ED 052 972 SE 012 074

TITLE Science Framework for California Public Schools, Kindergarten--Grades One Through Twelve.
INSTITUTION California State Dept. of Education, Sacramento.
PUB DATE 70
NOTE 160p.

EDRS PRICE EDRS Price MF-$0.65 HC-$6.58
DESCRIPTORS *Curriculum, *Elementary School Science, Instruction, *Objectives, Scientific Concepts, *Secondary School Science, State Curriculum Guides, Systems Approach
IDENTIFIERS ESEA Title V

ABSTRACT

An application of a systems approach to the improvement of science education from kindergarten through grade 12 is described. The report assesses the need for science curriculum reform, takes into account the philosophies, learning theories, curriculum organization patterns, and teaching strategies being advocated by current leaders in science, psychology, and education, and provides models and guidelines for science curriculum development and instruction consistent with specified goals and current instructional philosophies. Examples of behaviors indicating pupils' attainment of specified terminal objectives are provided for each of the four main goals of science education: attitudes, rational thinking, scientific skills, and knowledge of scientific processes, principles, concepts, and generalizations. An annotated bibliography precedes appendices detailing a conceptual scheme useful for selecting content, outlining methods of assessing needed teacher competencies, and analyzing alternative teaching strategies. (AL)

Science Framework

FOR CALIFORNIA PUBLIC SCHOOLS

KINDERGARTEN - GRADES ONE THROUGH TWELVE

CALIFORNIA STATE DEPARTMENT OF EDUCATION
Max Rafferty Superintendent of Public Instruction
Sacramento, 1970

Science Framework

for California Public Schools

Kindergarten — Grades One Through Twelve

Prepared by the
California State Advisory Committee
on Science Education

Adopted by the
California State Board of Education

This publication, which was funded under provisions of Title V of the Elementary and Secondary Education Act, was edited and prepared for photo-offset production by the Bureau of Publications, California State Department of Education, and was published by the Department, 721 Capitol Mall, Sacramento, CA 95814.

Printed by the Office of State Printing

1970

FOREWORD

Developments in science and technology have improved our way of living and have become a major influence on our culture. No person in our society escapes the direct influence of science. We are concerned about maintaining a livable environment. We are surrounded by the plants that supply our food, heat and light from the sun, and the mineral resources of the earth. All these things suggest the breadth of science. Because of the impact of science on our social, economic, and political institutions, every responsible citizen must have a realistic and functional understanding of science.

The need for trained scientists and technologists will continue. At the same time, the need for every citizen to have a sound background in science is becoming more critical. To meet these needs, science education must begin in kindergarten and continue through the twelfth grade. It must emphasize the skills, the rational thinking processes, and the attitudes of science as well as scientific information. It is important that science programs in the schools be subjected to continuous appraisal and that appropriate improvements be made.

In this Framework the State Advisory Committee on Science Education provides a model for science curriculum development to assist science curriculum specialists, administrators, teachers, and teacher educators in their efforts to improve the quality of science education in California public schools.

Max Rafferty

Superintendent of Public Instruction

PREFACE

The *Science Framework for California Public Schools* was prepared by the State Advisory Committee on Science Education at the direction of the California State Board of Education. It sets forth and defines the essential ingredients and structure of a science education program for kindergarten through grade twelve.

Recognizing that behind any such document there must be a rationale, the Committee first states its philosophical position and describes the unique nature of science as it relates to science education. Emphasis is then placed on a system of curriculum development based on the goals, operational objectives, and instructional strategies and techniques essential to a good science program. Prescriptive and definitive listings are avoided. While all listings are illustrative and open-ended, they are useful in designing a "model" to assist persons responsible for science curriculum development and science instruction. The listings are also of value to writers and publishers of instructional materials in the field of science.

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ACKNOWLEDGMENTS

During the course of development of the Science Framework, the California State Advisory Committee on Science Education received invaluable assistance from many sources. It is impossible to recognize individually all of the persons who contributed to the success of the project. Preliminary materials were read and discussed by hundreds of representatives of school districts, offices of county superintendents of schools, and collegiate institutions. Their suggestions were most helpful.

Special acknowledgment is extended to former members of the Advisory Committee and to members of the Curriculum Commission Committee on Science who assisted in the development of the Science Framework and to persons who served as consultants and assumed writing assignments for the Committee. The help of the following persons is gratefully acknowledged.[1]

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Introduction

The national reform movement to improve the teaching of science in American schools began a little over a decade ago. The origin of this movement was in a period of crisis, and the need for reform was regarded as a national emergency. In the years following the crisis, the scientific community took on the major responsibility for building new courses in science from kindergarten through high school. The original intent was to update the subject matter of the curriculum to bring it in line with contemporary thinking on science, particularly with reference to modern theories, laws, and systems of ideas. But some scientists and educators saw the need to redirect the goals for teaching science as well as to reorganize the courses. They would have science taught for the contribution it makes to intellectual development. To accomplish this purpose, the development of inquiry processes was identified as a major purpose of science instruction. The scientists and educators also recognized the overload of factual information in science courses, and they selected the content for the new courses in terms of a limited number of fundamental concepts and basic theories. These decisions made new demands on how science was to be learned by young people and on the ways of teaching science.

These developments were not intended to be radical, but for many reasons they did come as a curriculum "shock." The subject matter of courses was different from the past. "What it means to learn science" had a new interpretation. The complexity of these changes engendered difficulty in communicating their philosophical meaning and their implications for educational practices. To assist in bringing these modern points of view to the attention of teachers, school administrators, and teacher educators in California, a State Advisory Committee on Science Education was appointed by the California State Board of Education. This Committee has spent several years analyzing the reform movement and defining its implications for a coordinated science program from kindergarten through grade twelve in California schools. The major part of this report is devoted to describing and illustrating the curriculum components of a new science program.

The Advisory Committee assumed the responsiblity for designing an approach to science curriculum reform that would be of practical use to the schools in their own efforts to modify science offerings and which, at the same time, would reflect modern educational thought. To achieve this purpose, it was felt that a modified systems approach to curriculum development would prove to be most useful for local science committees at both the elementary and high school levels.

A systems approach to the definition and solution of an educational problem (e.g., how to improve science education) offers such advantages as its logical and orderly approach to problem solving and its analytical procedures for checking the validity of suggested problem solutions against the resources and constraints of the real world in which they are expected to operate. Total application of the approach in the present situation, however, would involve use of technical terms and procedures which are as yet unfamiliar to a large segment of the educators for whom this framework is intended. The Advisory Committee's intent, therefore, is to apply the steps of systems analysis to the problem and to describe these steps, whenever possible, in the more familiar language of curriculum development. This means the Committee looks upon the educational enterprise as a complex system of many parts and functions which must operate in a logically coherent manner to attain the objectives for which schools exist. In this system we must consider people (children, teachers, administrators, and the public), the characteristics of our culture and its direction (social, economic, and political), and the nature of the discipline concerned (its concepts, acceptable methodologies, and explanatory structures). These are the constraints influencing the philosophy, policies, and practices of a mission to improve the teaching of science.

The first step in a systems approach to the solution of an educational problem is the identification and definition of the problem for which a solution is sought. In this instance the problem was identified by the State Board of Education in its charge to the Advisory Committee. In general terms the problem, as stated by the Board, was to recommend to the California Curriculum Commission and the State Board of Education ways and means for improving science education in California elementary schools and high schools. As defined by the Committee, the problems were (1) to assess the present status of science education in California schools; (2) to review the philosophies, learning theories, curriculum organization patterns, and teaching strategies and techniques which are being advocated by current leaders in science, psychology, and education; and (3) to provide information, models, and guidelines which will assist all persons and agencies responsible for curriculum development and instruction in updating and upgrading the science learning experiences and teaching processes that they provide for their children and youth.

This document, a solution to the problems as stated by the Board and as discerned by the Committee, is a suggested plan which is intended as a model for developing science curricula and teaching strategies. The Committee realizes that human behavior does not often follow the logical order of a systems approach; it is used here to assure that significant aspects have been considered in curriculum development.

To sharpen the focus and to provide a logical approach to curriculum analysis, a flow chart was developed (see Figure 1). It shows the major functions that are performed in curriculum development and revision and the order in which each should be carried out. The defined sequence of functions does not imply a separation of activities; rather, there is need for continuous interaction and feedback in all phases of curriculum development to assure consistency and to profit from refinements in thinking and new insights.

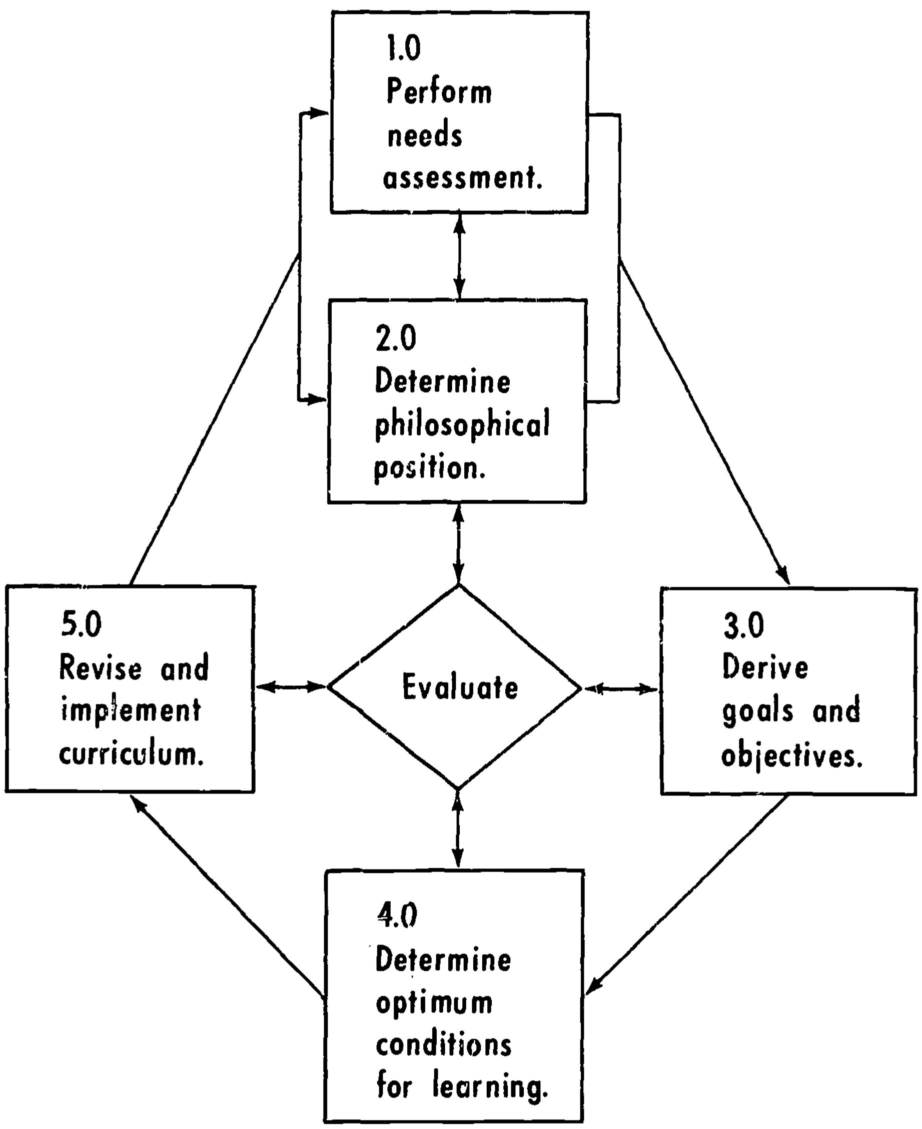
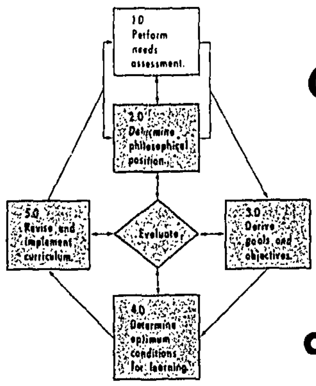


Fig. 1. Sequence of Functions in Curriculum Development



CHAPTER I

Assessing the Need for a Science Curriculum Reform

One starting point for curriculum revitalization in the sciences is to reexamine our premises about the importance and the place of science in general education. This requires an assessment of the needs of students in a modern scientific-technological-industrialized society and a determination of the most significant contributions that science teaching can make to the fulfillment of these needs.

Educational aims and objectives for science education are derived from analyses of (1) the nature of society; (2) the nature of the learner; and (3) the nature of the discipline called science.

The State Advisory Committee on Science Education believes that it is not appropriate to present in this document a detailed analysis of either the nature of society or the nature of the learner. In a complex culture with a pluralistic value system and in which different segments of society participate in decisions regarding the

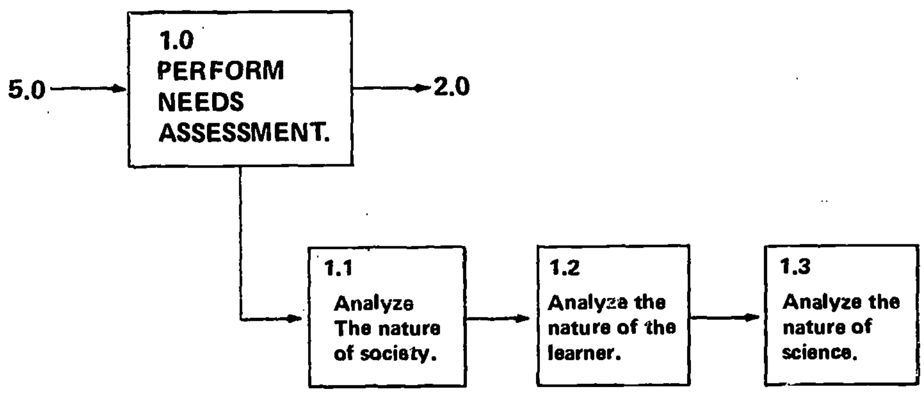


Fig. 2. Analysis of Function 1.0 — Perform Needs Assessment

nature and emphasis of education, educators have the difficult task of deciding which of the many societal and personal needs should receive priority in the schools for which they are responsible. This implies that curriculum planners at the district and school levels must assess the needs of the particular society and individuals they serve while being aware of the complexities and idiosyncrasies of the society of the state and nation.

