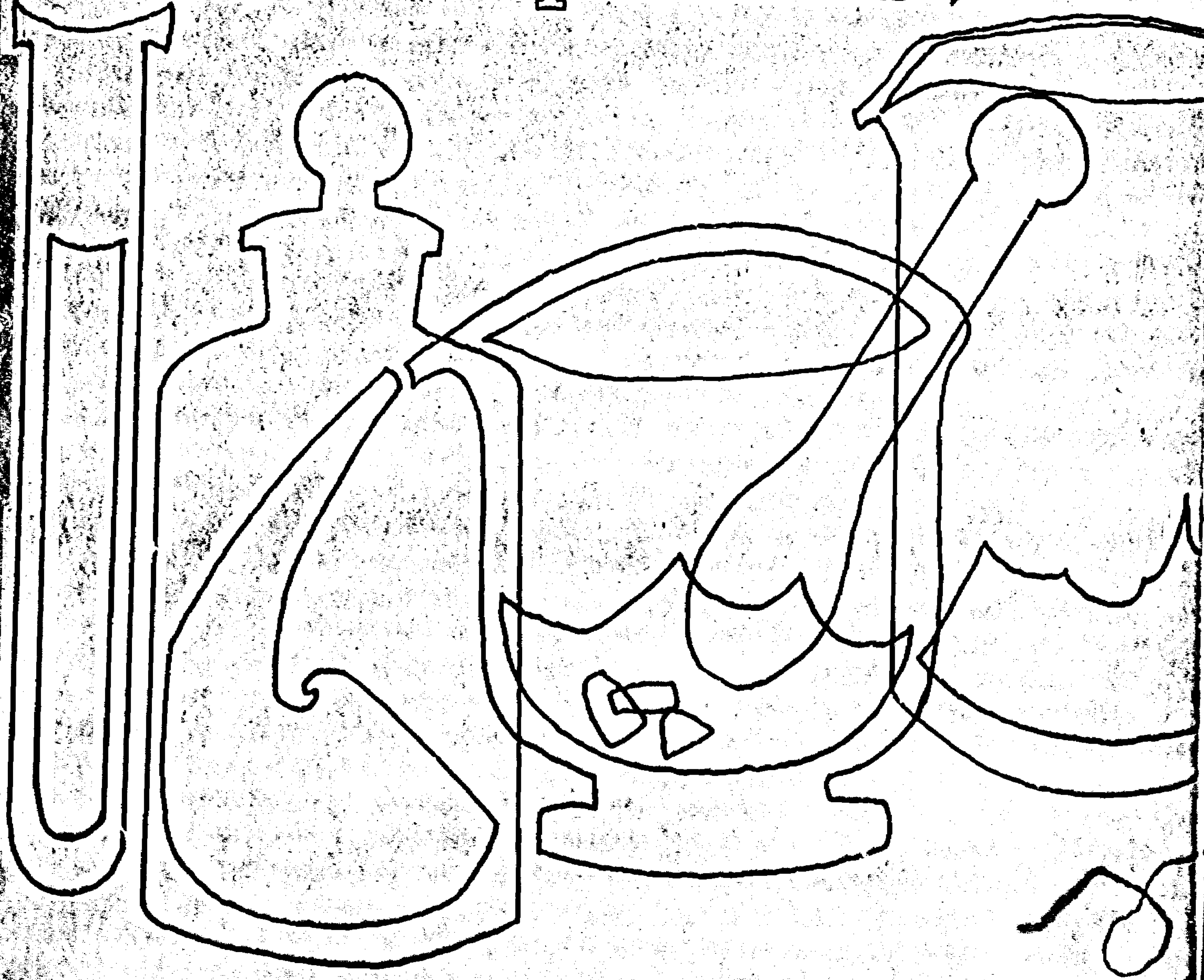
Concept Learning in Science

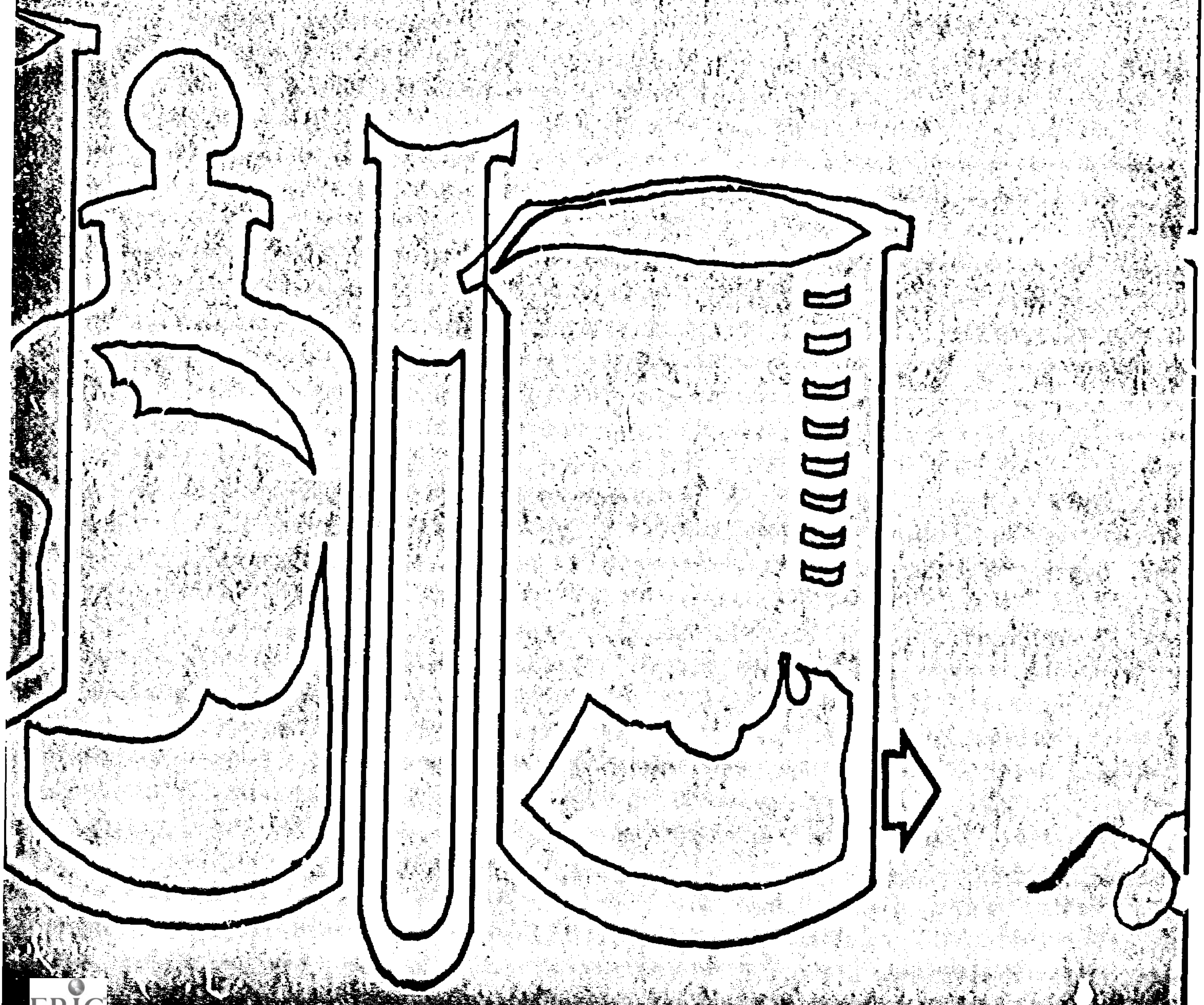
Concepts have been cited as the products of scientific processes, as the basis for further scientific studies, and at times as the knowledge that is applied by the technologist. Concepts in and of science, according to some educators, are to be the desired outcomes of science instruction.

Concepts are important not only because they are the warp and woof of science, but also because they provide the possesssor with a means of coping with the development of knowledge in the future.

Milton O. Pella, *The Science Teacher*, December, 1966.

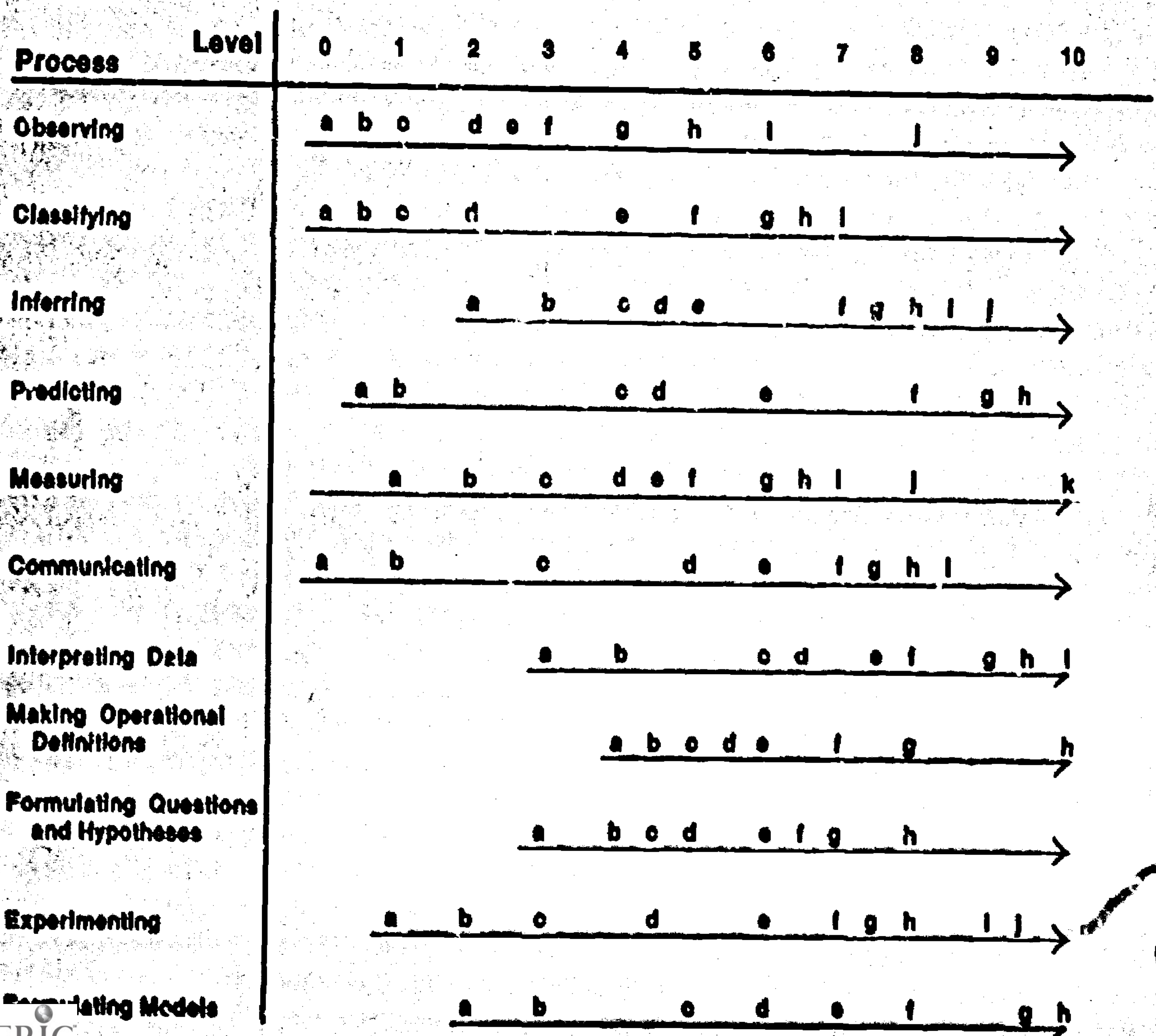
science processes ➪





The Processes of Science

This chart is an attempt to relate the processes to the concept levels. The "O" level indicates the desirability of working with the processes prior to beginning an emphasis on concept development. The arrows indicate the range over which the processes might be developed. The letters on the arrows indicate specific behaviors as described by the process sequence. Letters between levels indicate the introduction of that particular behavior during the time span used to teach the concepts for a given level.



Science Processes

Science concepts are man-made. They result from man's attempt to categorize, correlate and explain his observations of his physical and biological environments. Each concept must be regarded as a tentative statement, useful to the extent that it predicts future events and raises further questions while providing direction for making more observations. Thus, the conceptual structure of science is a dynamic rather than a static body of knowledge. Each concept has certain limitations depending on the observations on which the concept is based and the mental processes used to devise the concept. The precision of the observations determines the validity of the concept as does the degree to which the observations represent all possible observations. Each concept is restricted in its applicability since it may be used only in situations similar to those in which the original observations were made.

Thus, *the conceptual structure of science is intimately related to the various mental and motor processes used to make the observations and devise the concepts.*

Some of the relationships of science processes and science knowledge may be identified through a study of this simplified model:

OBSERVATIONS —(1)→ CONCEPT —(2)→ OBSERVATIONS

The model suggests that concepts are derived from observations and that these concepts lead to further observations. The concept may be considered to be the inference resulting from observations. Its credibility and serviceability are evaluated by observations made subsequent to the design of the concept.

Because *the concept is man-made* and because *man both designs the observational system and selects and groups pertinent observations from the system, ONE MUST UNDERSTAND THE PROCESSES EMPLOYED IN GENERATING THE OBSERVATIONS AND THE CONCEPTS* if one is to understand and use the concepts. One must also recognize that more than one concept may be inferred from a given set of observations. The task of deciding which of several concepts should be accepted by the scientific community is often long and arduous.

Various processes are implied by the model. Arrow (1) represents the process of inferring. Arrow (2) represents the process of predicting as a means of verifying the usefulness of the concept. In order to accumulate and analyze observations, such processes as measuring, observing, interpreting data, making operational definitions, classifying and experimenting are used. Usually the selection of observations is determined by formulating questions and hypotheses. Implied at many points in the model is the process of communicating. In general, the model implies some ordering of the processes in that the use of one process often precedes the use of another. However, this ordering is meant to be neither rigorous nor prescriptive.

Any one of the processes involves many related sub-processes; these sub-processes may be tentatively arranged in a hierarchy. This arrangement may then serve as a starting point for the inclusion of the processes in a science curriculum. *Certain processes can and should be included in the curriculum prior to beginning an emphasis on concept development; others should be introduced much later.* Once developed, a given sub-process should be applied as it is needed throughout a student's experience.

Eleven major processes have been identified which include the great majority of student activities appropriate for school experience. The terms associated with these processes are:

Observing
Classifying
Inferring
Predicting
Measuring
Communicating
Interpreting Data
Making Operational Definitions
Formulating Questions and Hypotheses
Experimenting
Formulating Models

The descriptive paragraphs on the following pages will clarify the intended meaning of these terms. Following each paragraph is the *Process Sequence* — a hierarchy of behaviors within that particular process. On the fold-out page is a diagram relating the specific behaviors to the levels used in the development of the conceptual framework. These sub-processes should be used as much as possible in developing the student's understanding and acceptance of the concepts.

PROCESS — Observation

Observations can be made in a variety of ways using all of the senses. Where direct sense experience is not adequate for making needed observations, indirect methods are used. Objects and events may be observed with respect to many qualities and quantities. When observations are made to accumulate data from which inferences will be drawn, the precision of the observations is critical. Precision is often improved by making quantitative observations. Observations are influenced by the experience of the observer.

Process Sequence

a. Distinguishing differences in physical properties of objects by direct observation.
b. Manipulating or changing an object in order to expose its properties for observation.
c. Using instruments to aid the senses in making observations.
d. Making observations without inference.
e. Repeating observations as a means of improving reliability.
f. Using measurement as a means of refining observations.
g. Ordering events chronologically.
h. Identifying changes in properties and measuring rates of change.
i. Differentiating constants from variables.
j. Identifying correlational changes in variables.

PROCESS — Classifying

Classifying is the grouping or ordering of phenomena according to an established scheme. Objects and events may be classified on the basis of observations. Classificational schemes are based on observable similarities and differences in arbitrarily selected properties. Classificational keys are used to place items within a scheme as well as to retrieve information from a scheme.

Process Sequence

a. Perceiving similarities and differences in a set of objects.
b. Separating a set of objects into two groups according to those that have or do not have a single characteristic.
c. Grouping a set of objects on the basis of a gross characteristic, such as color or shape, where many identifiable variations are possible.
d. Developing arbitrary one-stage classificational schemes where all included objects of phenomena may be put into mutually exclusive categories.
e. Using quantitative measurements as criteria for grouping.
f. Setting limits as a means of grouping on the basis of a continuous variable.
g. Developing classificational schemes of two or more stages of subsets having mutually exclusive categories.
h. Using an accepted classificational system or key to identify objects or phenomena.
i. Using characteristics observed under imposed conditions as a basis for grouping.

PROCESS — Inferring

Inference, while based on observations, requires evaluation and judgment. Inferences based upon one set of observations may suggest further observation which in turn requires modification of original inferences. Inference leads to prediction.

Process Sequence

a. Demonstrating that inference is based upon observation.
b. Separating pertinent observations upon which given inferences are based from those which are extraneous.
c. Developing an inference from a set of related observations.
d. Developing a series of inferences from a set of related observations.
e. Stating cause-and-effect relationships from observation of related events.
f. Identifying limitations of inferences.
g. Modifying and extending inferences to include discrepant events.
h. Developing plans to test the validity of inferences.
i. Using inferences to suggest further observation.
j. Extending inferences to formulate models.

PROCESS — Predicting

Prediction is the formulation of an expected result based on past experience. The reliability of prediction depends upon the accuracy of past observations and upon the nature of the event being predicted. Prediction is based upon inference. Progressive series of observations and, in particular, graphs are important tools of prediction in science. An experiment can verify or contradict a prediction.

Process Sequence

a. Distinguishing between guessing and predicting.
b. Using repeated observations of an event to predict the next occurrence of that event.
c. Using a series of related observations to predict an unobserved event.
d. Using quantitative measurement as a means of improving the accuracy of predictions.
e. Limiting variation in conditions affecting prior observations in order to improve the accuracy of predictions.
f. Demonstrating the accuracy of predictions in order to establish the vadility of previously held concepts upon which the predictions are based.
g. Using interpolation and extrapolation as a means for making predictions.
h. Establishing criteria for stating confidence in predictions.

PROCESS — Measuring

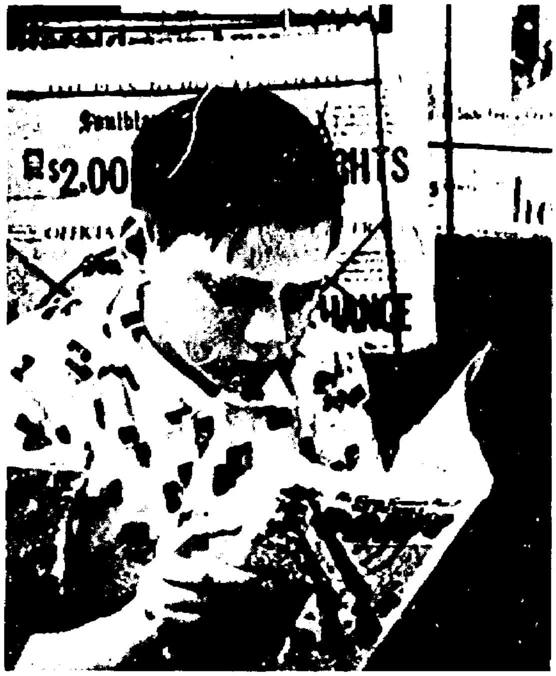
Measuring properties of objects and events can be accomplished by direct comparison or by indirect comparison with arbitrary units which, for purposes of communication, may be standardized. Identifiable characteristics which can be measured may be interrelated to provide other quantitative values that are valuable in the description of physical phenomena.