This document includes a few suggestions, questions, and ideas that could be of assistance to curriculum workers as they analyze the nature of society and the nature of the learner. The nature of science, on the other hand, is detailed in this document because it can be generalized and is applicable in a wide variety of local situations.

1.1 Analyze the nature of society.

The Nature of Society

We are living in a world which has shrunk in space and time and which is changing at an accelerating rate. Advances in science have contributed to many of these changes. The ability of scientists to generate new knowledge is one of our major economic assets. The support of research to develop more knowledge has in many instances become a political issue. The interaction of science and technology has brought about changes in our way of living – some to our advantage, such as a greater freedom from disease, and others that give rise to an unfavorable environment, such as the widespread pollution of air, water, and soil. The production of new knowledge and its importance to the progress of our culture make increasing demands upon the science curriculum. They also influence the goals of instruction. No longer is it possible to teach a child in school all that he should know in life; rather, we must focus on a few concepts that may be widely generalized and then teach the child to think rationally. These observations are only illustrative of the ways in which present conditions within our society influence the character of science teaching.

Even this brief overview brings out some of the difficulty of prescribing how education can meet the needs of a society of the future. The Advisory Committee, aware of the enormity of the task that faces the educator, believes that science education can contribute toward solutions the man's problems of living with man.

1.2 Analyze the nature of the learner.

The Nature of the Learner

The characteristics of the learner influence not only the choice of subject matter for the curriculum but also the instructional conditions under which the learner attains the goals of learning. One purpose of a curriculum is to provide a design for relating teaching procedures to the intellectual growth, including skills and attitudes, of the individual. An effective science curriculum is one that supports the desired learning endeavors, is valid in terms of science, and is in harmony with society, which must itself be supportive of the learner's efforts.

The learner characteristic we are most certain about is the uniqueness of the learner as an individual. At any time or place, a class represents a range of diversities, with differences among its members influenced by society and culture, responses to environmental conditions, genetic potential, levels of aspiration, and other conditions. This leads the Committee to suggest that the intellectual growth of all pupils requires a curriculum with different kinds of learning components that are taught through a rich array of instructional techniques, paced at a rate that assures individual mastery, and designed to bring every child to his maximum potential as a self-directed learner.

If the curriculum is to promote intellectual achievement, it needs to be organized and sequenced in terms of the growth and developmental characteristics of young people. The cognitive growth of the individual depends upon the structure and processes of the curriculum. As the child learns — that is to say, acquires verbal, symbolic, and attitudinal mediators — he moves through phases of intellectual development assuring an ever-increasing potential for further intellectual achievement.

The Advisory Committee recognizes that the intellectual growth of the child results from the interaction of a complexity of unique individual characteristics that are influenced by the family, the culture, the curriculum, the mode of instruction, and the organization and operation of the school.

1.3 Analyze the nature of science.

The Nature of Science

The most remarkable discovery made by scientists is science itself; that is, scientists owe their growing success during the last 300 years to the way they have been able to identify certain elements in the processes that they go through in order to make their discoveries. Some of these elements can be learned; more people have learned to be scientists in our lifetime than in all human history before us. We cannot, of course, teach people to make great discoveries, but we can, at least, describe some aspects of how discoveries were made. The evolution of this process and identification of some of its elements has been the essential discovery of science.

A Systematic Way of Answering Questions

In the sense that we are speaking of here, science is a systematic way of answering questions. A description of ***how*** scientists go about this task and *why* this has yielded such a vast amount of knowledge is not simply a technical matter; on the contrary, the how and why imply a special relation and attitude of man to his environment and are therefore important to every thinking person.

There are some points that must be clear in our minds before we begin to discuss how the scientist works. Science is not a mere register of facts; and indeed our minds do not (like a cash register) tabulate a series of facts in a natural sequence one after the other. Our minds connect one fact with another — they seek for order and relationship — and in this way they arrange the facts so that they are linked by some inner law into a coherent network.

Essentially, it is the very process of establishing order and relationship among facts that has been systematized and further developed into a set of procedures we have chosen to call science — a systematic way of answering questions. As a result of this process, an organization of knowledge is being built.

An Organization of Knowledge

The facts are observable, but their organization is not. Man invents an organization which seems to fit the facts he observes. The scientist tries to build a conceptual model of possible organization step by step, probing and testing each step. The nub of being "scientific" is the procedure of testing whether a model of the relationships within nature remains consistent with the facts when we add a new fact to those from which the model was formed.

In science, this is the crucial test, and to make it the scientist must think of places and phenomena that have not yet been explored. Therefore, he seeks the implications of his model and uses the model to make predictions about nature in new and different situations. Predictions are made by reasoning logically from the model, but they can only be tested by seeing if they are consistent with nature in the new situation. Sometimes such a situation occurs of itself; astronomers had only to wait for the eclipse of 1919 and good weather to test Albert Einstein's prediction that light is bent toward massive bodies. Usually the situation has to be created artificially, as Gregor Mendel did in his monastery garden to test his theory of inheritance, or as modern geneticists have done to test Watson and Crick's model of the DNA helix. In essence, every "good" experiment is a challenge of this kind in which a model's degree of power to explain and predict is indicated. The laboratory is often a convenient setting for a scientific challenge because it is designed to keep out whatever is irrelevant. In the laboratory the scientist tries to strip his test to the naked essentials.

If a new fact contradicts his prediction, then the scientist knows his model was in error. That is simple and precise. But when the facts conform to the prediction, the matter is not simple. The model now has a new fact to support it, but ***support is not proof.*** The new supporting fact is just added to existing knowledge; it confirms the application of the model, and widens its range, but it cannot be decisive – it cannot show that the model is universal. Evidently no model is universal, and the point of experimentation is inevitably to uncover a situation in which the model fails. Thus, scientific theories of 100 years ago look crude and primitive today and were mistaken in many of their underlying concepts. It is the fate of theories to be right up to a point and thereafter wrong; and this is precisely the basis for scientific progress.

The Progress of Science

During the Middle Ages (leaning upon the axiomatic approach of the Greeks, particularly of Aristotle), it was thought that all knowledge of nature could be gained by reasoning from a basic model, the features of which scientists believed were self-evident. Francis Bacon, early in the seventeenth century, turned this view upside down by proposing that only practical observation and experiment would yield a knowledge of nature. He believed that the laws of nature and a connected model of their organization would flow from this empirical knowledge and leap to the mind in a self-evident way. But since 1666, when Sir Isaac Newton conceived the law of gravitation and thought out a test for it by calculating the period of the moon, scientists have worked by coupling the two procedures in alternate steps. This coupling of reason and empiricism, in a constant "leapfrog one over the other," was explicitly enunciated by Alfred North Whitehead 50 years ago.

Thus, the progress of science relies on a to-and-fro movement between the two procedures. On the one hand, there is the procedure of reasoning to find new implications of a model. And, on the other hand, there is the procedure of setting up practical experiments to test these implications in new situations which are as decisive as possible. Sooner or later, a decisive experiment reveals that the model is deficient in some respect because it fails to explain the new fact being tested. Then the conceptual model will have to be amended if it is to include the new fact. And so is begun a new round of reasoning to find the implications of the new model and then of testing these implications empirically with experiments which challenge new situations.

In recent years, Karl Popper and J. Bronowski have shown a third agent in the progress of science. They have demonstrated that when an empirical test shows that a model is deficient, it is not self-evident in which of several ways the model is best changed; and the next model cannot be constructed by any logical process of pure reasoning. The new model can only be conceived by an act of imagination. What Francis Bacon called ***induction*** is really ***imagination;*** and the progress of science from model to test, and from test to new model, requires the human imagination as an active agent.

The great role of imagination can be seen in the change from Newton's system to the new outlook. It took from the 1880s until 1905 to effect the change because a new and fundamental concept had to be created, and great minds were busy trying to make that radical innovation. In the end it took Albert Einstein's outstanding imagination to form the principle of relativity — a profoundly new way of visualizing the organization of events and a new philosophy of nature.

An Attempt at a Single Definition of Science

Science is the organization of our knowledge in such a way that it commands more of the hidden potential in nature. The first part of this definition summarizes in the word "organization" the three-legged conjunction of reason, experiment, and imagination. The second part of the definition states our belief that we progress by constantly uncovering more in nature than we knew to be there.

Why have scientists been so successful for 300 years in steadily enlarging man's control over his physical and biological environment? Why have we achieved a command of natural forces that is so much more effective and persuasive than our command, say, of social forces?

The answers to these questions are implicit in our definition, namely, that *it is knowledge of nature that gives us command of her potential.* This is the essential conception of science, and it is a relatively modern conception. It was unknown in the Middle Ages. At that time many men still thought that the forces of nature could be dominated by magic. The alchemists of that era were not seeking the laws of nature, but, on the contrary, their own selfish ends, which would turn the laws aside. Their underlying belief was that man could turn nature to use by bewitching her so that she would be compelled to run counter to her normal laws.

The essential method of discovery, which we call science, is an outright rejection of this view. Scientists believe that the potential of nature cannot be commanded by magic, exhortation, or persuasion; it can be commanded only by knowledge. We cannot overthrow the laws of nature, nor even flout them. Instead, what we have to do is discover the laws and organization of nature and then think of ways in which we can use them to do for us what we want done. That is how the dynamo was invented, as well as antibiotics, the jet engine, and the laser beam. Scientists succeed in practice because they succeed in theory — because they accept the inner organization of nature as they find it and then arrange to put it to human use. No magic spell could have produced a nuclear chain reaction; it was produced from the modest finding that natural uranium contains several isotopes, and then by patiently sorting out one isotope from another, nothing more. There can be no more vivid demonstration of the definition: ***Science is the organization of our knowledge in such a way that it commands more of the hidden potential in nature.***

A Basic Change of Outlook and Its Effect Upon Society

The success of science has its roots in a basic change of outlook which began over 400 years ago. It was then that Renaissance thinkers came to take a different view of nature and to see it not as an antagonist but as an ally. The key to a fuller physical life, they saw, is not a secret hermetic formula — the philosopher's stone or the elixir of life — that will cow nature and force it to run counter to its own laws. On the contrary, the key is knowledge — an active and practical method of discovery which enters into the very processes of nature and by which man can learn to direct those processes to human ends. For example, the alchemists tried for centuries to conjure one metal into another and failed; yet, we now know how to do it simply because we have learned how it is done in the stars. So profound a change in outlook is not merely a technical matter or a useful device for professionals. The scientific temper has spread through the whole community of man and created a universal climate in which knowledge is indeed seen as a key to a full life — a consistent intellectual life as well as a full physical life. For example, the gradual erosion of superstition by science is, we now see, something more than a happy accident; it lies at the root of our conviction that nature can be rationally understood and can be guided to our ends by understanding. One of the major social influences of science has been the belief, in this sense, in the power of knowledge. This is basic to the democratic view that every man has the right to be heard and have a voice in guiding the actions of his community. Precisely here has the scientific experience shown the value of the dissident voice. This has been a powerful social influence in smoothing the way for the evolution of Western society by democratic reforms.

There is another feature of modern, and particularly Western, societies which is bound up with scientific thought: science is an active mode of knowledge. We do not believe, as some Eastern cultures do, that the universe can be plumbed and understood by contemplation alone. Reason and imagination are indeed necessary to the progress of knowledge, but they have to be tested constantly by active experiments. Moreover, scientists do not claim that human findings will ever be final. On the contrary, they proceed to enlarge knowledge by a constant series of corrections and refinements. A passage from W. K. Clifford puts this cogently: "Scientific thought is the guide of action; the truth at which it arrives is not that which we can ideally contemplate without error, but that which we may act upon without fear."[1] Clifford drew from this statement the bold conclusion that "Scientific thought is not an accompaniment or condition of human progress, but human progress itself."[2]

No doubt this overstates the place of science in our society. Yet it does draw attention to the essentially active outlook that scientific thought has given to the modern world, the reliance on originality and individuality, the drive for personal achievement as the foundation for communal progress. The meaning of human life ***is*** its achievement, particularly the achievement of knowledge.

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[1] W. K. Clifford, "Aims and Instruments of Scientific Thought," quoted in William Kingdon Clifford, ***The Common Sense of the Exact Sciences.*** New York: Alfred A. Knopf, Inc., 1946, ii (frontispiece).

[2] ***Ibid.***

An Ethic of Science

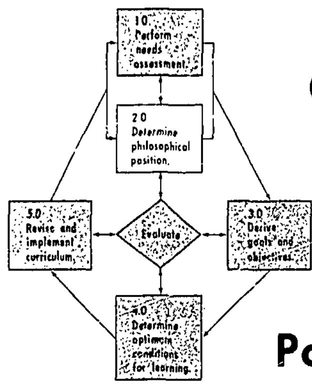
It is sometimes asked whether science has any ethical meaning: "Surely," say the doubters, "knowledge is neutral." And, indeed, knowledge as a closed and ticketed entry in a catalog of facts is neutral, because in that form it is as lifeless as any museum exhibit. But the ***pursuit*** of knowledge — the dedicated struggle from the known to the unknown, the will to extend the territory of truth — is not neutral. It demands from the community of scientists high standards of cooperation and trust, and these in turn can only hold if the members of that community accept the demand for honesty and integrity in their own work.