Process Sequence

a. Ordering objects by inspection in terms of magnitude of selected common properties such as linear dimension, area, volume or weight.
b. Ordering objects in terms of magnitude of properties by using measuring devices without regard for quantitative units.
c. Comparing quantities such as length, area, volume and weight to arbitrary units. Comparing time to units developed from periodic motions.
d. Using standard units for measurement.
e. Selecting one system of units for all related measurements.
f. Identifying measurable physical quantities which can be used in precise description of phenomena.
g. Measuring quantities which depend upon more than one variable.
h. Converting from one system of units to another.
i. Using and devising indirect means to measure quantities.
j. Using methods of estimation to measure quantities.

PROCESS — Communicating

In order to communicate observations, accurate records must be kept which can be submitted for checking and rechecking by others. Accumulated records and their analysis may be represented in many ways. Graphical representations are often used since they are clear, concise and meaningful. Complete and understandable experimental reports are essential to scientific communication.



Process Sequence

a. Describing observations verbally.
b. Describing conditions under which observations were made.
c. Recording observations in a systematic way.
d. Stating questions and hypotheses concisely without ambiguity.
e. Constructing tables and graphs to communicate data.
f. Planning for communication of procedures and results as an essential part of an experiment.
g. Reporting experimental procedures in a form so other persons can replicate the experiment.
h. Using mathematical analysis to describe interpretations of data to others.
i. Using tables and graphs to convey possible interpretations of data.

PROCESS — Interpreting Data

Interpreting data requires the application of other basic process skills — in particular, the processes of inferring, predicting, classifying and communicating. It is through this complex process that the usefulness of data is determined in answering the question being investigated. Interpretations are always subject to revision in the light of new or more refined data.

Process Sequence

a. Selecting data pertinent to the question asked.
b. Processing raw data to expose trends or relationships.
c. Describing information as it is displayed on tables or graphs.
d. Making and explaining inferences from tables or graphs.
e. Setting criteria for assessing the validity, precision and usefulness of data.
f. Comparing sets of related data to test the credibility of inferences and generalizations.
g. Selecting the most acceptable interpretation from multiple interpretations of the same set of data.
h. Determining estimated values of statistics from sample data and evaluating probable errors.
i. Stating criteria for restricting inferences and generalizations to those inferences and generalizations supported by data.

PROCESS — Making Operational Definitions

Operational definitions are made in order to simplify communication concerning phenomena being investigated. In making such definitions it is necessary to give the minimum amount of information needed to differentiate that which is being defined from other similar phenomena. Operational definitions may be based upon the observable characteristics of the phenomena and upon the operations to be performed. Operational definitions are precise and, in some cases, based upon mathematical relationships.

Process Sequence

a. Distinguishing between operational definition and general description.
b. Selecting characteristics of a phenomena suited to use in operational definition.
c. Stating minimal observable characteristics required for an operational definition.
d. Establishing the criteria for operational definitions according to the use intended for the definitions.
e. Evaluating the suitability of operational definitions.
f. Describing the limitations of operational definitions.
g. Using mathematical relationships in making operational definitions.
h. Formulating operational definitions of experimental parameters such as system boundaries, data gathering procedures and interactions of variables.

PROCESS — Formulating Questions and Hypotheses

Questions are formed on the basis of observations made and usually precede an attempt to evaluate a situation or event. Questions, when precisely stated, are problems to be solved through application of the other processes of science. The attempt to answer one question may generate other questions. The formulation of hypotheses depends directly upon questions, inferences and predictions. The process consists of devising a statement which can be tested by experiment. When more than one hypothesis is suggested by a set of observations, each must be stated separately. A workable hypothesis is stated in such a way that, upon testing, its credibility may be established.

Process Sequence

a. Separating questions which can only be answered philosophically from those which can be answered from experience.
b. Answering questions confined to the observations which can be made.
c. Separating broad questions into parts which, when answered, will contribute to a comprehensive explanation.
d. Restricting questions to those that demand only a positive or negative response.
e. Asking questions or stating simple hypotheses which can be tested.
f. Stating hypotheses in forms which suggest the variable to be manipulated.
g. Differentiating between hypotheses which must be tested qualitatively and those which can be tested quantitatively.
h. Stating negative hypotheses in an attempt to eliminate variables.

PROCESS — Experimenting

Experimenting is the process of designing data-gathering procedures as well as the process of gathering data for the purpose of testing a hypothesis. In a less formal sense, experiments may be conducted simply to make observations. However, even here there is a plan to relate cause and effect. In an experiment variables must be identified and controlled as much as possible. An experimental test of a hypothesis is designed to indicate whether the hypothesis is to be accepted, modified or rejected. In designing an experiment, limitations of method and apparatus must be considered.

Process Sequence

a. Manipulating apparatus to make pertinent observations.
b. Identifying observations which are relevant to an experiment.
c. Distinguishing useful from extraneous data
d. Describing the problems involved in making desired observations.
e. Identifying relevant variables in an experimental situation.
f. Maintaining an accurate record of experimental procedures and results.
g. Controlling those variables not a part of the hypothesis being tested.
h. Identifying sources of experimental error.
i. Describing the limitations of experimental apparatus.
j. Describing the limitations of the experimental design.

PROCESS — Formulating Models

Models, whether physical or mental, are devised on the basis of acceptable hypotheses or hypotheses that have yet to be tested. Models are used to describe and explain the inter-relationships of ideas. In many cases the model implies new hypotheses; if testing these hypotheses results in new information, the model must be altered to include it.

Process Sequence

a. Distinguishing between models and reality.
b. Explaining observed phenomena by using models devised by others.
c. Constructing a physical representation, a drawing or a mental image to explain observed phenomena.
d. Extending physical or mental models to include related phenomena.
e. Modifying existing models to include new observations.
f. Formulating physical or mental models idealizing observed conditions in order to minimize variations.
g. Devising tests for the credibility of an existing model.
h. Stating limitations for models.

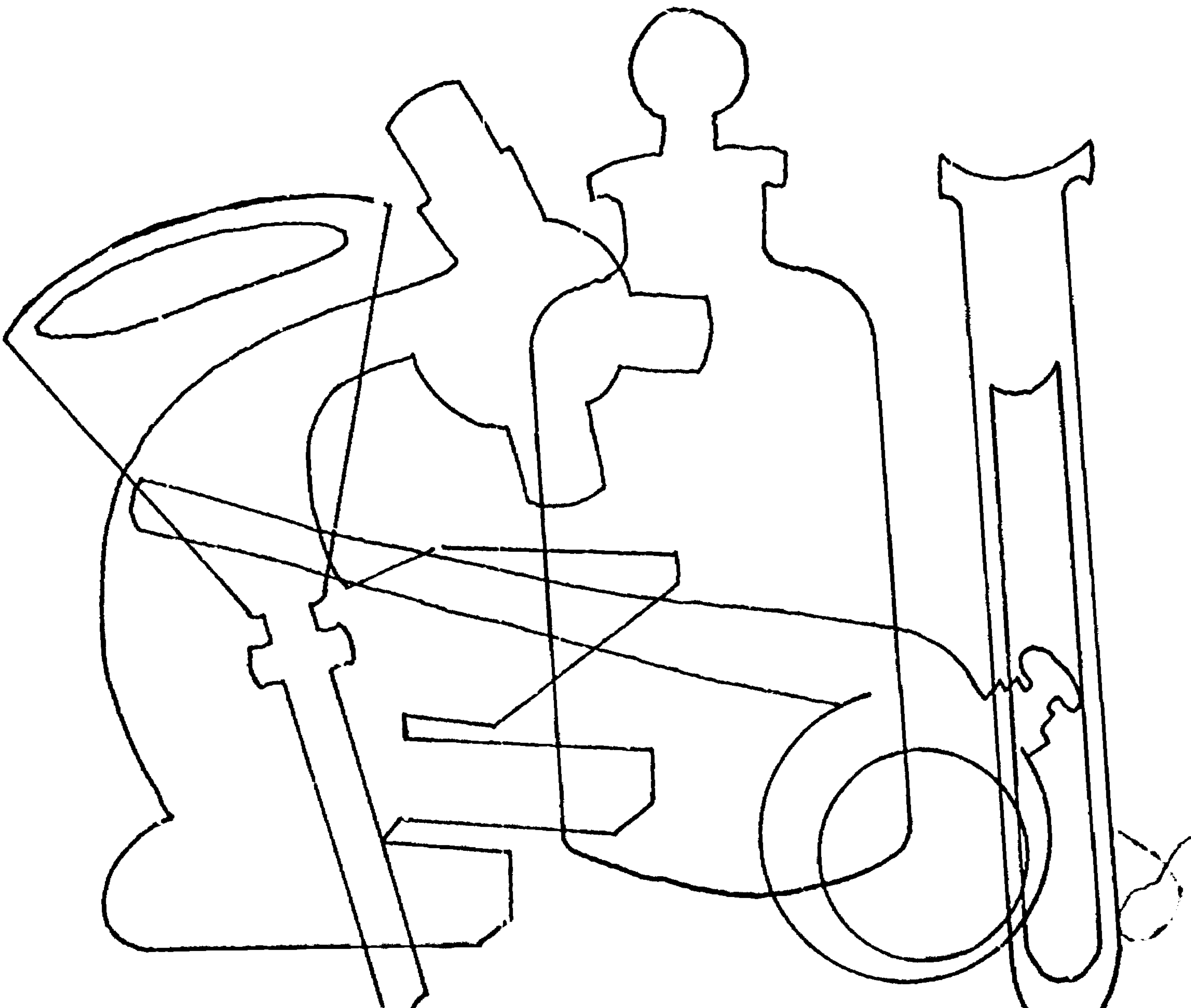
Process in Science for the Elementary Grades

My own view is that science processes should be emphasized all along, since I think of these as the intellectual strategies that are so important for an adult human being to have, even if he never studies much science in a formal way. But, at the same time, I should surely expect a student who has learned some processes to be able to undertake the serious study of any particular science content with a great deal of facility.