Scientific knowledge is achieved step by step by men who continually must put their ideas to the test. For the scientist the ultimate judge and arbiter is the experimental fact. The facts must be literally and precisely true, without evasion or manipulation. No appeal to dogma or to expediency can relieve the scientist from the duty to abide by that ethic.

The spread of this ethic is far-reaching. In this century, it has effected marked changes in private belief and in public conduct and has been a powerful force in fostering the growth of a self-reliant democracy. It has been an agent in freeing the modern mind and, more positively, in giving a direction to the intellectual fulfillment of man. The ethic of science is not the whole of human ethics, but it is an important part of it, and it ought to stand out clearly and naturally in the teaching of science.

The Place of Science in Modern Culture

The investigative procedures of science and the applications of the knowledge generated by these procedures have become major forces in shaping the modern world. Science is now broadly integrated into all of life, its intellectual as well as its humane phases. In America today, one is likely to become a stranger to his own culture if he lacks an understanding of the influence of the scientific enterprise upon his life. The achievements of the scientist have great potential for improving the material, social, and aesthetic welfare of mankind, and, at the same time, pose a threat to man's very existence. This seems to indicate a vital need for science education dedicated to the development of citizens who have an understanding of science, its processes, its achievements, and its potential.



CHAPTER II

Developing a Philosophical Position on Science Education

The importance of science in modern living and the need for scientific literacy on the part of all citizens seem well documented. The next step is to develop a brief but precise description of education in the sciences that will serve as a guidepost and a consistency check throughout the curriculum development project. The second phase is not independent of the first phase but grows out of it as shown in Figure 3.

Developing a philosophical position on science teaching requires a consideration of contemporary society, an analysis of the nature of science, a review of the development characteristics of children, and a consideration of learning assumptions. These functions need to be carried out with regard to the overall goals of education and with a consideration of the objectives of other subject matters within the curriculum of the school.

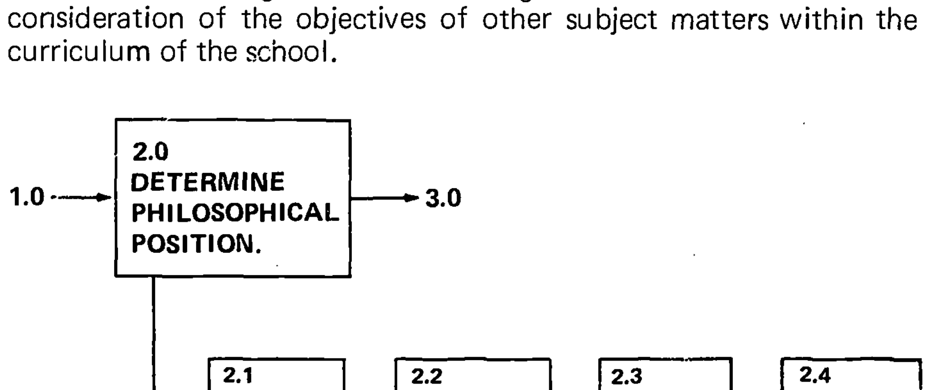


Fig. 3. Analysis of Function 2.0 — Determine Philosophical Position

The State Advisory Committee on Science Education recognizes that, as science and society change, science education in schools needs to be reevaluated and made consistent with newer developments. The Committee also recognizes that from time to time the goals of science instruction, as well as the content and organization of the science curriculum, must be reviewed and the balance corrected between the demands of the modern age and the state of the curriculum. The Committee has given serious consideration to guidelines that may be used in the preparation, evaluation, and selection of science curriculum materials. These guidelines may be used by elementary and high school personnel to focus upon curriculum improvements in science. Deliberations within the Committee led it to take the following positions on science teaching, which it believes are consistent with the nature and spirit of science, with the educational demands for living in our scientific-technological-industrialized society, and with the humane demands of this age.

2.1 Determine position on goals and objectives.

Goals and Objectives

The California State Advisory Committee on Science Education believes that:

2.1.1 A knowledge of the scientific enterprise is important for an appreciation of contemporary civilization, not alone for its intellectual achievements but also as a factor in understanding modern social, economic, and political developments.

2.1.2 A major goal of education is the development of the powers of critical observation, careful description, and rational thinking, and the proper study of science must stress the development of the processes and attitudes of scientific inquiry.

2.1.3 Knowledge of basic concepts and general principles is essential to understanding science, and the teaching of facts alone does not serve this end.

2.1.4 Individuals should be sufficiently literate in science to understand the spirit of inquiry and its basic concepts and how both are used for the advancement of human welfare.

2.1.5 The student should understand the relationship between science and technology and appreciate the contributions that both have made to the intellectual and economic development of America.

2.2 Determine position on instructional organization.

Curriculum Organization

The California State Advisory Committee on Science Education believes that:

2.2.1 The curriculum in science at all levels can be organized around representative conceptual systems, their major supporting concepts, and the processes of science, since concepts and inquiry processes are economical and highly transferable forms of learning.

2.2.2 The sequence of instructional materials from kindergarten through high school can be efficiently organized around (a) the processes of science with continuing growth in meaning and use at successive levels; and (b) the major conceptual systems of science to provide vertical coherence to the curriculum. Supporting concepts should be introduced at several levels to increase the comprehensiveness and the interpretive power of each concept.

2.2.3 A wide range of instructional media — reference books, films, laboratory and field experiences, among others — is essential for science education.

2.3 Determine position on evaluation.

Evaluation

The California State Advisory Committee on Science Education believes that:

2.3.1 All curricula, materials, and methods of instruction in science education need to be evaluated for use in terms of (a) their consistency with the nature of science, the needs of society, and the needs of the individual; (b) their basis in learning theories; and (c) their appropriateness to the developmental level of the learner.

2.3.2 Some appropriate focuses for evaluation of student progress are (a) the student's ability to think rationally; (b) the student's ability to interpret the natural world; (c) the student's understanding of the nature of science; (d) the development of the student's attitudes toward science and nature; and (e) the increase of student autonomy within the learning process.

2.3.3 School personnel at all levels should be encouraged and supported in using their own classes to develop, use, test, and evaluate, in terms of student learning, (a) experimental curricula; (b) various instructional media; and (c) innovative practices that may lead to the improvement of science teaching.

2.3.4 A continuing program of research and development and the testing of research findings in the classroom are desirable activities for teachers and administrators and are essential for educational advancement.

The Committee is of the opinion that the preceding philosophical position statements are consistent with each other and provide a logical and coherent framework for science education in California schools.

2.4 Determine position on science education.

The Nature of Science Education

The curriculum reform movement of the past ten years is regarded as the first phase of a continuing effort to refine the teaching of science in an attempt to keep science courses close to the frontiers of knowledge. Mechanisms for doing this are not difficult. However, as science continues to exert a greater influence on our intellectual life and on the course of our culture, new and more profound reasons for teaching science will become apparent. We are also at a point where we need to consider the educational implications of science, the relationship of science to public policy, the use of science for humane ends and social progress, and the means for assuring the continued generation of knowledge through research. In addition, we must recognize that the mood in which science operates is changing. This suggests that young people will, in time, need to view the scientific enterprise in a different light.

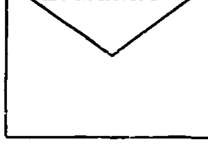
The Advisory Committee is aware of the social and cultural reforms now taking place in American life and sees the need to relate the science curriculum to these forces in a way that assures progress and positive accomplishment rather than frustration, disillusionment, and despair. Education in general and science teaching in particular have a responsibility for "inventing the future" that we, as a people, desire and for assuring the intellectual resources needed to attain that future. This means that in the next phase of science teaching reform, we must look more to the future and the lifetime of the children we teach for curriculum guidelines. The Advisory Committee is not unaware of the many new problems facing schools — the "urban crisis," continuing education for all individuals, changing occupational patterns, the knowledge "explosion," educational technology, and others. The Committee sees these as challenges to be met and as needs for the continual reassessment of the science curriculum.

While the Advisory Committee believes that our present analysis can do much to help schools bring science curriculum into harmony with modern science and the culture of our time, it sees the need, too, for an educational awareness and for a continuing effort to make the education of the 1970s a bridge to the twenty-first century.

A statement of a school district's philosophical position relative to science education and its place in the total educational program is of little value unless it is reflected in the day-to-day classroom interactions among teachers and pupils. It is essential, therefore, that teachers be actively involved in the development of such statements.

As indicated in Figure 4, a school district's philosophical position and its science education needs are interrelated. Many curriculum planners feel that a school district's philosophical attitude toward science education provides one of the bases for determining its needs. Those adhering to this point of view may wish to develop a philosophical statement prior to or in conjunction with determining their district's science education needs. Others take the position that problem areas in the existing program are identified by other means and that a school district's philosophical position provides only one set of criteria for determining which of several solution strategies is most appropriate.

The Advisory Committee's problems have been somewhat more general than those that confront school districts, schools, or individual teachers. The charge given to the Committee by the State

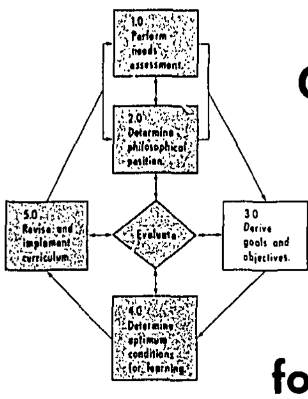


FOCUS: To identify and delineate problems underlying needs and to establish a philosophical position for planning needed changes in the science curriculum

DECISION: To reach consensus among those concerned on a philosophical statement that will provide guidelines for implementing needed changes

Fig. 4. Evaluation of Philosophical Position

Board of Education was to recommend ways and means for improving science education in California's elementary schools and high schools. The Committee selected as its initial task an analysis of those general education needs to which science education can make major contributions. In Chapter I these needs were identified and analyzed in terms of (1) societal needs; (2) individual needs; and (3) science education needs based upon an analysis of science disciplines. The philosophical position statements in this chapter incorporate the Committee's point of view relative to societal, individual, and science education needs, with a summary of its position relative to appropriate ways and means for meeting these needs. The intent of this philosophical statement is twofold: first, it provides a theoretical basis for checking the consistency of the recommendations of goals and objectives for science education and the optimum classroom conditions for attaining these objectives; and second, it may be used by science curriculum planners as a point of departure as they begin to develop a theoretical basis for determining their needs and their philosophical position relative to meeting these needs.



CHAPTER III

Deriving Goals and Terminal Objectives for the Science Curriculum for Kindergarten Through Grade Twelve

Goals and long-range objectives should be consistent with each group's philosophical position and statement of needs. The goals and objectives proposed in this chapter for science curricula for kindergarten through grade twelve were formulated on the basis of the needs described in Chapter I and the philosophical position statements in Chapter II.

Goals are meant to convey the intent of the science program. All goals must be continually reassessed to see if they are consistent with changes in cultural values, societal problems, the needs of the learner, and the nature and structure of science. The relative importance given to each category of goals may vary in accordance with each group's philosophical position. Care must be taken, however, not to stress any one goal to the point that the others will be neglected. All goals are interrelated; each is a necessary factor in the development of scientifically literate citizens.

The Advisory Committee elected to describe goals under the following headings:

1. **Scientific attitudes**
2. **Rational thinking processes**
3. **Manipulative and communication skills**
4. **Knowledge**

Operational objectives are behavioral descriptions of what the students will be able to do as a result of instruction. Such objectives are derived from and should be consistent with the goals. It is assumed that the cumulative effect of students' confrontation with situations in which the desired behaviors are practiced and demonstrated will result in their attainment of the goals. The most useful statement of an operational objective is the one that best communicates the instructional intent of the persons who select the objective.

Operational objectives may range from statements of the desired outcomes of the total science curriculum to statements describing specific behaviors that represent the intent of a single activity or learning step. Three levels of objectives — terminal, interim, and learning-step — will be described and illustrated in this document.

Terminal objectives (sometimes referred to as educational or end-of-school-influence objectives), as the term is used here, are broad statements of instructional intent for the total science program for kindergarten through grade twelve. Since student aptitudes for science vary, and since not all students receive the same amount and kind of science instruction, some students will attain each of the terminal objectives to a greater degree than will other students. Terminal objectives are usually stated by program developers and other groups concerned with the outcomes of the total science curriculum. Preliminary statements of terminal objectives are checked against performance specifications and constraints for a particular program operating in a particular school and are modified when necessary.

Interim objectives are the desired outcomes of a unit, a year's course, or some other portion of the science curriculum. Individual student performance is expected to progress along a continuum. Points along this continuum may be indicated by more precisely stated interim and learning sequence objectives. They may be stated by authors or by local curriculum committees. In selecting and stating interim objectives, consideration should be given to performance requirements for a particular group or individual and to constraints imposed by the local situation, such as the time and equipment available for science instruction at each grade level.

Learning-step objectives (or specific objectives) describe the instructional intent for a single lesson or lesson sequence. Expected outcomes of each lesson or lesson sequence are identified by naming a specific operation, giving the conditions under which the operation will be performed, and stating the performance requirement that will indicate minimum achievement of the objective. The conditions under which desired behaviors will be expected to occur are dependent upon the specific content, media, and instructional techniques used during the learning sequence. Performance requirements may vary according to the abilities of groups and individuals.

Teachers, therefore, have a major responsibility for deriving and/or selecting and ordering learning-step objectives.