Robert M. Gagne, Sixteenth Annual Convention, NSTA. March, 1968.


EGGS

the nature of the scientific enterprise



The Nature of the Scientific Enterprise

An analysis of the history of science indicates that man's effort to increase his understanding of his natural environment has been greatly influenced by the acceptance of identifiable procedures, beliefs and ethical standards. These factors, together with the activities of investigation, comprise the *Nature of the Scientific Enterprise.* To be a scientist is to be involved in physical and mental activities which have proved to be effective in developing an understanding of natural phenomena.

Science is often considered to be the application of rational thought to data gathered from experience. This notion is incomplete and somewhat misleading. A detailed inquiry into the nature of science reveals that scientists do not usually state a set of primary assumptions about nature — but they do subscribe to them. Scientists tend to agree that these unwritten rules control their behavior. Such rules, the result of centuries of philosophical development, have been critical in the development of science as an intellectual pursuit.

In order to understand and appreciate the conceptual structure of the products of science and the processes by which science concepts evolve, it is necessary for the science student to understand what a scientist is, what he does, what he believes and how he conducts his investigations. Such understanding does not require intimate knowledge of highly specialized techniques and

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I. The Philosophy of Science

- A. The Assumptions of Science
  1. Assumptions Concerning Nature
     - a. Reality
     - b. Consistency
     - c. Causality
     - d. Comprehensibility
  2. Assumptions Concerning Processes and Products of Scientific Investigation
     - a. Repeatability
     - b. Probability
     - c. Tentativeness
     - d. Contingency
- B. Ethical Rules of Science
  1. Empiricism
  2. Openmindedness
  3. Parsimony
  4. Immunity
  5. Reliance

II. Actions of the Scientist

- A. Making Selections
- B. Allowing for Serendipity
- C. Making Empirical Investigations
  1. Planning an Investigation
  2. Conducting an Investigation
  3. Interpreting Data
- D. Expanding Scientific Knowledge
  1. Developing Classificational Schemes
  2. Forming Correlational Relationships
  3. Establishing Theoretical Constructs
- E. Communicating Scientific Information

methods, but does require knowledge of the context in which scientific investigations are conducted. Such knowledge cannot be accomplished by simple indoctrination. Therefore, the curriculum designer should seek ways to include the philosophy of science in classroom and laboratory activities. This may be done by asking the student to analyze the assumptions and beliefs that influence his own actions and decisions in laboratory investigations. It may also be accomplished through learner analyses of examples of well-known scientific works. To some extent it may be accomplished through analogy and philosophical discussion. The curriculum designer must be responsible for determining the most appropriate approach for a given situation.

The following outline is an attempt to separate the *Nature of the Scientific Enterprise* into some of its major parts so that each may be considered individually; it does not imply that there are artificial barriers which segment the activities and mental processes involved in pursuing science. The *philosophy of science* includes the assumptions and ethical rules which influence the *actions of the scientist*. There is no fixed order in which a scientist must consider these influences, nor is there any definite pattern which he must follow in his activities. Since the methods employed are determined by the phenomenon or object under investigation, there is no single scientific method which the research scientist must honor.

The Nature of the Scientific Enterprise

I. **The Philosophy of Science** — Scientific disciplines, as well as other disciplines, depend upon fundamental assumptions and behaviors. Together these constitute the philosophy of science.

A. **The Assumptions of Science** — The first truths of science must be assumed. Although there is no preponderance of evidence that indicates the final proof of assumptions, observable positive facts and absence of negative evidence makes assumption possible. Thus, the very high credibility of an assumption allows the scientist to use it as a point of departure in his investigations. If at any time evidence is presented that indicates the assumptions are false, they must be revised and the investigations based upon them redone.

1. Assumptions Concerning Nature — An attempt to understand natural phenomena requires assumptions concerning the characteristics of the natural environment and man's relationship to it.

a. Reality — It is assumed that the universe exists outside the minds of men. Thus the universe and all natural phenomena within the universe are real.

b. Consistency — It is assumed that nature is not capricious and that there is a corresponding regularity in natural phenomena.

c. Causality — It is assumed that natural effects have natural causes. Stated in another way, there is a functional dependence between associated occurrences.

d. Comprehensibility — It is assumed that the human mind is capable of understanding natural materials and their interactions.

2. Assumptions Concerning the Processes and Products of Scientific Investigation — In attempting to understand his environment, man must make assumptions concerning the validity of his processes of investigation and the products which result from them. He must also be concerned with the limitations which always exist.

a. Repeatability — It is assumed that if an experiment is repeated in exactly the same way under exactly the same conditions the same result will always occur.

b. Probability — It is assumed that all experimental results, measurements and other products of science will not be statements of absolute truth. There always exists a certain probability of error in observation and a corresponding probability of error in the inferences made.

c. Tentativeness — It is assumed that procedures of investigation and results obtained are acceptable only until better procedures and more accurate results are available. It is also possible that a given set of observations may produce more than one seemingly correct inference. The acceptance of one inference over the other is always subject to change.

d. Contingency — It is assumed that the usefulness of experimental data and the interpretations of such data are dependent upon the validity of a variety of accepted assumptions and information. It is also assumed that any change in basic assumptions requires a re-examination of inferences that have been made.

B. Ethical Rules of Science — Although there is no written code of scientific conduct, most scientists recognize an obligation to perform their tasks in a way that will communicate their findings as efficiently as possible and will not mislead their fellow workers.

1. Empiricism — Theories in science are based upon evidence that is gathered by direct or indirect methods. Imagined data outside of stated accepted assumptions are rejected by the scientist. Although differences of interpretation are accepted, dishonesty is always rejected.
2. Openmindedness — Investigations in the domain of science are done without personal bias and results are never predetermined. The job of the scientist is not to argue for or against a personal belief, but rather to objectively ascertain the credibility of a proposition and to communicate the results to his colleagues.
3. Parsimony — Simplicity is preferred to complexity. If a choice is to be made between two different scientific theories, both of which account for the observed facts, the least complex is chosen. Similarly, comprehensiveness is preferred to specificity. There is a continuous effort among scientists to develop a minimum number of fundamental concepts to explain the greatest possible number of observations.
4. Immunity — The conceptual products of pure science are developed without regard for social ethics or practical requirements. The products of science are amoral; the morality associated with scientific discovery is only a result of society's use of the discovery.
5. Relevancy — In attempting to advance understanding of the natural universe, a scientist will accept those theoretical constructs which have shown to be successful in explaining observed phenomena and will reject those which have been non-productive. In short — he accepts the useful and rejects the useless.

II. Actions of the Scientist

— There is no single scientific method or procedure. Instead, the scientist proceeds according to the nature of the problem with which he is concerned. The more varied the possible approaches, the more critical the decision becomes as to what approach is to be used. The scientist proceeds with the belief that no one method will guarantee success, but that in pursuing the mental maze toward understanding there are many paths which may be followed.

A. Making Selections — Much of the scientist's work involves choosing between relevancy and irrelevancy. The adequacy of the selection process determines economy of time and effort and the reliability of the results. Selection includes:

1. Collecting and examining available facts and assumptions prior to formulating working hypotheses.
2. Classifying the facts and assumptions in order to reduce the number of factors to be related.
3. Establishing a cumulative fund of knowledge as a basis for scientific knowledge.
4. Determining the nature of the observations that have the highest probability of yielding results.
5. Recording those observations relevant to the working hypotheses.
6. Limiting the number of variables being observed at any one time.
7. Choosing, when possible, numerical measurement and quantitative data over qualitative description to increase precision.
8. Maximizing the precision of measurement by using appropriate instruments and proficient skills.
9. Considering the probability of error in obtaining and utilizing data.

B. Allowing for Serendipity — In all scientific investigations, there is the chance that a result will appear that is not anticipated. It is the responsibility of the scientist to be aware that such results may occur and to be sensitive to their importance. The advancement of scientific knowledge in this way has been more the result of the investigator's alert anticipation than the result of happy accidents.

C. Making Empirical Investigations — The empirical nature of science asserts that knowledge of nature can be inferred from direct or indirect observation. Empiricism is opposed to simple dependence upon intuition and to the philosophies of totalitarianism, rationalism and subjectivism. Pure, logical thinking will almost certainly yield a distorted view of the characteristics and relationships of the natural world. Investigations are designed to serve as a source of empirical data. Such data is useful in ascertaining the credibility of theoretical constructs that have resulted from natural observation or the planned collection of other empirical data.

1. Planning an Investigation — Seldom, if ever, does the random observation of phenomena provide evidence for the formulation of significant understandings. To conserve time and effort, careful planning must be a part of every investigation. The strategies employed in an investigation depend upon the nature of the problem to be investigated. There is no fixed order for carrying out the planning activities related to conducting an investigation.
   a. A scientist develops a clear understanding of the nature of his problem and reviews any relevant associated literature.
   b. In order to develop criteria for the collection of data, one or more hypotheses will be stated in simple and precise terms in a manner that makes it possible to test their credibility from the data to be collected.
   c. The investigation will be designed so that the nature of the data to be collected and the method by which the data will be treated will be known prior to any action. In some investigations, trial runs may be conducted as a means of testing the experimental design. Such trial runs may result in the restatement of the problem or the hypothesis and may possibly indicate a need for revision of the overall plan.
   d. The variables involved in the investigation must be identified and examined in light of prior information. It will then be determined which of the independent variables can be controlled and which cannot. The experimental design will provide for manipulating the controlled variables and for determining the possible effect of the uncontrolled variables on the data.
2. Conducting an Investigation — The experimental aspect of an investigation is an attempt to set up an artificial situation in which the control of variables is greater than in the ordinary course of events. In carrying out the planned investigation, a systematic series of observations are made under controlled conditions by one or more persons whose actions are guided by the assumptions and ethical rules recognized by scientists.
   a. Special skills and equipment will be used as extensively as necessary to carry out the planned investigation.
   b. Observations will be made objectively according to the experimental design.
   c. Although there will be continued scrutiny of the progress of the investigation while data is being accumulated, no conclusive statement will be made until the experiment is completed.
3. Interpreting Data — An extensive accumulation of data will not be considered meaningful in terms of scientific investigation until it is interpreted. Rational thought may be applied to empirical data in a variety of ways in order to develop classifications, correlations and theories.