The Advisory Committee has been concerned primarily with stating the major goals and terminal objectives of California's public schools for science education in kindergarten through grade twelve. The following example for goal 3 (manipulative and communication skills) illustrates how program producers and county and school district educators might break down one of the suggested terminal objectives into more specific statements of instructional intent:

> *Goal 3: Manipulative and communication skills.* The student develops fundamental skills in manipulating materials and equipment and in obtaining, organizing, and communicating scientific information.
>
> *Illustrative terminal objective:* The student organizes and records his observations and ideas in a precise, thorough, and orderly manner.
>
> *Illustrative interim objective:* The student represents data by means of bar graphs.
>
> *Learning-step objective:* After observing for a given period of time the growth of peas in three different types of soil, the student is able to prepare a bar graph which shows the average height of plants grown in each type of soil and which identifies the units of linear measure on one axis and the types of soil on the other axis.

The portion of the functional flow diagram shown in Figure 5 summarizes the steps for analyzing function 3.0, derive goals and select terminal objectives. The results of the Committee's analysis of this function are presented in the following pages of this chapter.

As indicated in Figure 5, a first-level analysis of function 3.0 (derive goals and select terminal objectives) generates three subfunctions: 3.1, derive goals (based on needs and philosophical position); 3.2, select terminal objectives; and 3.3, select tentative interim and learning-step objectives A second-level analysis describes each selected goal of science education, states terminal objectives derived from the goals, and illustrates interim behaviors that demonstrate student growth toward each selected terminal objective.

3.1 Derive goals.

3.1.1 Describe attitude goal.

Attitude Goal:

To Develop Those Values, Aspirations, and Attitudes Which Underlie the Personal Involvement of the Individual with His Environment and with Mankind

Scientific thinking is not the cold, calculating sort of human endeavor that is often depicted as a characteristic of scientists. On

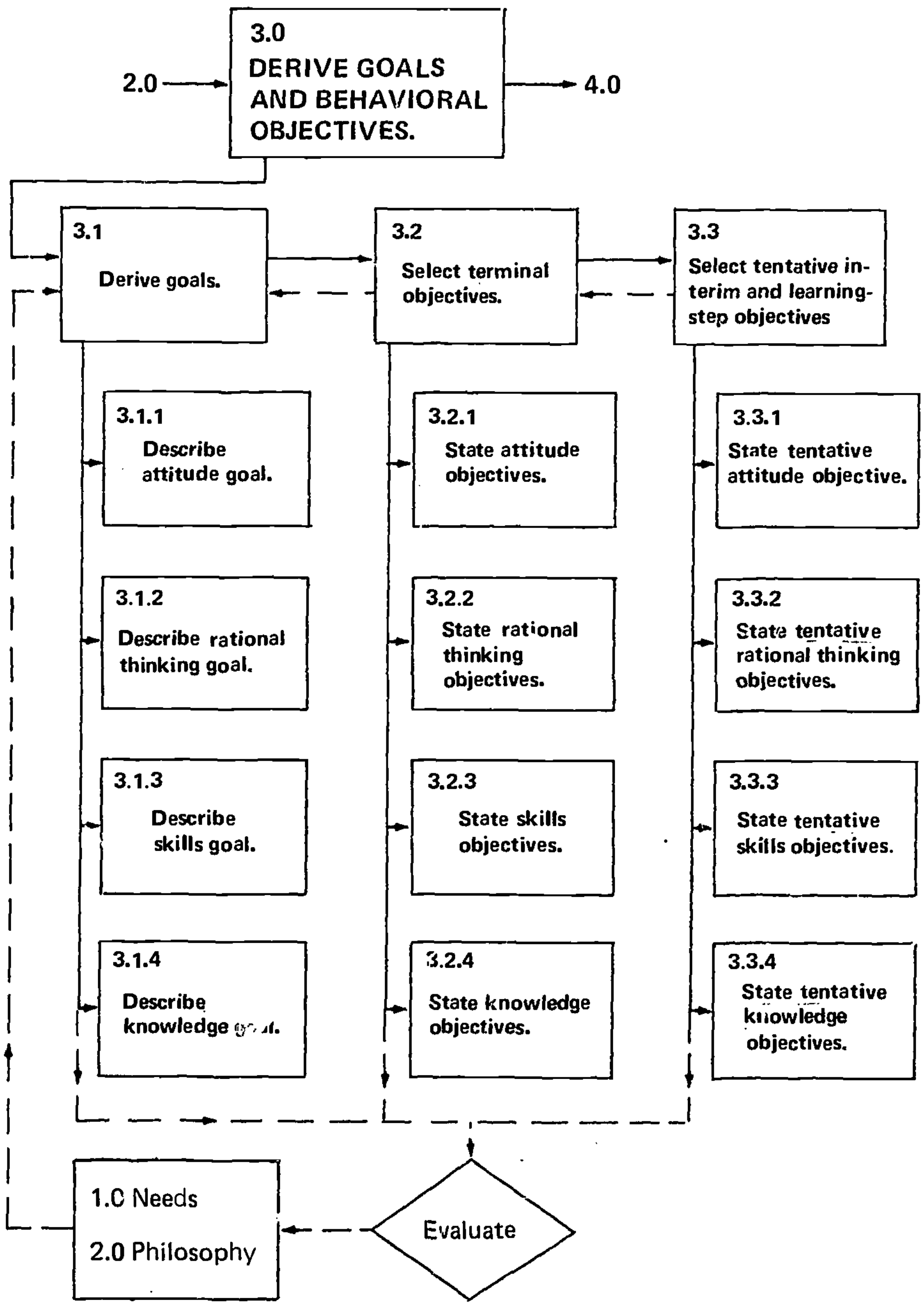


Fig. 5. Analysis of Function 3.0 — Derive Goals and Terminal Objectives

the contrary, much personal judgment and personal excitement enter into the picture. This is true both for the scientist in whose mind an idea originates and for his colleagues who help to elaborate it. Creative endeavors by the scientist are not too different from those of the artist or the poet.

Similarities between the scientific enterprise and other human endeavors have been pointed out in Chapter I. Teachers of science need to emphasize these similarities. At the same time, it should be pointed out that there are some differences.

Scientific thinking emphasizes disciplined, rational, ordered, critical, and creative thinking. It must at all times be open to criticism and welcome the challenge of conflicting thoughts. Those interested in science should realize its limitations and leave room for different approaches to the quest for truth.

The scientist plays a key role as a person. He has a sense of awe and mystery that nature inspires. Most scientists today view the natural world as an open-ended source of new discoveries. Each new theory acts as a window to the next unknown. As the scientist penetrates ever more deeply into the mystery of the atom, living matter, or the cosmos, he sees a beauty that surpasses every expectation. About this he can be passionate, and his personal involvement becomes an essential part of the motivation that drives him on to make further discoveries.

If one is to understand the nature of science, he must realize the importance of the scientific community. The productive scientist must be a part of this community; that is, he must be involved as a person with other scientists. This does not mean that he must necessarily work in collaboration with others, though that is very common, but at some point in his work he must expose his ideas to other scientists, seek their criticisms, and accept their praise. Every scientific theory is thus tested in the community of scientists.

Publications, private discussions, and public meetings play an essential role role in the whole process of verification and stimulation to further endeavors. It is usually said that support from experiments provides the crucial test for a scientific theory, but theories must also pass the test of open criticism by those working in the same scientific area. This constant exchange of ideas with others provides a bond that draws scientists together and requires that each one conduct his work with integrity. It is important that this idea be emphasized at every level of science education.

3.2 Select terminal objectives.

Fig. 6. Selected Behavioral Descriptions — Attainment of Goal 1, Attitudes

3.2.1 State attitude objectives.

Terminal objectives	Examples of student behaviors which demonstrate growth toward objectives
1. He is intrigued by objects and events in his environment.	When given several substances and asked to determine their properties, he speculates about properties that are not testable with his resources.
2. He is aware of and responds in a positive manner to beauty and orderliness in his environment.	When observing and investigating his environment, he searches for and reports evidence of order and symmetry.
3. He habitually applies rational and creative thinking processes when attempting to explain discrepant events, when trying to find relationships among seemingly unrelated phenomena, and when seeking solutions to science-based problems.	During post-lab evaluations, he suggests rational explanations for events, points out contradictions between data and explanations, criticizes explanations which cannot be tested in a rational way, and bases conclusions on experimental evidence.
4. He recognizes the limitations of scientific modes of inquiry and the need for additional, quite different approaches to the quest for reality.	When discussing possible solutions to societal problems, such as smog or the population explosion, he points out economic, psychological, or religious factors which must be considered in any proposed solution.
5. He conducts and reports the results of his scientific investigations in an honest and objective manner.	When presenting the results of laboratory investigations, he reports conflicting data, gives credit to others, points out limitations of data, and logs only those data which he actually gathered.

Fig. 6. Selected Behavioral Descriptions —
Attainment of Goal 1, Attitudes (Continued)

Terminal objectives	Examples of student behaviors which demonstrate growth toward objectives
6. He willingly subjects his data and ideas to the criticism of his peers.	During group or class discussions, he shows willingness to expose his tentative ideas and explanations to others and reconsiders his explanations in the light of his objective evaluation of additional data and conflicting explanations. He also revises his own judgment if convinced that the findings of others are superior to his own and changes his behavior to encompass these new findings.
7. He has a critical, questioning attitude toward unsupported inferences, hypotheses, and theories.	He questions hypotheses of his peers and others which cannot be tested in a rational manner and suggests alternative hypotheses.
8. He appreciates the interrelatedness of science, technology, and society.	His logical arguments demonstrate his knowledge of the relationship of technology, society, and the concomitant advancement of scientific thinking and discovery.

3.1 Derive goals.

Rational Thinking Goal:

3.1.2 Describe rational thinking goal.

To Develop the Rational Thinking Processes Which Underlie Scientific Modes of Inquiry

An effective way to describe the rational thinking processes employed in scientific inquiry is to review what the scientist does. As we examine the nature of science as stated in Chapter I, we find that what a scientist mainly does is to build and test hypotheses. Hypotheses emerge from assumptions and beliefs. They are tools invented by man which he uses as he attempts to predict and control events or to explain phenomena in his environment.

But science involves more than formulating hypotheses; each hypothesis must be tested to see how well it explains an object or event. The need for new theoretical models arises when a scientist is confronted with phenomena that he cannot adequately explain by existing theories, or as he seeks a more fundamental understanding of some aspect of nature than it is possible to attain using existing theories and models. New theoretical models come out of presently available data and theories when coupled with the inventive genius of one or more individuals.

To test, support, refine, or reject his hypothesis, a scientist generates and gathers relevant information from many sources. The more routine and concrete skills involved in obtaining, quantifying, recording, organizing, and communicating data are described in this document under goal 3 (manipulative and communication skills). Goal 2 (rational thinking processes), as defined here, refers to the higher-level cognitive processes involved in scientific modes of inquiry. Included are such processes as hypothesis formulation, "if-then" reasoning, drawing inferences from data, generalizing, predicting, and theorizing. The scientist uses these processes in a cyclical manner. He may move from data to a hypothesis, which, when defined operationally by an "if-then" statement, guides his search for answers to such questions as: What data should be gathered? How shall the data be organized? What shall be the bases for selecting relevant data? Which data will be reliable, and which should be discarded? An "if-then" statement guides experimentation by suggesting which variable should be controlled in the experiment and when the experiment will be completed. While carrying out the data-generating-and-gathering operations, the data may be recorded and/or organized in a way that will facilitate the intellectual operation of drawing inferences from the data in relation to the hypothesis that originally set the data-generating-and-gathering operations in motion.

In the event that the data generated by the experiment prove to be consistent with the hypothesis, the hypothesis is thereby supported. If the data do not match, the hypothesis may be rejected, refined, or rethought, or the experiment may be redesigned. Thus, theories and models emerge as powerful explanatory tools only as hypotheses are subjected to the cyclical processes of inquiry. A theory does not emerge full-blown. Rather, as more data are generated to substantiate the theory, it gains increasing power. Power is frequently demonstrated in the form of predictions. A prediction occurs when one says with a degree of certainty, "If I do this, then such and such will happen." The more data generated to substantiate a theory, the greater is the predictive power of the theory.

The processes of scientific inquiry may be functionally classified as data-generating processes and hypothesis-building processes. Examples of processes involved in each of these functions include the following:

Data-generating processes		**Hypothesis-building processes**
Observing Experimenting Verifying Predicting	↔	Organizing Inferring Analyzing Synthesizing Generalizing

Emphasis on the processes as well as the products of scientific inquiry provides students with a realistic understanding of the nature of the scientific enterprise. Moreover, this emphasis provides for all children and youth opportunities to perform the operations for themselves so that they may be able to subject their own theoretical models for explaining objects and events in their environment, as well as those invented by others, to the processes of rational scientific inquiry. Such an emphasis promotes the development of autonomous learners, a major goal of education.

3.2 Select terminal objectives.

Fig. 7. Selected Behavioral Descriptions — Attainment of Goal 2, Rational Thinking Processes

3.2.2 State rational thinking objectives.

Terminal objectives	**Examples of student behaviors which demonstrate growth toward objectives**
1. He selects criteria for and develops classification systems and uses his systems and those of others to classify given objects and events.	When given a set of objects and asked to classify them according to their observable properties, he constructs a one-, two-, or multistage classification system and names the observable characteristics upon which his classification is based.

Fig. 7. Selected Behavioral Descriptions — Attainment of Goal 2, Rational Thinking Processes (Continued)

Terminal objectives	Examples of student behaviors which demonstrate growth toward objectives
2. He formulates tentative statements (inferences, hypotheses, theoretical models) to identify and explain natural phenomena.	When asked to state a hypothesis which may provide an explanation for some familiar phenomenon in his environment, he examines the problem at hand in the light of the relevant information which is available to him and states his supposition in a manner that suggests a procedure for testing it experimentally.
3. He generates relevant data to verify or define inferences, hypotheses, and theoretical models.	When provided with the necessary apparatus to test an "if-then" statement deduced from a particular hypothesis and asked to obtain experimental data which will support and/or refute the "if-then" statement, he reports the relevant data he obtains and identifies those data which support and those which refute the hypothesis.
4. He senses the existence of discrepant events and problems which arise when he is investigating natural phenomena.	When conducting investigations to test inferences, hypotheses, and theoretical models, he recognizes and reports data that are not consistent with the statements being tested.
5. He draws inferences from data and distinguishes between empirical data and inferences.	After writing descriptive statements of objects interacting in a system (such as a burning candle, a bimetalic strip alternately heated and cooled, or organisms in an aquarium), he is able to indicate which statements are observations and which are inferences.
6. He formulates and tests predictions derived from inferences, hypotheses, and graphic and theoretical models.	After conducting a simple experiment in which the value of one measurable quantity depends on the value of another, tabulating and plotting on a graph the series of observed measures, and drawing a curve to connect points at which observations were made, he is able to predict the approximate value of the dependent variable at another point on the curve and to verify the predicted value experimentally.

Fig. 7. Selected Behavioral Descriptions — Attainment of Goal 2, Rational Thinking Processes (Continued)

Terminal objectives	Examples of student behaviors which demonstrate growth toward objectives
7. He identifies the variables which may materially influence a given interaction in a system and finds ways to control and manipulate the identified variables.	When confronted with a problem involving interactions of objects in a simple system, he identifies variables by observing the components of the system and determining their properties. He then determines whether a given variable does influence a part of the system by manipulating it while holding other variables constant.
8. He uses the processes described under this goal, requisite manipulative and communication skills and attitudes, and his functional understanding of the concept(s) involved to design, carry out, and report the findings of an experiment.	When given a problem, he proceeds in a rational, systematic manner, acting on the basis of reliable data.

3.1 Derive goals.

3.1.3 Describe skills goal.

Skills Goal:

To Develop Fundamental Skills in Manipulating Materials and Equipment and in Gathering, Organizing, and Communicating Scientific Information

As he employes rational thinking processes to develop a conceptual understanding of the natural environment, the scientist uses a variety of skills. He obtains information through his own observations and experiments, from reading, and from listening to his peers. He uses measuring instruments and constructs and uses laboratory apparatus. He handles materials and equipment in a safe manner. He applies linguistic, mathematical, graphical, and tabular skills in recording and organizing data in a manner that facilitates the learning of the reader or the listener. If science education is to be consistent with the way scientists work, a major goal of the teacher must be to provide opportunities for his students to develop and use these manipulative and communication skills.

This goal can also be justified in terms of its contributions to the personal and social goals of education. Entrance into skilled, technical, and professional occupations requires proficiency in many or all of the manipulative and communication skills. Accountants, salesmen, bankers, managers, and social scientists, as well as engineers, physicians, nurses, and all kinds of scientists, must be able to obtain, record, process, interpret, and report information and to communicate ideas in a clear and convincing manner. The kinds and sources of information may vary, different measuring instruments may be used, and each occupation may employ its own communication symbols. Nevertheless, the fundamental skills are common to a broad spectrum of occupations. Linguistic, mathematical, and social skills also contribute to the development of competencies needed for effective citizenship.

3.2 Select terminal objectives.

3.2.3 State skills objectives.

Fig. 8. Selected Behavioral Descriptions Attainment of Goal 3, Manipulative and Communication Skills

Terminal objectives	Examples of student behaviors which demonstrate growth toward objectives
1. He constructs and handles laboratory apparatus in a skillful manner, giving due attention to accident prevention.	When given the opportunity to design and construct laboratory apparatus in order to obtain data to verify a hypothesis, he selects from available materials, equipment, and measuring devices those which are most appropriate for his particular task. He handles dangerous materials and equipment according to prescribed safety rules.
2. He gathers descriptive and quantitative information needed for developing or testing inferences and hypotheses by means of purposeful, objective observations of things and events.	When observing things and events to obtain data for the purpose of testing an inference or hypothesis, he chooses the variables in the system which seem most relevant to the problem and uses all of his senses to detect the properties of and changes in the selected elements of the system.

Fig. 8. Selected Behavioral Descriptions
Attainment of 3, Manipulative and
Communication Skills (Continued)

Terminal objectives	Examples of student behaviors which demonstrate growth toward objectives
3. He gathers needed data, which have been generated by others, from a variety of sources.	When the need arises during a problem-solving situation to gather data which he cannot obtain by means of his own observation and experimentation, he is able to obtain and abstract relevant data from printed and graphic materials and from questions posed to qualified persons.
4. He records observations accurately and organizes data and ideas in ways that enhance their usefulness.	He uses precise language in recording experimental results. He tabulates measures involving a series of paired quantities in a manner which enables him to visualize the effect that modifying one variable has on the second variable.
5. He communicates with others, orally and in writing, in a manner that is consistent with his knowledge of scientific conventions and that facilitates the learning of his readers or listeners.	When communicating scientific information to others, he describes objects or events in words that provide a clear mental picture and defines operationally terms that may not be familiar to others.

3.1 Derive goals.

3.1.4 Describe knowledge goal.

Knowledge Goal:

To Develop Knowledge of Specifics, Processes, Concepts, Generalizations, and Unifying Principles, Which Leads to Further Interpretation and Prediction of Objects and Events in the Natural Environment

Facts, concepts, and generalizations constitute an important segment of science. As indicated in the descriptions of goals 2 (rational thinking processes) and 3 (manipulative and communication skills), the student, through the practice of inquiry skills, develops his own knowledge, formulates his own principles, applies principles and concepts to situations that are new to him, and seeks his own solutions to problems. But if knowledge were to be restricted to what the student could discover by himself, it would be limited indeed. As he engages in intellectual pursuits, the student must have available from his memory and from reference sources many facts, concepts, and principles that have been developed and verified over many decades of scientific investigation. In this respect the student resembles the scientist, who is also dependent upon his predecessors and his peers. Sir Isaac Newton acknowledged this dependence when he said: "If I have seen farther than other men, it is because I have stood upon the shoulders of giants."

Information stored in a person's memory includes personal experience, information called facts, and information organized into categories, called concepts. Related and mutually interdependent concepts may become either generalizations or principles. Broad unifying generalizations and principles are referred to in this document as conceptual systems. They provide significant patterns of scientific knowledge. Such themes cut across subject matter fields and provide a structure for integrating the most basic and enduring achievements of science.

Much of the specific scientific information that students use in their inquiries into scientific phenomena cannot be determined until the topics and problems to be investigated have been selected. Such information is also subject to frequent change. The terminal knowledge objectives stated in Figure 9 are therefore described in general terms and reflect categories of knowledge rather than specifics. The specific knowledge that a particular group of students is expected to attain is described in the interim and learning-step objectives generated by each teacher or curriculum development group; these objectives are continuously revised in the light of new data and interpretations.

Information in the form of the major theories, concepts, and principles of science, however, is more generally applicable. Although still subject to change and new interpretations, conceptual systems and the conceptual structures subsumed under each of these systems remain relatively stable for a period of years.

The Advisory Committee, with the assistance of a number of scholars representing various science disciplines, selected a number of conceptual systems and described them in a manner that presents a "big picture" of scientific knowledge as it exists today. It is hoped that these descriptions will provide guidelines for selection of significant learning experiences for children and youth and a map that will assist curriculum builders in determining the direction in which to go without prescribing the route for getting there.

It is with some hesitancy that the Committee lists at this point only the titles of the systems, because only a full description can convey their meaning and significance. The reader is urged to refer to the more detailed descriptions in Appendix A. The titles of the conceptual systems are as follows:

A. Most events in nature occur in a predictable way, understandable in terms of a cause-and-effect relationship; natural laws are universal and demonstrable throughout time and space.
B. Frames of reference for size, position, time, and motion in space are relative, not absolute.
C. Matter is composed of particles which are in constant motion.
D. Energy exists in a variety of convertible forms.
E. Matter and energy are manifestations of a single entity; their sum in a closed system is constant.
F. Through classification systems, scientists bring order and unity to apparently dissimilar and diverse natural phenomena.
   1. Matter is organized into units which can be classified into organizational levels.
   2. Living things are highly organized systems of matter and energy.
   3. Structure and function are often interdependent.
G. Units of matter interact.
   1. The bases of all interactions are electromagnetic, gravitational, and nuclear forces whose fields extend beyond the vicinity of their origins.
   2. Interdependence and interaction with the environment are universal relationships.
   3. Interaction and reorganization of units of matter are always associated with changes in energy.

The Committee recognizes that there are other ways of describing these conceptual systems. In this context conceptual systems identify the content of the curriculum; they are learnable but not teachable. Selected concepts, principles, and processes of inquiry provide the subject matter in areas of study. Conceptual systems represent the long-range goals of instruction; it is these that an individual should appreciate at increasing levels of understanding throughout his lifetime. Specific concepts and inquiry skills serve as the more immediate objectives in areas of study or courses. Through an understanding of contributing concepts and relevant processes, a conceptual system acquires meaning for a student.

3.2 Select terminal objectives.

3.2.4 State knowledge objectives.

Fig. 9. Selected Behavioral Descriptions — Attainment of Goal 4, Knowledge

Terminal objectives	Examples of student behaviors which demonstrate growth toward objectives
1. He demonstrates a knowledge of specifics - facts, conventions, sequences, classifications, and criteria.	When verifying inferences and hypotheses, he recalls previously learned facts which are relevant to the problem, and he uses them to support or refute the suppositions. He is able to name, in proper sequence, the developmental stages in the life histories of representative species of the plants and animals that he has studied. When shown drawings of a variety of cells and asked to classify them as plant or animal cells, he classifies them in terms of his knowledge of the characteristics of plant and animal cells.
2. He knows the major processes and procedures which are employed in scientific inquiry.	He is able to give operational definitions of major inquiry processes (i.e., inferring, hypothesizing, controlling variables).
3. He demonstrates a knowledge of concepts, generalizations, and unifying principles.	When asked to describe the properties of solid, liquid, and gaseous states of a substance, he applies his knowledge of such concepts as the particulate nature of matter and of the effect of heat on the motion of molecules in describing the kinds of molecular motion associated with the various states of matter. He uses his knowledge of matter-energy relationships and of the properties of living things to explain the interdependence of plants, animals, and nonliving substances in an ecosystem.
4. He demonstrates a knowledge of the relationships between science and society.	When discussing the reasons for the recent explosion of scientific knowledge, he points out the massive increase in federal support of scientific research and development resulting from the cold war and the "space race."

Evaluation Criteria Used by the Advisory Committee

The Advisory Committee used the following criteria in evaluating statements of goals and terminal objectives for science education. The statement of goals and terminal objectives should:

1. Be consistent with the statement of needs and the philosophical position and in general agreement with the purposes of science education as stated by leading authorities in the field.

2. Encompass expectancies for a majority of students in the public school systems of California.

3. Be future-oriented. The goals and terminal objectives should be thought of as desired outcomes of programs that are designed in terms of the best available research on teaching-learning theories and practices and the most effective instructional materials.

4. Provide a balance of emphasis among the four goal categories.

5. Indicate ways in which the attainment of objectives in one category may be related to the attainment of objectives in other categories.

6. Be stated in a manner that facilitates derivation of interim and specific learning-step objectives by individuals and groups responsible for developing and implementing science curricula.

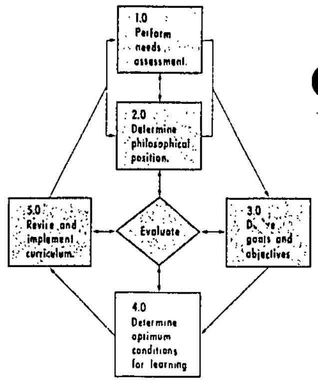
Evaluation	**FOCUS:**	**To match preliminary statements with philosophical performance requirements and constraints**
	DECISION:	**To accept tentatively or modify goals and objectives and/or performance requirements and constraints**

Fig. 10. Evaluation of Goals and Behavioral Objectives

With slight modifications, the evaluation criteria used by the Advisory Committee may be used by those responsible for determining local goals and terminal and interim objectives. Additional criteria, such as the following, apply primarily to the statement of interim and learning-step objectives for students in a particular course, school, or district.

The statement of objectives should:

1. Contribute to the school's broad goals of education.
2. Be appropriate for the developmental level of the learner.
3. Be attainable within such constraints as (a) time available for science instruction; and (b) availability of learning experiences and materials which will promote attainment of the desired behaviors.



CHAPTER IV

Determining Optimum Conditions for Learning

A distinctive quality of the change in modern science education is the search for consistency. Therefore, those responsible for improving science instruction should select or design courses and course sequences in which the objectives, the curriculum, classroom teaching, and the resultant learning harmonize with (1) the nature of science; (2) learning theories; (3) the needs of society; and (4) the developmental levels of the learners. These elements (and there may be others) serve as foundations from which teaching strategies and techniques and other consistencies which promote optimum learning in science are developed. In addition, these elements provide the following criteria against which the results of the teaching-learning process and product can be evaluated:

1. To be consistent with the ***nature of science,*** teaching must provide opportunities for students to practice some of the same kinds of inquiry processes that scientists use in investigating the natural environment.
2. Research in ***learning*** has demonstrated repeatedly that learning takes place best when the child is actively, not passively, involved. Attitudes, cognitive processes, skills, and concepts are learned as a totality in an individual's experience.
3. The ***needs of society*** at a particular moment of time provide one criterion for selecting content samples that are relevant for general education.
4. Knowledge about the ***developmental level of the learner*** is an integral part of the teaching process. Piaget, Vygotsky, Bruner, and others have provided some insight into learners' developments and achievements.