D. Expanding Scientific Knowledge — The products formulated by scientists emerge in the form of concepts. These concepts may be classificational schemes of objects or phenomena, correlational relationships between natural phenomena or theoretical constructs. All such concepts are the result of the application of human intelligence, imagination and creativity to empirical data.

1. Developing Classificational Schemes — The wide range of information collected from nature would be of little value to mankind unless a system were developed for retrieving necessary information when it is needed. A portion of scientific effort is devoted to categorizing observed phenomena.

   a. Classificational schemes may be based upon observable similarities and differences.
   b. Classificational schemes are invented by man and imposed upon nature. The schemes are not inherent in the natural phenomena being classified.
   c. Classificational schemes are developed as a means of storing information and exposing possible trends inherent in nature.
   d. Classificational schemes are both exhaustive and exclusive; that is, every item in a group of observations must fit into one of several classes, but no item can fit into more than one class.

2. Forming Correlational Relationships — One of the tasks of scientific investigation is to establish functional relationships between effects and their causes. This functional relationship may be simple or it may be a chain of events leading to a final effect. The basic assumption of consistency in natural phenomena is used in establishing such correlational relationships.

   a. Correlational relationships may be established by the *method of agreement*: if the circumstances leading to given event have in all cases had one factor in common, that factor may be the cause or related to the cause of the event. Since it is not possible to know all of the possible relevant factors involved, correlational statements derived by this method are stated in terms of probabilities.
   b. Correlational relationships may be established by the *method of difference*: if two or more circumstances differ in only one factor and the one circumstance containing the factor of difference leads to the events and the other circumstances do not, that one factor may be proposed as the cause of the event. Again, these correlational products are expressed in terms of probabilities.
   c. Correlational relationships may be established in terms of *mutual change*: if factor x changes greatly as factor y changes greatly over a wide range of measurements, the parallel changes are an indication of possible functional dependence.

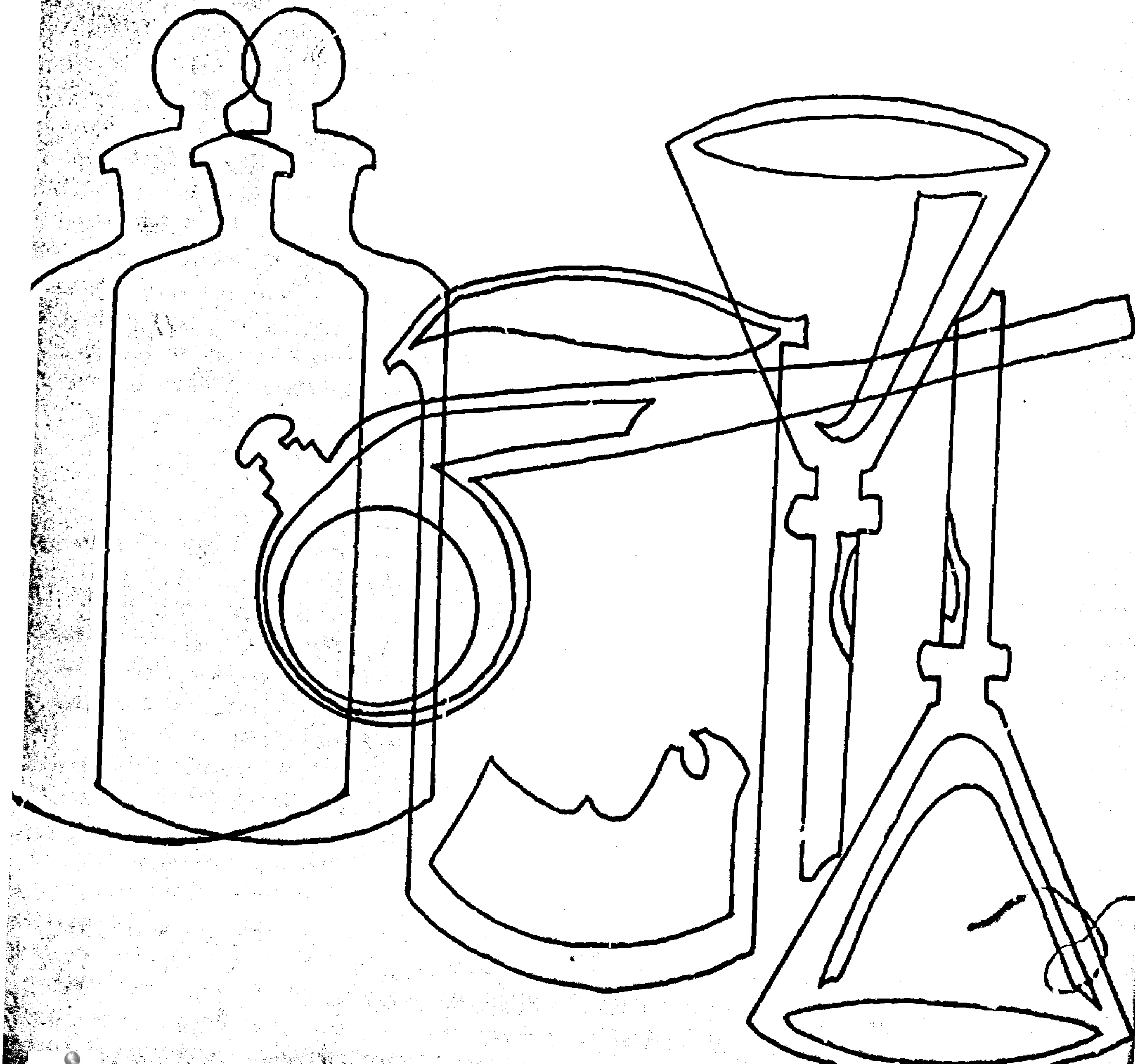
3. Establishing Theoretical Constructs — Theories emerge when gaps appear in the available facts. A theory has higher credibility than a hypothesis, but lower credibility than a fact. Theories are based upon a higher order of assumption than classifications and correlations.

   a. Theories are developed from assumptions as well as facts.
   b. Theories are developed so that they may be expressed in the simplest possible way without unduly limiting the number of phenomena they can explain or their usefulness in making predictions.
   c. Theories are never proven true or false. It is only possible to establish or deny their credibility.
   d. Theories are considered tentative and are modified whenever new evidence is presented.

E. **Communicating Scientific Information** — The scientist is obligated to publish or disseminate in other ways new research results so that all members of the academic community may benefit or may have the opportunity to test the formulated concepts. All contributions to the fund of scientific knowledge become public domain with only minimum credits going to the researcher for his achievement. The presentation of publications and the review of scientific results by the community of scientists provide a system of self-imposed checks and balances that regulates the quality of the products of scientific endeavor.

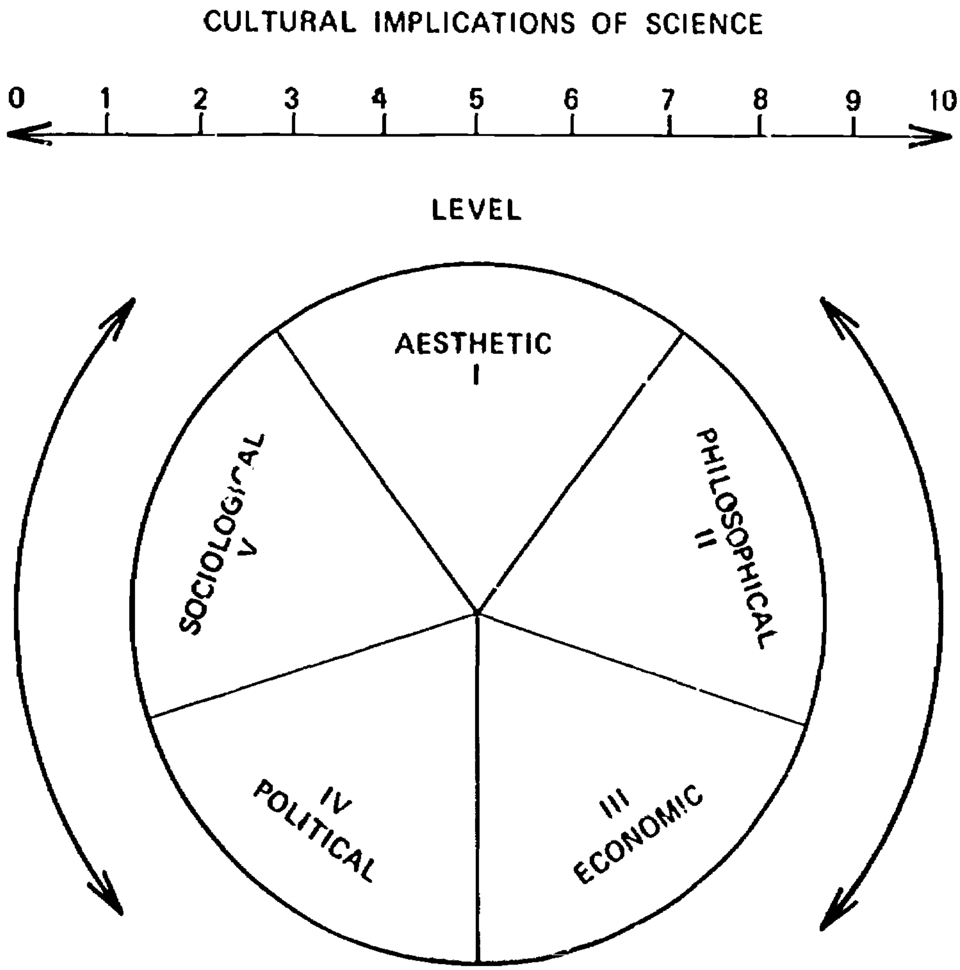
The body of scientific knowledge is a variable that moves ahead as a series of approximations. Each investigator has the right and obligation to proceed upon the theories and assumptions of those who came before him. In essence, science is an intellectual invention of man which has brought the universe within his comprehension.

the cultural implications of science



The Cultural Implications of Science

The *Cultural Implications of Science* could be structured as a sequence of concepts. However, because the conceptual schemes and the processes in this Guide are intended to provide a framework for the science curriculum, it is recommended that the cultural aspects be included within the context of these major aspects of science. This does not mean that the cultural implications are of any less importance to the curriculum. They should pervade all levels of the suggested conceptual framework. The ideas involved should be interwoven with the science concepts in every teaching unit.