Before proceeding to analyze some of the optimal conditions for learning which the Advisory Committee believes to be consistent with these four criteria and with the Committee's statement of goals and objectives, it should be noted that what follows is merely an illustration of what can result from such an analysis; alternate appropriate procedures for attaining these goals may be selected. Furthermore, the conditions which theoretically will provide for optimum learning in science must be tested repeatedly to ascertain whether they actually do facilitate measurable growth toward the desired behaviors. If the performance of this and other functions suggested by Figure 11 becomes a dynamic and continuous process, it makes possible meaningful and continual evaluation of teaching techniques, experimentation with increasingly powerful teaching strategies, and reassessment and refinement of goals and objectives.

At least two major theories of intellectual development are found today in educational and psychological literature. Each stems from a different philosophical conception of the nature of learning. According to one theory, the learner acquires certain general concepts, such as conservation of volume, before he can comprehend related science concepts. Another theory is that he learns to account for what he observes.

The problem facing the curriculum designer and teacher is to decide which is to come first: (1) experiences that are direct

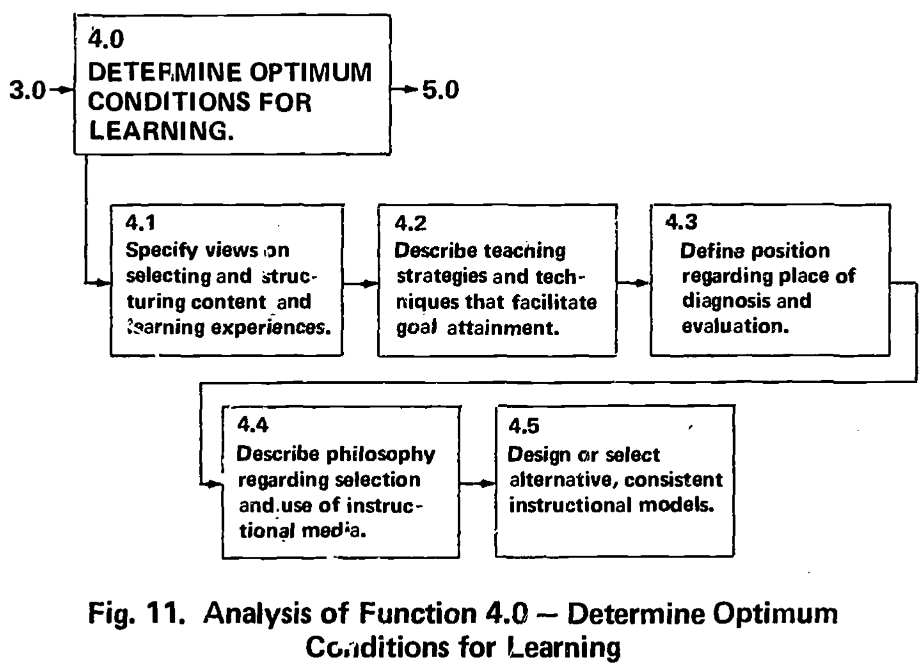


Fig. 11. Analysis of Function 4.0 — Determine Optimum Conditions for Learning

observations of phenomena to be used to shape concepts; or (2) available concepts that will guide observations and investigations. Either approach is valid for some purposes but not for others. It is not necessary to choose either approach exclusively, but one ought to be aware of the approach he is taking and the specific purposes to be achieved. One should also consider the balance and emphasis between the approaches related to his philosophy of science education and to the developmental levels and cognitive styles of the children involved.

Conditions that facilitate learning are described here under the following headings. Some persons may wish to identify additional conditions.

4.1 Specify views on selecting and structuring content and learning experiences.
4.2 Describe teaching strategies and techniques that facilitate goal attainment.
4.3 Define position regarding place of diagnosis and evaluation.
4.4 Describe philosophy regarding selection and use of instructional media.
4.5 Design or select alternative, consistent instructional models.

The Committee's views regarding each of these aspects of a science education program are stated in the following pages.

4.1 Specify views on selecting and structuring content and learning experiences.

Guidelines for Vertical and Horizontal Structuring of the Curriculum

There are two aspects involved in the selection and structuring of curriculum content and learning experiences:

1. *The horizontal structure* -- selection and arrangement of topics and learning experiences for study during a semester or a year
2. *The vertical structure* — sequencing and organization of content and learning experiences from kindergarten through high school

The horizontal structure is based upon the outcomes sought from a particular level of study. This structure is planned in terms of interim and learning-step objectives. Goals and terminal objectives, which may require years to attain, determine the vertical focus of the curriculum. A curriculum planned vertically as well as horizontally provides for maximum coherence and effectiveness. Unnecessary repetition is minimized. Concept/process growth is enhanced. A curriculum designed in this manner is a matrix of developmental learning experiences that comprises dimensions within and between levels of science. Within this matrix the series of problems, confrontations, topics, processes, or courses to be presented are organized and sequenced in a way that facilitates learning and measurement of the extent to which teacher and learner objectives are attained.

According to one learning theory, the conceptual systems and major rational thinking processes provide the vertical organization for the curriculum, giving continuous direction for learning experiences. To fully appreciate the unifying principle, "frames of reference," requires numerous encounters with this principle in a variety of contexts. From kindergarten through high school, specific objectives and learning experiences are selected to enhance the meaning of each conceptual system and the coordinate relation of all the systems.

Selected concepts, subsumed under each conceptual system, and specific encounters with each of the major inquiry processes, together with the skills and attitudes that promote or evolve from concept/process development, provide the framework for science instruction at each level. Programs designed to promote learner growth toward all four of the goals described in Chapter III include fewer topics, each studied in greater depth, than do programs that emphasize only knowledge. Content selection for such programs is a crucial aspect of curriculum development. Topics selected for study encompass basic and relevant concepts and generalizations. Trivial, out-of-date, and unscientific concepts and generalizations are avoided.

To make them meaningful to students, the analogies and applications of science are directed to situations or phenomena that are familiar to students. Making use of local materials is more a matter of teaching strategy than of curriculum.

The selection of science concepts and processes for a particular level is made in terms of the learners' intellectual, social, and educational maturity and is reflected in statements of interim and and learning-step objectives. Sequencing of concepts and processes is also dependent upon the developmental characteristics of the learner.

The sequence within a level and from level to level is developmental, beginning with concepts and learning experiences that promote understanding of the subsequent range, meaning, or performance of more complex processes. Each time a learning experience is provided, it builds upon what has come before it and creates a "readiness" for the next learning experience. In part, sequence is dependent upon contributing concepts derived from the discipline that make subsequent learning more meaningful and emphasize the interrelatedness of different areas of science. A student, for example, needs some understanding of an energy cycle and of light phenomena before he can comprehend the process of photosynthesis.

The sequencing of the process skills is dependent upon the meaning that each of them will impart to certain concepts and upon the next learning step needed to make the student's inquiry more effective. Hierarchies of process-skill objectives are derived by breaking down desired terminal competencies into their component parts. Specific skills derived in this way are sequenced from simple to complex in a manner that facilitates cumulative learning.

When this theory of learning is used, a concept or process is introduced because the teacher selects it and feels that it is important at a particular time. It is hoped that these concepts and processes will build each upon the other and will be useful when the student needs to apply them.

Another learning theory, advocated by Bruner, Suchman, and others, views knowledge not as a product but as a dynamic process. It calls for the student to develop the need for concepts and processes first. This is done by presenting to him a discrepant event or problem which challenges his present beliefs or skills. He is stimulated to find an explanation or to gather data to explain the discrepancy. The teacher can then introduce conceptual organizers and provide instruction in the processes because the student can recognize them as immediately useful in his quest for meaning. In this case, the student is motivated from within — intellectually — to close the gap between his beliefs and his observations. Advocates of this learning theory hold that this type of learning is more durable, applicable, and transferable because the student sees the relationship between what he learns and his need for learning it.

The teacher's strategy would be one of diagnosing where the learner is conceptually and then introducing problems or discrepancies that challenge that learner's present knowledge or cognitive structures. In order to assimilate this new knowledge, the learner would have to rearrange or reorganize his own concepts, gain new skills, or experience new processes that would accommodate the new learning.

The sequence of learning tasks, therefore, is determined by the learner himself as he develops the need for a new learning — whether it be a process, a concept, or a skill. When the learner determines his own need for gaining a new learning, that is the time it would be introduced. Naturally, all learners would not have the same sequence of needs but would require varying amounts of time to accomplish different learning tasks.

Transfer of learning is thought of as the ability to transfer knowledge-getting processes or strategies to new situations rather than transferring content or subject matter. From this point of view, learning is an outgrowth of the learner's attempts to derive meaning for himself in each new problem he confronts.

Planning a total school or school district science program that is consistent with this learning theory is a complex task. Since each teacher assumes major responsibility for selection of problems and discrepant events that are appropriate for individuals in his class at a particular time, vertical articulation presents a problem. One solution would be to maintain and pass on from teacher to teacher a cumulative record of the problems and discrepancies confronted by each student. An elementary or junior high school staff might select a large variety of problem-oriented units of lesson sequences based upon discrepant events and assign to teachers of each level those that seem appropriate for most students at that level. In addition to selecting problems from this list in terms of diagnosis of individual needs and interests, teachers would be encouraged to let their students work on problems of their own choosing. High schools might offer courses in a number of science disciplines and/or interdisciplinary problem courses and counsel students to enroll in courses most appropriate to their needs and interests. These courses would then be organized into problem areas with student/teacher diagnosis determining the particular problems and sequence of problems that each student would study.

A more suitable approach for some schools or school districts might be to develop a scope-and-sequence plan that applies both of the learning theories outlined in this chapter. Part of each year would be devoted to development of concept and process objectives (and related attitudinal and skill objectives) designated for study at that level. Individual differences among students could be taken care of by varying the number, nature, and depth of the problems to be solved within each assigned area. During each year time would be set aside for students to work on problems of their own choosing and on those that grow out of the teacher's diagnosis of individual needs.

4.2 Describe teaching strategies and techniques that facilitate goal attainment.

Relationship of Learning Theory to Teaching Strategies and Techniques

Teaching strategies are more than mere lesson plans. They are ingenious ways in which the teacher conducts himself and manages the environment so as to elicit, observe, and evaluate desired behaviors in learners. Teaching strategies may vary with each goal, objective, teacher, and group of learners. They include "mental maps" which the teacher uses to direct discussions, investigations, and other activities that point toward long-term goals and objectives of instruction. Strategies also serve as guides for making the most appropriate moment-to-moment decisions in the midst of the many problems that are constantly bombarding the teacher. They assist in distinguishing those behaviors that should be reinforced and those that should be ignored or modified. Having a strategy in mind ensures a more rational basis for decision making.

Strategies and Techniques That Optimize Learning in Science

Teaching strategies encompass what is known about learning theories and appropriate educational methodology. They take into account general principles of learning such as sequence, reinforcement, and transfer. The specific strategies applied to the attainment of each of the four goals of science education, however, are different. What the teacher does to establish desirable attitudes in students will be different from what he does to develop broad conceptual understanding. The present discussion focuses on how students develop the competencies related to each of the four goals of science instruction: (1) attitudes; (2) rational thinking processes; (3) manipulative and communication skills; and (4) knowledge.

Within each strategy the teacher uses techniques that are consistent with that strategy. Techniques are the procedures that the teacher uses to cause the learner to behave in desired ways. They include the overt tactics that a teacher employs to motivate, question, reinforce, elicit, encourage, observe, diagnose, interpret, prescribe, reject, and so forth. When further differentiation of teacher actions is desirable, the term "techniques" is sometimes limited to generalized procedures such as discussing with groups, asking questions, and utilizing students' ideas. More specific teacher behaviors designed to implement particular functions are then referred to as "tactics." Tactics comprise the specific interactions between teacher and students, students and students, and the interaction of both teacher and students with the content and materials of instruction. Because of the general nature of the present discussion, the term "techniques" may be assumed to include tactics.

Since teaching and learning theories are still somewhat vague and sometimes even contradictory, they are open to a variety of interpretations. The material presented in this section represents a consensus of the thinking of the Advisory Committee.

Strategies and Techniques That Facilitate Goal Attainment in Science

Achievement of objectives in any one of the four goal categories is dependent upon achievement in one or more of the other categories. Rational thinking processes, for example, are surely dependent to some degree upon manipulative and communication skills as well as upon knowledge. The development of desirable attitudes very likely depends upon the exercise of rational thinking processes and the acquisition of manipulative and communication skills under conditions in which satisfying outcomes are attained. Thus, there are many kinds of direct interactions among the capabilities implied by these objectives; they cannot be conceived as residing in separate "compartments" of the human mind. Even more important, perhaps, is the likelihood that achievements of objectives are ordered in complexity of function and, therefore, that certain kinds of capabilities must be available to the individual before he can acquire others.

Recognizing that different kinds of learning do not occur in isolation, we now proceed to describe some of the results of educational research on how attitudes, rational thinking processes, skills, and scientific knowledge are acquired and to suggest some teaching strategies and techniques that may be generated from these findings.

Strategies and techniques for teaching scientific attitudes. An attitude is a mental disposition. An individual's attitudes may be discovered by inference from the choices he makes. The choices made by an individual who has attained the attitude goal of science education include those of choosing evidence with a scientific base, choosing to credit statements made by scientists within their recognized field of competence, and choosing science as a satisfying field of human endeavor.

Positive attitudes toward science are likely to be acquired under conditions in which the learner (1) relates his own choices to those made by other persons (especially adults) whom he seeks to emulate; and (2) experiences success in carrying out scientific thinking and other scientific activities. Both these conditions pertain to the motivational development of the individual. In the first case, conditions encourage the kind of motivation related to becoming an adult and to the individual's life goals. In the second, the result is an increasingly strong attachment to types of human activity that provide satisfaction. The practical implications for teaching strategies are as follows:

1. The student needs to interact with teachers and others who derive satisfaction from scientific activities and modes of thought. Enjoyment will be communicated to the student, who will tend to acquire this attitude.
2. Science instruction should be designed to provide "success experience" from the earliest grades onward. In the beginning, the child can achieve success with relatively simple tasks such as classifying objects according to properties he selects. Later, he may experience the excitement of the scientist in seeing how data "fit" his hypotheses.