The above diagram indicates that the cultural implications of science are to be applied to all levels within the conceptual framework.

"The Purpose of Knowledge Is Action and Social Betterment"

In the field of science, the great discoveries are yet to be found in the minds and the capability of people who have been left out. I'm calling upon the scientific community today for more breakthroughs. You're constantly opening up new vistas; you're constantly discovering something; you're constantly putting together new compounds. Do it with people. Open these doors of opportunity.

Vice President Hubert Humphrey, Sixteenth Annual Convention, NSTA. March, 1968.

The Cultural Implications of Science

Man lives in a world in which his activities and his way of life are profoundly influenced by science. Science in turn influences technological development. It is not possible to discuss science outside of its relationship with human beings, since science, both as a body of knowledge and as a process, is a product of the human intellect. The main interrelationships between science and human activities on both intellectual and physical grounds may be expressed as follows:

1. **Science is a significant part of our culture, having aesthetic and humanistic as well as practical values.**
2. **Science is influenced by the philosophical structure of the society in which it exists and in turn science affects the philosophical structure of that society.**
3. **Scientific and technological structures of a society have a strong influence on the level of economic development.**
4. **Governmental policies affect the growth of science and are in turn affected by scientific activities. Society's wisdom in the support and application of science is related to the level of understanding of the purposes, strengths and limitations of science.**
5. **The rapid accumulation of scientific and technological knowledge and the decrease in the time lag between development and sociological application creates serious problems when the society accepts the new developments without taking time to anticipate the consequences.**

For the purposes of curriculum development, these statements express the fact that science influences human activities and that science in turn is influenced by these human activities. For the purpose of simplification, the five statements will be referred to hereafter by the following adjectives:

1. **Aesthetic**
2. **Philosophical**
3. **Economic**
4. **Political**
5. **Sociological**

The attitudes and appreciations related to the *Cultural Implications of Science* are manifested by the behaviors of individuals in their relationship to society. The teaching strategies used to develop acceptable attitudes and appreciations toward science are different from those strategies used to develop concept understanding or process dexterity. The major ideas of the cultural implications of science should be introduced to children early in their education and then re-introduced using appropriate methods whenever reasonable within the structure of the conceptual schemes and processes. The progress of science in relation to human development dramatically demonstrates the interaction of science and society. Students may develop an appreciation of this interaction by using direct quotations from the writings of well-known scientists and science educators, such as the few included examples. Since the social involvement of science varies with time and with local and regional situations, the classroom teacher should exert every possible effort to keep references relevant to the social experience of students.

I. Aesthetic

The word "art" can be used to describe fine paintings, pieces of sculpture and great works of music and literature. The word may also be used to describe the process of developing these accomplishments. The word "artist" denotes a person who uses his materials, whether they be oil and canvas, clay and bronze or pen and paper, to create a product of his investigations and contemplations. The words "science" and "scientists" are very similar to "art" and "artist." The scientist finds the same creative satisfaction in creating models, explanations and predictions of natural phenomena as the poet finds in creating memorable verse or the artist finds in developing new relationships between his materials. A scientific investigation of nature is a creative activity which has enormous intellectual challenges and satisfactions. Just as the artist is limited by the nature of his materials, so the scientist is limited by the behavior of the materials of nature.

The aesthetic nature of science is apparent at all levels — from the most elementary observations of the young child to the sophisticated investigations of the professional scientist. Aesthetic satisfaction can be found in the simple observation of the color of flowers, the patterns of butterflies, the green of the landscape, the blue of the sky, the form of seashells and the complexity of crystals. At a higher level, the professional scientist sees beauty in his physical and mathematical models of theoretical constructs. As with great works of art, an immense satisfaction may be conveyed to students by introducing them to great scientific works, such as Faraday's experiments with magnets, coils and wire to gain an understanding of electro-magnetic induction. There is a special beauty in Pasteur's studies of the relation of the form of tartrate crystals to the rotation of polarized light. Emil Fischer's work on the structural formula of grape sugar is an inspiration to beginning organic chemists.

"Science is the creation of scientists and every scientific advance bears somehow the mark of the man who made it . . . . The Creative scientist, whatever his field, is very deeply involved emotionally and personally in his work, and . . . he himself is his own most essential tool."

Anna Roe 1961

"Knowing how contented, free and joyful is life in the realm of science, one fervently wishes that many would enter its portals."

Dmitri Mendeleev 1868

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other and so dependent upon each other in so complex a manner, have all been produced by laws acting around us . . . Thus, from the war of nature, from famine and death, the most exalted object we are capable of conceiving, namely, the production of the higher animals, directly follows. There is grandeur in this view of life, with its several powers, having been originally breathed into a few forms or into one; and that, whilst this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful, and most wonderful have been, and are being evolved."

Charles Darwin 1859

"Personally I am inclined to agree with Schopenhauer in thinking that one of the strongest motives that lead people to give their lives to art and science is the urge to flee from everyday life, with its drab and deadly dullness, and thus to unshackle the chains of one's own transient desires, which supplant one another in an interminable succession so long as the mind is fixed on the horizon of daily environment."

Albert Einstein 1932

"Science is used so loosely these days to account for all manner of things — from the why of nature to the despair of the poet, from the highest reaches of man's intellect to the deadening of humanistic culture, from the preservation of civilization to its destruction ... it is not surprising that control of nature is frequently confused with man's intellectual desire to understand it ... the utility of science looms so large in the affairs of men as to shadow its esthetic values."

Morris H. Shamos 1961

"There are, in fact, four very significant stumbling-blocks in the way of grasping the truth, which hinder every man however learned, and scarcely allow anyone to win a clear title to wisdom, namely, the example of weak and unworthy authority, long-standing custom, the feeling of the ignorant crowd, and the hiding of our own ignorance while making a display of our apparent knowledge. Every man is involved in these things, every rank is affected. For every person, in whatever walk of life, both in application to study and in all forms of occupation, arrives at the same conclusion by the three worst arguments, namely, this is a pattern set by our elders, this is the custom, this is the popular belief: therefore it should be held."

Roger Bacon, c. 1260

"To magnify thought and ideas for their own sake apart from what they do ... is to refuse to learn the lesson of the most authentic kind of knowledge — the experimental — and it is to reject the idealism which involves responsibility. To praise thinking above action because there is so much ill-considered action in the world is to help maintain the kind of world in which action occurs for narrow and transient purposes. To seek after ideas and to cling to them as means of conducting operations, as factors in practical arts, is to participate in creating a world in which the springs of thinking will be clear and ever-flowing."

John Dewey 1929

Max Casper wrote of Johannes Kepler that "Indeed while following his Mars research one gets the impression that sometimes he deals with individual tasks and proofs out of pure delights and pleasures." This is one of many examples in the history of science where an investigator goes to needless ends for the aesthetic satisfaction obtained from pursuing further evidence rather than abandoning a problem as soon as the practicability of a solution has been demonstrated.

Every science student should have an opportunity to encounter the vast jigsaw puzzle of information available to him from prepared resources and from his environment in order to build a personal model of his universe — regardless of how broad or restricted it may be. The science educator has a special responsibility to encourage the student to develop his appreciation of science as a creative activity.

II. Philosophical

The climate created by scientific thought has profoundly influenced man's way of thinking. In turn, philosophical attitudes have either retarded or stimulated science, depending upon the particular circumstances.

Until the 17th century, scientific thought was dominated by ancient Greek philosophy. This dominance was largely due to the ideas of Aristotle, who thought that causal relationships were of primary importance in the analysis of any particular subject. Aristotelian philosophers treated phenomena of nature in much the same way that the geometer treats his subject: they worked through a logical system based upon a set of "self-evident truths." The Aristotelians believed that the earthly sphere was made up of earth, air, fire and water; the sky was made up of the fifth element, quintessence, which was a perfect material. Following Plato's teaching, they believed that motion in the sky was perfect. Since the circle is a perfect figure, then the motion observed in the sky must be circular. They assumed also that this celestial motion was regular — neither slowing down nor speeding up. As a consequence of these rigid beliefs, explaining observed irregularities in the otherwise constant eastward drift of the planets required the invention of a highly sophisticated geometric system involving circles moving on circles.

In the 16th century Copernicus initiated a revolution in astronomy. He explained the irregular motion of the planets as an overtaking phenomenon where the earth moved around the Sun in an orbit between that of Venus and Mars. Subsequent students of the subject, such as Kepler and Galileo, found that the Copernican system made a great deal of sense, especially when modified by Kepler to place the planets into elliptical rather than circular orbits.

The new astronomy created an intellectual crisis; Aristotelian philosophers were unable and unwilling to accept the new point of view despite the fact that it led to a simpler geometric system with good predictive value. Both Protestant and Catholic philosophers sought in vain to block acceptance of the new explanation.

The new astronomy contributed to the development of a completely new philosophical view of nature. During the 17th century, accurate data began to be gathered resulting in the formulation of theoretical models consistent with observations rather than with "self-evident truths." Observations were no longer distorted to fit these "truths." The new point of view ultimately led to rapid progress in the understanding of natural phenomena. This was the beginning of the scientific revolution.

Toward the end of the 17th century a philosophical reaction occurred which developed into the Enlightenment period. Advocates of the Enlightenment philosophy were convinced that the universe performed like a fine piece of clock-like machinery and that the job of the philosopher, and therefore the scientist, was to gain an understanding of natural laws in order to better comprehend the unexplored aspects of nature. The Enlightenment philosophy affected popular thought as evidenced by the literature of the period which reflected the influence of natural philosophy. Despite an opposing view that evolved during the Romantic period, the empirical approach to the understanding of nature continues today to be the principal manner of gaining a better understanding of natural phenomena.

The theory of organic evolution put forth by Charles Darwin and Alfred Wallace in 1859 imposed another major strain on conventional ideas. From studies of biology and geology, these men developed the theory that animal and plant species undergo changes resulting in natural selection. They proposed that animal and plant species undergo small accidental changes, which, if favorable, enable the changed generation to better survive in its environment and thus supplant the original forms.

The theory of organic evolution met strong opposition in theological circles since the teachings of Darwin seemed to be in direct conflict with Biblical ideas of creation. If evolution were to be seriously considered a reality, the age of the earth needed to be vastly expanded from the approximate 6,000 years accepted by Biblical scholars. But opposition to evolution slowly receded as evidence was presented to indicate that the earth was much older than had been interpreted from the Genesis account. Again, interpretation of observations brought about a major change in philosophical thinking.

"I shall begin by making some experiments before I proceed any further; for it is my intention first to consult experience and then show by reasoning why that experience was bound to turn out as it did. This, in fact, is the true rule by which the student of natural effects must proceed although nature starts from reason and ends with experience, it is necessary for us to proceed the other way around, that is — as I said above — begin with experience and with its help seek the reason. Experience never errs; what alone may err is our judgment, which predicts effects that cannot be produced in our experiments. Given a cause, what follows will of necessity be its true effect, unless some external obstacle intervenes. When that happens the effect that would have resulted from the cause will reflect the nature of the obstacle in the same proportion as the obstacle is more or less powerful than the cause."

Leonardo da Vinci 1500

"The main business of natural philosophy is to argue from phenomena without feigning hypotheses, and to deduce causes from effects, till we come to the very first cause, which certainly is not mechanical; and not only to unfold the mechanism of the world, but chiefly to resolve these and such like questions: What is there in places almost empty of matter, and whence is it that the sun and planets gravitate towards one another, without dense matter between them? Whence is it that nature doth nothing in vain; and whence arises all that order and beauty which we see in the world?"

Sir Isaac Newton 1704

As the student proceeds in the study of science, he should be aware of the effect that the philosophical climate has upon assumptions and activities which control scientific investigations. He should become aware that scientific efforts are conducted in a philosophical climate which cannot be entirely controlled by the scientist. Philosophy might well be so much a part of the scientist's thought processes that it could restrict his observations and encroach upon his interpretations.

Young men, young men, have confidence in those safe and powerful methods, of which we know only the first secrets. And, whatever your career may be, do not let yourselves become affected by a denigrating and barren skepticism, do not let yourselves be discouraged by the sorrows of certain hours which pass over a nation. Live in the serene peace of laboratories and libraries. Say to yourselves first, "What have I done for my education?" and as you gradually advance, "What have I done for my country?" until perhaps you may have the immense happiness of thinking that you have contributed in some way to the progress and to the good of humanity. But whether or not our efforts bear fruit, let us be able to say, when we come near the great goal, "I have done what I could."

Louis Pasteur 1892

III. Economic

Pure science has been developing for centuries. However, it was not until the middle of the 19th century that scientific developments began to have practical and therefore economic consequences. Prior to this time, most of the technological developments which resulted in important inventions, such as the steam engine, the printing press and many others so important to bringing about economic revolution, were based upon trial-and-error development designed to produce a specific product, and not upon the results of scientific investigation. However, in the past 100 years, the dependence of economic development upon the outcomes of scientific research has increased sharply.

During the last half of the 19th century, the electrical industry, which could hardly have developed from random invention and empirical discovery, began to thrive from the input of scientific knowledge. This industry was based upon fundamental knowledge of magnetism and electricity which had been developing for several hundred years, but which had come to fruition only through the important investigations of Volta, Ampere, Oersted, Faraday and Maxwell. The contributions of these men made possible the development of new forms of communication and, by about 1870, the development of practical electrical generators and motors. It became possible to generate electricity in sufficient quantities for such large scale use as the operation of streetcars and industrial motors. About 1890, electricity made possible the preparation of various chemicals through the use of electrolytic cells. In the 1880's, the work of Hertz led to recognition of electro-magnetic waves transmitted through space. Application of this knowledge led to the development of radio and ultimately radar and television.

The dye industry is another industry based on application of theoretical chemical knowledge. Although the first synthetic dyes were discovered on empirical grounds, the German chemical profession successfully investigated the processes by which the synthesis of organic compounds having good dyeing properties could be accomplished. These chemists learned the nature of the chemical groups responsible for color and described those chemical groups which had mordant properties. By 1880, the close relationship between the German dye industry and the chemical profession led the dye industry to branch out into the fields of drugs and photographic chemicals.

The close tie between science and national economics which proved so important in the 19th century developed on a massive scale during the 20th, particularly in the western world. Many industrial companies now maintain extensive research and development laboratories in order to discover new products for introduction to the consumer market and new processes to more efficiently manufacture these products. Plastics, synthetic textiles, synthetic rubber, modern drugs and pesticides are largely products of 20th century scientific research and the resulting technological innovation.

The most prosperous countries of the world are those which have an economic system solidly based on the application of scientific discovery to technology. However, it is equally important to point out that the development of science is favored in a country which already has a strong economy. Science first flourished in England, France and the parts of western Europe where a strong economic structure already existed. Scientific activity is fundamentally expensive since many investigations lead only to other investigations. Although new knowledge may result from such investigations, there is no assurance that this knowledge will lead to technological application within a predictable period of time. For this reason a strong financial backing is needed in order to foster research to the point where it can become profitable. The scientific discoveries which have resulted from such research without having any direct technological application are invaluable in the further development of pure science. It is impossible to know which scientific discoveries will eventually lead to practical application and which will ultimately represent contributions to man's knowledge. However, that small portion of scientific knowledge which has economic value will ultimately feed into technology and therefore into national and world economy. An economic structure which is too weak to support a sizeable scientific population shows little promise of developing, or even borrowing from other countries, the kind of science which will become important in technology.

Since each student is destined to become an adult dependent upon the economic structure of his country, he should have some prior knowledge and appreciation of the direct effect which scientific research and the resulting scientific knowledge have upon his potentiol earning power and the consumer goods that will be available to him. He will, hopefully, appreciate the soundess of an investment in research — whether it be by the company in which he has an interest or by the government upon which he depends.

"Professor Graham Bell, the inventor of the telephone, is not an electrician who has found out how to make a tin plate speak, but a speaker, who, to gain his private ends, has become an electrician."

James Clerk Maxwell 1878

"Where (in industry) the degree of empiricism is low and the objective is to reduce still further this element of our understanding, we are concerned with a phase of that revolutionary activity which started about 350 years ago and which we designate science .... In general, the more we understand the fundamentals, the more likely we are to succeed in a new scientific or technological endeavor; in short, the lower the degree of empiricism involved the better."

James B. Conant 1960

"Recent statistical studies suggest that technological progress accounts for a considerably larger fraction of America's economic growth than capital accumulation."

Rendigs Fels
Vanderbilt University 1961

"The basic institution upon which everything else depends is the scientific department of the university ...."

C. E. K. Mees, Vice Pres.
Eastman Kodak Co. 1950

"What faces man is not, in any restricted sense, a scientific problem. The problem is one of the relation of science to public policy. Scientific issues are vitally and almost universally involved. The special knowledge of the scientist is necessary, to be sure; but that knowledge would be powerless or dangerous if it did not include all areas of science and if it were not effectively pooled with the contributions of humanists, statesmen, and philosophers and brought to the service of all segments of society.

"What is to be done? Scientists certainly have no arrogant illusion that they have the answers. But they do want to help. They are, moreover, convinced that the time is overripe for a more understanding collaboration between their special profession and the rest of society."

Parliament of Science Report
1958

"It is clear that science occupies a conspicious place in national policy making . . . . And the reasons are impressive: science provides new and fast routes to economic growth, international bridgebuilding, national defense, technological advance, and such human values as overcoming want and disease."

William D. Carey
U.S. Budget Bureau 1967

"The creative spirit is one and indivisible. It cannot live and work under servitude or external control . . . . It we are right in holding that the most urgent business of our age is to devise better laws of conduct in the arts of human government, within and beyond the limits of nationality, success depends upon stimulating in as many spots as possible the largest number and variety of independent thinkers, constructing and maintaining among them the best conditions of free intercourse and cooperation and finally enabling their creative thought to play freely in criticism and in reform upon the existing modes of political and economic life."

John Atkinson Hobson 1926

"Through the practical applications of scientific discovery our civilization is undergoing constant change. In turn, these changes bring about situations which threaten the well-being of future generations. The welfare of our civilization is now almost wholly dependent upon scientific progress. Society must respond with adequate and intelligent control."

J. Darrell Barnard 1958

IV. Political

A sympathetic governmental policy toward science is important to developing and maintaining forceful scientific activities in any country. This first became evident in Germany during the period of Bismarck when political strength was built upon science and the resulting technology. It is evident in the present century in the United States and the USSR, where a significant amount of governmental encouragement toward the pursuit of science has been available for a number of decades. However, this does not automatically mean that strong nations should enthusiastically appropriate money for scientific activities simply for the sake of scientific activity, nor does it mean that support of scientific endeavors will automatically guarantee increased strength for the supporting government. In a democratic political structure, the society which supports the government should understand the nature of science, its strengths and its limitations. When such understanding is lacking or when the society does not exert control over government, government policy could very easily support scientific ventures of little significance for the society.