Strategies and techniques for teaching rational thinking processes. Learning to think rationally and systematically about scientific phenomena seems to be primarily a matter of practicing thinking under conditions in which problems grow progressively more complex or more abstract and in which the activity becomes progressively more autonomous. Initially, the child may learn to think out problems in only a partial manner. For example, he may practice deducing the consequences of some theory given to him, or he may make and test inferences about a discrepant event he has observed. Ultimately, the student should learn to look at a phenomenon and make his own observations and hypotheses, decide how to test them, carry out the verifications, and interpret his findings. What is desired, in other words, is that solutions to problems and explanations for natural phenomena be sought through application of the rational thinking processes of scientific inquiry.

Although there is general consensus that rational and systematic thinking is an important goal of science education, educational theorists and practitioners do not all agree on what teaching strategies are most appropriate for achieving this goal. The following alternative strategies have been derived from current schools of educational philosophy and psychology and have been applied successfully by some teachers, under some conditions, with some students.

1. Create classroom situations in which the students participate in scientific investigations — situations in which students are asked

to seek solutions to problems by means of scientific inquiry. For instance, they may be confronted with a discrepant event for which they propose explanatory hypotheses, test their hypotheses experimentally, and draw conclusions and make predictions from their results.

2. Gradually introduce increasingly complex and progressively less defined problem situations. Moving too rapidly may lead to such undesirable consequences as (a) dependence upon "hunches" that have an inadequate basis; (b) formulation of hypotheses that are not tied satisfactorily to reality by means of operational definitions; and (c) experimental investigations whose conceptual frameworks are inadequately understood.
3. Build, as much as possible, on prior learning of simple inquiry processes. Some theorists hold that to perform the more complex thought processes, one must be able to make observations and inferences, to quantify and classify data, and to develop operational definitions. Others find that these and similar simple processes are more effectively learned, by some students at least, when a situation arises in which they need to attain these competencies in order to find their own solutions and explanations for problems and events that they encounter. The efficacy of these and alternative strategies is determined in the process of developing curriculum sequences. One approach may be more effective in some situations, and another may be more appropriate in other situations.
4. In selecting and sequencing problems and events that stimulate the use of rational thinking processes, consider the relevant knowledge that students should acquire and have previously acquired in order to inquire in a meaningful and satisfying manner into the selected problems and events. While it may be true that thinking in general can be done without relevant knowledge, the rational-systematic thinking of science cannot be. Some science educators hold that the problems selected for investigation should involve facts, concepts, and generalizations for which the students already have some degree of comprehension. If the students' experiences are to parallel those of the scientist, practice should be provided that involves phenomena about which the students have already acquired some relevant knowledge. Another strategy, advocated by some psychologists and employed by some contemporary curriculum project developers, is to present students initially with a large, complex problem that they cannot solve using only their existing

knowledge. The problem is then broken down into small component problems that can be investigated and solved. In this manner, the thinking processes and knowledge needed to solve the larger problem are systematically and cumulatively developed to the point that students can handle the more complex problem. A third strategy – one which some feel enhances the learners' desires and abilities to seek and test solutions to their own problems – is to encourage students to define their own problems and to assist them in obtaining and processing the data they need to verify their hypotheses and find explanations that may be incomplete but that are satisfying to the student at that particular stage of his intellectual development. The emphasis placed on each of these strategies is determined by the philosophical position that is taken and by decisions made relative to selection of objectives and assignment of priorities to those objectives

Although descriptions of the many and varied teaching techniques appropriate for use in attaining the objectives of science education cannot be included in this brief discussion, the Advisory Committee again emphasizes that teachers should select and use those techniques and tactics that are consistent with each strategy and appropriate for each teaching situation. If, for example, the strategy calls for students to conduct an assigned investigation to verify, operationally, the generalization that green plants require warmth and light for growth, the teacher, after completion of an initial investigation, may ask questions calling for adaptive responses; e.g., "Which plants grew faster – those in the warm closet or those in the refrigerator?" On the other hand, if the strategy is to have the students develop and test their own hypotheses, the teacher might say, "Here are three pots of bean plants, all planted at the same time and in the same kind of soil. What do you think causes the plants in one pot to become sturdy and green; those in the second pot to grow tall and scrawny; and those in the third pot to look small, shriveled, and brown? Can you write your 'hunch' in the form of a hypothesis and then design and carry out an investigation that will test your hypothesis?"

The sample lessons outlined in Appendix C include additional examples of teaching techniques.

Strategies and techniques for teaching manipulative and communication skills. As indicated previously, the development of manipulative and communication skills and the development of rational thinking processes go hand in hand. Generally, student acquisition of a skill or its application in scientific study is considered to be more effective if it is taught at a time when learning the skill or its application contributes to the attainment of more complex skills or to the development of other goals. Thus, in deciding how and when to teach a needed manipulative or communication skill, curriculum specialists and teachers determine how and when that particular skill will contribute to the acquisition of other needed skills and/or to the development of other goals, analyze the elements that make up the skill, and then decide how and when to teach it. The following guidelines are pertinent to such decisions:

1. Skill development is usually gradual and sequential. One cannot expect a child to be competent in reading scientific formulas and symbols before he is proficient in the more general skills of reading. Likewise, competence in mathematics precedes competence in many aspects of natural science. This does not imply, however, that the child must be proficient in reading and mathematics before he begins to study science. In fact, his desire to understand the cause of an observed natural event may contribute to his development of reading and mathematics skills. Such related skills often develop best when opportunities are provided for one to feed the other. While skill development is sequential and gradual, as far as the learner is concerned, the unique sequence that is appropriate for a particular learner may not always be the one that is followed by the curriculum or the teacher. This implies that predetermined hierarchies for developing skills must be modified by the teacher on the basis of individual diagnosis.
2. Demonstration prior to practice often facilitates skill mastery. Learning a skill is generally more efficient if the student has an opportunity to observe demonstrations of it by someone who has already mastered it. Such demonstrations should be accompanied by opportunities for the child to attempt to practice the skill and should be conducted in a manner that allows for several repetitions of the demonstrate-try sequence. Although this is a general strategy advocated for skill development, alternate strategies may be more effective in certain situations. Some students, for example, may be motivated to make precise observations and to organize their data only after they find that the information they are seeking from an investigation cannot otherwise be obtained and interpreted.
3. Opportunities for continuing practice should be provided. Most manipulative and communication skills require considerable

practice before competency is attained. Continued practice at intervals is necessary for maintenance and improvement of skills. Providing repeated opportunities for practicing skills in meaningful and interesting problem situations is one strategy recommended for skill development. The motivation supplied by the problem may enhance a student's interest to the point that he will want to continue to practice until he has reached the needed competency level. Supplemental and remedial exercises may be provided for those students who need additional instruction and practice.

4. A student is motivated to attain a skill when he sees a need for developing it. Mature students are often motivated to acquire basic manipulative and communication skills because they realize that competency in a needed skill will save their time or that it is needed to complete an assigned task successfully. Immature learners may only realize that "If I don't do it right, it will break." Such students need to be helped to see how basic skills can be of value to them.
5. Development of manipulative and communication skills may be facilitated by means of student-student interaction. Providing opportunities for students to work together enables them to observe the ways that their peers operate and to verbalize their successes and problems relative to developing a particular skill.
6. The highest order of skill competency attainment occurs when students can develop for themselves the manipulative and communication skills they need to conduct an independent investigation. Such skills may be entirely new to them or they may be modifications of skills that they have already acquired.

Strategies and techniques for teaching acquisition of knowledge. Scientific knowledge (goal 4, as described in Chapter III) includes personal experience, facts, concepts, generalizations, and principles. As far as intellectual functioning is concerned, knowledge (1) makes it possible for the individual to relate his abstract thinking to concrete operations; (2) provides a framework of interrelated ideas that makes possible the acquisition and interpretation of new knowledge; and (3) makes possible self-initiated practice in the application of newly learned rational thinking processes.

A concept has been defined as a system of classifying information. Personal experiences, facts, generalizations, and principles contribute to this classification process. We infer that concepts have been learned when we see a person distinguish among objects and events or classify them into categories. We can test a person's understanding of a concept directly by presenting him with various stimuli and asking him to categorize them. A classification system implies that some things belong in a particular category and that others do not. Associated with each concept is a set of defining characteristics. Thus, a concept, such as "kinetic energy," is defined by its properties and operations and by the context in which it applies. In categorizing, the individual attends to some characteristics that he observes and ignores others. To learn a concept, one must learn both its defining characteristics and the range of values of these characteristics. For example, if the leaves of one category of tree are described as having four points, we want to know whether this tree's leaves may sometimes have only three or as many as five points.

When a concept is defined as a system of classifying information, it is useful to think about how persons learn to distinguish among characteristics in sets for particular concepts. Let us think of a person as an information-processing system in which previously acquired information influences the processing of new information by causing the person to attend to some aspects of the available information and to ignore others. Previously acquired information also influences the interpretation and evaluation of incoming information. A person's set of concepts determines how he classifies new information and how he relates it to his already acquired information. Thus, concepts are "elements" used in the thinking process.

Although this brief description of the relationship of knowledge to thinking may appear static, it is easy to show that it represents instead a dynamic model. Old information is sorted into categories, suggesting a stable system. However, whenever the person encounters discrepant information that he cannot sort into the old categories, he must revise the system or ignore the information. People frequently do the latter. But, as we know, great advances in science, even great personal changes, have been made when the person adjusts to the new information by changing his category system.

A teacher cannot "give" a learner his concepts and the accompanying category system. He can, however, provide a psychological and physical environment that will stimulate the learner's desire and need to formulate concepts that will help him to explain the natural objects and events he encounters in his everyday life and in the science laboratory. Such an environment includes strategies which facilitate concept formation and assist the learner in determining which concepts are most useful in a given situation.

Providing such an environment is a complex task that emphasizes again the necessary interrelationship of attitudes, rational thinking processes, manipulative and communication skills, and knowledge. The following are several examples of teaching strategies and techniques for facilitating attainment of conceptual knowledge goals. These strategies and techniques have been derived from the psychology of concept formation.

1. Provide opportunities for the learner to use a defining property or characteristic as a criterion for classifying sets of familiar objects into "has" and "has not" categories. One technique is to provide learners with a collection of objects or pictures of familiar objects, ask them to select a characteristic that some of the objects have and others do not have, and then to place the objects that have the selected characteristic in one group and those that do not have it in another group. This activity may be extended by having other students observe the groups to see if they can determine the defining characteristic that was used or by giving other students some similar objects to place in the proper groups without telling them the defining characteristic. If the purpose is to develop a particular concept, the procedure may be varied by describing a definitive property of the concept and then having the students select from a set of objects those that exhibit the property and those that do not. When appropriate, this activity may be continued by using other basic properties of the concept.
2. Select a sequence of learning experiences that enables the learner to proceed from simple to more complex concepts. Generally speaking, simple concepts are those which (1) are the most concrete, familiar, interesting, and useful in the eyes of the learner; (2) have the most readily observable defining properties; (3) are most closely related to known concepts; and (4) require the learner to process the least possible information at each learning attempt. Since a broad and complex concept includes the characteristics of its more narrowly defined component concepts, the characteristics of the subconcepts are found in the broad concept. Thus, if an objective of elementary school science is to have children develop some insight into ecosystems, a strategy might be devised that would enable the children to observe and identify the characteristics of such subsumed concepts as habitat, population, and community before they are expected to identify the many and varied characteristics of an ecosystem. In other instances, a more

appropriate approach might be to develop properties of a broader concept prior to defining characteristics of concepts subsumed by it. Properties of the concept "matter," for example, are usually developed in operational terms prior to providing investigations that aid children in identifying some of the special properties of gases, liquids, and solids.

3. Provide a variety of situations in which the learner will confront the concept. Conceptual systems are built as the learner sees connections and interrelationships between a concept learned in first one situation and then in another. Thus, he may uncover "hidden" similarities in a variety of encounters and generalize his learning into a broader conceptual pattern.
4. Confront the learner with information that does not match his present conceptual comprehension of a familiar object or event. Such a strategy stimulates inquiry, which results in a broader or deeper conceptual understanding. Taking advantage of discrepant events that arise from the student's own observations and investigations is an even more productive strategy.
5. In presenting examples or in helping learners identify examples of concept applications, devise or have the learners devise some technique that highlights the relevant characteristics. Simplified diagrams, models, and cuing devices all help to call the learners' attention to the significant aspects of the stimuli used in categorization. Having the learners develop such devices also causes them to analyze the concept in order to select from many properties those which are most significant.
6. Provide experiences that will aid the learners to synthesize their knowledge of related concepts into a broader concept, a generalization, or a principle.
7. Encourage learners to use their conceptual knowledge to explain observations of objects and events in their daily lives. A student needs to practice identifying concepts that may provide rational explanations for common natural phenomena. In applying this strategy, encourage the student to propose a variety of possible explanations and then give him the opportunity to test each of them. If, for example, the odor of cooking food is noted in the classroom and the children are asked to give possible explanations as to how the odor came to be there, they might suggest that it was blown in by the wind or that it was noticed because it is lunchtime and they are hungry. They might also suggest that heating the food caused some of

its molecules to escape; these molecules then diffused into the air in the hall and were finally transported through the open door into the room.