Just as government-supported science is effective in meeting the internal needs of a country, it is also of utmost importance in establishing the international position of the country. No other field of intellectual activity has a comparable effect on the power struggle which goes on between nations, whether in direct conflict or in negotiation. It is essential to national prestige.

The increasing interest of the United States government in scientific research and development is dramatically demonstrated by the rate in which investment for this purpose has increased. In 1940, the total national budget for research and development was 75 million dollars. By 1953, it had increased to approximately 2 billion dollars. For the 1968 fiscal year, the total federal budget for scientific research reached nearly 17 billion dollars.

This kind of federal financial support for scientific purposes implies that there is a corresponding control upon the kind of scientific pursuits which may be undertaken on a grand scale. The time when a pure scientist could retire to his private laboratory and investigate natural phenomena tended to end when the gross observations were explained in theory and further advances had to be made in a much more intricate, sophisticated and, therefore, expensive way. In the present era, scientific research is almost always supported by some institution, either private industry or a privately funded research institution. But, to a large degree, funds for this kind of work come through tax policies from some level in the political structure. This is often true even in colleges and universities where academic freedom is prevalent, but where research is dependent upon grants.

Because of this dependence on governmental financing, there is a tendency toward political determination of the direction of scientific research. If the political policies governing this determination of direction are well advised, the purposes of science, society and the government can be advanced. The source of advice in scientific matters often comes from the practicing scientists themselves. However, in a democracy, an informed citizenry has the responsibility not to submit to the control of a limited number of scientific experts. Social techniques are needed to insure that decisions made by politicians, with the advice of scientists, concerning scientific research will truly reflect the needs of their constituents.

It is the responsibility of science educators to make students aware of the impact of science upon national strength and policy and, also, the impact of political influence upon scientific achievement. The nature of science and the resulting understandings and processes will become more meaningful to the lives of individuals when they can see how science is related to the strength and influence of their country.

"Our capacity to create new problems as rapidly as we solve the old has implications for the kind of society we shall have to design. We shall need a society which is sufficiently honest and open-minded to recognize its problems, sufficiently creative to conceive new solutions, and sufficiently purposeful to put those new solutions into effect. It should be, in short, a self-renewing society ready to improvise solutions to problems it won't recognize until tomorrow. The vitality of our science and technology will have a good deal to do with whether we achieve that kind of society."

John W. Gardner
U.S. Secretary of Health, Education and Welfare 1967

"Without such a major effort (as the space program) the medically important organizational details of the human cell could remain a closed book for a long time to come."

Dr. Norman G. Anderson 1967

V. Sociological

Until the latter part of the 19th century, scientists were pretty much independent of society; in turn, society was not influenced to any great extent by the application of scientific discoveries. Then, in the 1870's, technological development based upon the products of pure science began to affect the lives of people. While the changes were profound, they tended to be adopted slowly, allowing time for the adaptive process. However, as the scientific climate changed, the almost exponential rise in the rate of scientific discovery and the corresponding decrease in the time lapse between discovery and sociological application reached into the physical and emotional lives of large numbers of people simultaneously. This snowballing of technological advances has completely changed the attitude of non-scientist toward the scientist.

There is a distinction between science and technology that should be understood. Science refers to the accumulation of knowledge about natural phenomena. It includes not only the knowledge itself, but also the interpretation of the knowledge and the methodology by which such knowledge is gained. Technology, on the other hand, refers to the activities which result in the production of materials and services. Technology is almost always sponsored by commercial or governmental interests since it is largely through technological development that economic and social progress can be achieved. It is commonplace for laymen to speak of science when they really mean technology. Science and technology can and do interrelate, but they are not synonymous.

"*An entirely new character has been given to the whole of our modern civilization, not only by our astounding theoretical progress in sound knowledge of Nature, but also by the remarkably fertile practical application of that knowledge in technical science, industry, commerce, and so forth. On the other hand, however, we have made little or no progress in moral and social life, in comparison with earlier centuries; at times there has been serious reaction. And from this obvious conflict there have arisen, not only an uneasy sense of dismemberment and falseness, but even the danger of grave catastrophes in the political and social world. It is, then, not merely the right, but the sacred duty, of every honorable and humanitarian thinker to devote himself conscientiously to the settlement of the conflict and to warding off the dangers that it brings in its train.*"

Ernst Heinrich Haeckel 1900

"*As a result of our hard-won gains, we can begin to devote a greater proportion of our space effort to practical applications of scientific and technological research. The future holds much promise of even greater returns on our investment than the remarkable output of the past.*"

Homer E. Newell
Assoc. Administrator
NASA 1967

The use of new scientific knowledge by applied scientists and technicians requires the lapse of a variable period of time. Basic knowledge cannot be technologically applied until it is available and understood and until the practicality of the knowledge is appreciated. Once these criteria are met, it is only a matter of time before application occurs. An additional time lag occurs between development and the actual use of the product by society. Within this total time period, society must make its adjustment to the changes resulting from the new development. These changes may or may not be easily predictable.

The early application of fundamental knowledge to social uses took place very slowly. Faraday's discovery of electromagnetic induction was basic to the invention of the electric generator. However, while Faraday's discovery was made early in the 1830's, a practical electrical generator was not invented until 1870, a lapse of approximately 40 years between discovery and application. Today the period between discovery and application has collapsed to a small fraction of that time. The transistor principle was discovered in the 1940's and transistorized appliances were being manufactured by the mid - 1950's. In the present decade, space research is followed almost immediately by application.

While the shortening of this time lag may seem valuable, it is not without its problems. The fast rate of technological development creates corresponding needs which the pure scientist sometimes finds difficult to meet. For example, the rapid development of the space program created a need for special materials that could withstand the stresses of re - entry into the earth's atmosphere without being prohibitively heavy. When this problem was first recognized, the basic knowledge concerning such materials was not available to the materials engineers. It is, of course, in this kind of situation that scientific research receives pressure and therefore direction from society.

On the other hand, science depends upon technology for the development of new and better tools to make possible better techniques for scientific investigation. The development of the computer, an important example, has greatly enhanced scientific research since calculations can now be made much more rapidly than before and, more importantly, since previously unsoluble problems can now be solved or approximated through computer technology. Computer usage has also greatly reduced the problems of further technological development and sociological application.

One of the greatest problems resulting from the use of scientific knowledge in technology arises when application follows discovery in such short order that there is little time to anticipate possible adverse consequences. An example of this is evident in the indiscriminate use of persistent pesticides such as DDT. This insecticide came into use during World War II and within a decade was being applied to insect control problems on a world-wide basis. The insecticide was prized because of its persistence. Yet, because of that very persistence, the accumulation of DDT in the environment has created a hazard to many desirable animal species unable to tolerate the level of pesticide to which they are exposed. Sometimes such an adverse reaction can be more subtle. When detergents were first used to solve hard-water problems, the resulting pollution was not anticipated. Similarly, the invention of the internal combustion engine did not carry with it a warning about air pollution or traffic dangers. Not so subtly, the adverse social effect of the atomic and nuclear bombs was well known even before development began, but immediate needs were met without finding solutions to the related problems. In this respect, technology becomes involved in moral issues, whether such involvement is desirable or not. Unfortunately, moral issues are often set aside without a complete solution.

The student of science should be aware of the problems of technological advances based upon scientific knowledge so he can react to his ever-changing society in a positive way. Every generation will be faced with decisions involving technological progress intended to improve the lives of men. It is important that each person look intelligently and analytically at all aspects of such development. Everyone must realize that individuals, industry and the country as a whole stand to benefit from technological advances. However, they must also realize that the motives behind such advances do not always provide for the needs of society.

"The rapid progress true science now makes, occasions my regretting sometimes that I was born so soon. It is impossible to imagine the height to which may be carried, in a thousand years, the power of man over matter . . . O, that moral science were in as fair a way of improvement, that men would cease to be wolves to one another, and that human beings would at length learn what they now improperly call humanity."

Benjamin Franklin 1780

"The advance of the broad front of science . . . is largely governed by its application to current social needs."

Association of Scientific Workers 1945

"Hypotheses are the scaffolds which are erected in front of a building and removed when the building is completed. They are indispensable to the worker; but he must not mistake the scaffolding for the building."

Johann Wolfgang von Goethe c 1830

"Whoever rejects faith in the reality of atoms and electrons or the electro - magnetic nature of light waves or the identity of heat and motion, cannot be found guilty of a logical or empirical contradiction; but he will find it difficult to advance physical knowledge."

Max Planck 1913

"Science is the attempt to make the chaotic diversity of our sense experience correspond to a logically uniform system of thought."

Albert Einstein 1940

"The fundamental characteristic that is common to both children and science is that both are actively involved in interpreting the objects and events of the environment."

Gerald S. Craig 1958

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Committee Members

Kenneth W. Dowling, Coordinator
Wisconsin Department of Public Instruction

Calvin W. Gale
University of Wisconsin
Madison

Leonard J. Garside
Wisconsin State University
Platteville

Richard E. Haney
University of Wisconsin
Milwaukee

Aaron J. Ihde
University of Wisconsin
Madison

Hildegard Kuse
Wisconsin State University
Stevens Point

Harold G. Liebherr
Nicolet High School
Milwaukee

Richard G. Netzel
Wisconsin State University
Oshkosh

George T. O'Hearn
University of Wisconsin
Madison

Milton O. Pella
University of Wisconsin
Madison

Carl Pfeiffer
Monona Grove High School
Monona Grove

Cameron Smith
Racine Public Schools
Racine

Hjordis Wolfe
Spring Harbor Elementary School
Madison