4.3 Define position regarding place of diagnosis and evaluation.

Guidelines for Generating, Gathering, and Using Information About the Learner and for Assessing the Learner's Growth Toward Stated Goals and Objectives

Teaching strategies should be constructed to elicit student behaviors that the teacher can observe and measure. Inferences drawn from observing these elicited behaviors can provide the teacher with a rich source of information about a student's attitudes, readiness, level of understanding, experimental background, cognitive style, social awareness, other personal and educational characteristics, and so forth. The teacher uses this information at appropriate points in the teaching cycle to diagnose and evaluate the context in which a student is achieving the goals and objectives of education. These data also provide for the teacher the feedback he needs to prescribe the next learning steps and to modify his teaching strategies. Students, as well as teachers, monitor their behaviors and those of their peers and evaluate them in the light of their perceptions. To maximize and individualize learning, teachers need to communicate their interpretations of evaluative data to the learners, and the learners should feel free to share their perceptions with the teacher. Diagnosis and evaluation also provide feedback data to school officials, curriculum planners, and the community. Such data are needed to assess the overall effectiveness of the curriculum, school organization, and instruction.

Criteria for Assessing an Evaluation System

The purpose of diagnosis and evaluation is to provide information necessary for decision making. The test of the diagnosis-evaluation system is: ***Does it deliver the feedback that is needed, when it is needed, to the persons or groups who need it?***

To meet this test, an evaluation system must satisfy the following basic criteria, which have been adapted from an article by Fred T. Wilhelms entitled "Evaluation as Feedback."[1]

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[1]Fred T. Wilhelms, "Evaluation as Feedback," in ***Evaluation as Feedback and Guide*** (1967 Yearbook of the Association for Supervision and Curriculum Development [ASCD]). Washington, D.C.: Association for Supervision and Curriculum Development, National Education Association, 1967, pp. 4-8.

1. Evaluation must facilitate self-evaluation. The most fundamentally important outcome of evaluation is what happens within the learner himself. The kind of feedback that a student receives is crucial in his learning and development. It can lead him forward in his learning and to an enriched conception of himself and his goals, or it can strain and distort him, narrow his purposes, and give him a sense of defeat. If encouragement to the learner to set his own goals or to apply rational thinking processes to the problems that confront him is included in the instructional objectives, the learner should be rewarded when his behavior indicates that he is achieving these objectives.
2. Evaluation must encompass every objective valued by the school. This refers to the *total* evaluation system. It includes much that depends on personal sensitivity and intuition, not merely the testing and marking system, which may have to be more limited. The best guide to curriculum improvement is evaluation; to be an adequate guide, the system of evaluation has to be as "big" as the purposes of the curriculum.
3. Evaluation must facilitate learning and teaching. Instructional diagnosis lies at the very heart of good teaching. After each bit of evaluative data comes in, the teacher should be a little surer of how next to proceed. After each bit of evaluation, the student, too, should know better where he stands and how to move ahead.
4. Evaluation must produce records appropriate to the purposes for which they are essential. As long as the present system of grades and credits persists, the records generated by evaluation should be so good that whenever they are needed they can deliver precisely the truly significant information. Such records should say what counts in a way that genuinely communicates.
5. Evaluation must provide continuing feedback into the larger question of curriculum development and educational policy. It is one thing for a biology teacher to organize a continuing feedback system to guide him in teaching his class; it requires a different level of evaluation to tell whether his science teaching would be more effective if he injected more chemistry and mathematics into it. It may require still more evaluation to guide a school's relative investment in science as against social sciences and the humanities.

Diagnostic Teaching

In Wilhelms' conception, evaluation must be so integrally related to teaching strategies that the necessary kinds of feedback flow right out of the teaching situation to both learner and teacher.

Children and youth learn most effectively what they know they need, what they choose to learn, and what they have a part in planning. In a group situation, it is difficult to match the curriculum to each individual's needs. This can be done only if there is a continuous evaluation of the child's learning and needs both by himself and by his teachers. Evaluation, then, must be in terms of specific and immediate objectives as well as of long-range ones.

The following essential aspects of diagnostic teaching are also adapted from Fred T. Wilhelms' article, "Evaluation as Feedback."[2]

1. Each learner must learn how to establish his own goals and purposes.
2. Each learner must constantly be aware of these goals and purposes.
3. Each learner must devise for himself as well as plan with the teacher ways of achieving each goal and of recognizing his own accomplishment.
4. Within reasonable limits, each learner must be self-directing, self-pacing, and free to choose immediate objectives, materials, and procedures.
5. As far as possible, both teacher and learner must be aware of longer-term goals and objectives and larger frameworks of concepts to be developed for use as guides to more immediate learning and teaching steps.

For diagnosis to take place, the teacher must employ strategies that generate the desired data: gather the information, interpret it, and communicate it through the type of feedback system mentioned earlier.

Data are gathered prior to instruction, during each teaching-learning act, and at the end of instruction or after a total school experience in the following ways:

1. Data might be gathered prior to instruction by asking the learner to recall previous experiences with science processes and concepts, examining scores on tests and interest inventories, securing perceptions about the learner from previous teachers and from parents, and by examining health and attendance records.
2. Data gathering during the teaching-learning act requires some specialized tactical moves or behaviors on the part of the

[2] *Ibid.*, p. 76.

teacher. He must be alert to and listen to overt visual and verbal clues provided by the learners. Such clues include each learner's vocabulary and language patterns, facial expressions, gestures, manipulative behaviors, willingness to put forth his own ideas and purposes, and the operational level at which he demonstrates his ability to handle rational thinking processes and concepts. These clues may come in small random "bits," but the teacher who is "tuned" to catch them can make some inferences about the learnings that may or may not be taking place.

3. Data gathering after instruction or after a total school experience requires a structuring of the conditions in which learners will express or display the desired learning if learning has occurred. It is a time when the learner must function autonomously. It is a time when the teacher provides a problem focus and then "steps back" to see what happens. Such situations may call for oral, written, or manipulative responses. Little evidence that genuine learning has taken place can be gathered unless a situation is provided in which the learner can display his learning beyond the context in which it was learned originally.

Kinds of Evidence That Indicate Pupil Growth Toward Desired Objectives

A detailed description of evaluative techniques and instruments cannot be included here. However, a few illustrative behaviors might indicate that the student has attained some of the specific objectives suggested in Chapter III. The teacher may determine the degree of attainment of each student by answering the following questions about each student's behavior.

1. Attitudes. Has the student shown a willingness to have his ideas questioned? Has he questioned conclusions based upon incomplete data? Has he volunteered questions and speculations about natural phenomena that were not mentioned during the period of instruction?

2. Rational thinking processes. Can the student draw inferences from data? Can he suggest ways to test a prediction? When confronted with a discrepant event, can he state testable hypotheses that might explain it?

3. Manipulative and communication skills. Can the student graph ordered pairs of related measures? Can he tabulate and organize data in a manner that enhances their usefulness? Can he communicate his observations clearly and precisely? Can he read a thermometer?

4. Knowledge. Can the student select from a series of given concepts and generalizations those that most appropriately explain a given situation? Can he state the fallacies in a given analysis of an experiment?

4.4 Describe philosophy regarding selection and use of instructional media.

Educational Technology as a Means for Maximizing Learning and Teacher Efficiency

The use of a variety of instructional media has been an established principle of education for many years. This principle is of value only if the media are linked to the curriculum, to teaching strategies, to school organization, and, most important, to the improvement of learning in terms of the stated goals of instruction. Too often, innovative instructional materials — television, loop films, transparencies, computer-assisted instruction, open-ended laboratory experiments — have been developed and used with little regard to their specific roles in instruction and with inadequate evaluation of their educational effectiveness. The real value of a teaching device is determined by the extent to which it makes a positive contribution to the improvement of student learning.

What is required is a systems concept in which goals of science education, curriculum, modes of instruction, characteristics of students, and ways of learning are brought into harmony with the organization of a particular school and with the machinery and materials of education. Before selecting the materials and equipment for education, their potential contribution to the acts of learning must be considered. There are many kinds of learning: forming concepts, acquiring skills, developing attitudes, and using inquiry processes. Each demands different conditions. A single form of media for instruction, therefore, will not provide the optimum conditions for all kinds of learning. Developing a functional understanding of living things requires that one work with live, not just preserved, specimens. A skill is best acquired by engaging in activities in which the skill is used. Concepts are likely to be retained longer when operationally experienced in a variety of contexts; for example, through personal investigation, by observation in the field, by seeing a film or listening to a lecture incorporating appropriate analogies, and by extensive reading.

Media of instruction should be selected and evaluated at the time the curriculum is being developed and should be specifically linked to the planned learning sequence. This could result in the organization of learning "packages" which would harmonize teaching goals, teaching strategies, and instructional media. These packages would be disseminated only after field testing indicated that they provide the best available learning path for the stated objectives. As new media become available, they are evaluated to see if they will provide a more effective learning path than was provided by the previously selected material or equipment.

The specific conditions under which attainment of learning-step objectives is to be observed may depend, in part, on the particular media selected to facilitate instruction.

An often overlooked criterion for the selection of instructional media is the school's pattern of organization. In many instances, media that facilitate learning in standard classroom situations are inappropriate for large group instruction and independent study.

4.5 Design or select alternative, consistent instructional models.

Illustrations of Instructional Models Which Provide a Structure for Organizing and Sequencing Learning Experiences

The last step in the analysis of conditions that will facilitate attainment of science education objectives is to organize the recommended teaching strategies and other conditions into an instructional model that will provide a structure for sequencing learning experiences. It is at this point that the search for consistency in instruction often goes astray. The most consistent curriculum guide or highly relevant science program will not produce the desired results when the teaching and evaluation strategies and techniques actually being used in the classroom are inconsistent with the stated goals and objectives and with sound theory relative to effective sequencing of learning steps.

The development or selection of one or more instructional models consistent with a school district's philosophical and psychological position and statement of goals and objectives will provide those responsible for curriculum development with a major criterion to be used in selecting science programs and program packages which they may wish to incorporate into their new or modified science curriculum. Several such instructional models are illustrated here. Although they are all generally consistent with the points of view expressed in this document, each stresses a somewhat different set of major structural elements.

A Group Instruction Planning/Assessment Model

Figure 12, a modification of a model proposed by W. James Popham,[3] stresses planning and assessment steps rather than actual teaching procedures. This model suggests that a teacher, working from the sources of goals and objectives, makes major instructional decisions at several points during a teaching/learning process. He begins by selecting from the objectives stated in the course of study those that seem to be most appropriate for his particular class and for the instructional materials, media, and equipment that are available to him. These objectives contribute to the attainment of stated long-term goals and objectives, are appropriate for the learners in his class, are consistent with the philosophical and psychological foundations of science education, are stated in measurable behavioral terms, and specify minimum acceptable standards.

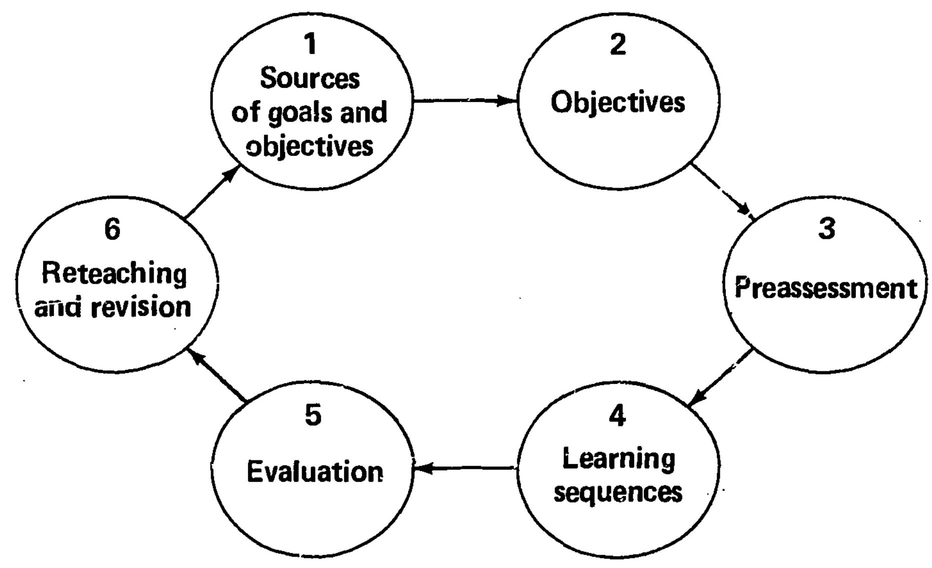


Fig. 12. A Group Instruction Planning/Assessment Model

Next, the teacher preassesses (diagnoses) his students to determine their current status with respect to the objectives and, when appropriate, revises his objectives in the light of these diagnoses. The teacher then selects and uses the teaching strategies, techniques, and

[3]W. James Popham, *The Teacher-Empiricist*. Los Angeles: Aegeus Publishing Company, 1965, p. 23.

instructional media that he feels will most effectively aid the students in attaining the desired objectives. Learning experiences are ordered in a manner that provides a graduated sequence, provides for individual differences as determined by the preassessment, and provides immediate feedback of results to both the student and the teacher. Next, the teacher evaluates the effectiveness and efficiency of his instruction relative to all objectives stated for each lesson sequence in terms of the students' achievement of these objectives. Finally, he reteaches unachieved objectives, perhaps with modified techniques and different materials and content samples. These modifications, if successful, are then incorporated into the revised teaching plan; if they are not successful, consideration may be given to modification of the objectives. Objectives readily attainable by all students in the group may be substituted for the original objectives. However, attention to varying capabilities of individual students should be kept in mind as objectives are revised and reteaching is planned.

A Diagnostic/Prescriptive Teaching Model

Figure 13 is adapted from an article entitled "Strategies for Developing Autonomous Learners," by Arthur L. Costa.[4] The figure represents the diagnostic/prescriptive mode of teaching needed to individualize instruction. It also highlights the importance of continuous diagnosis-evaluation described under subfunction 4.3 (define position regarding place of diagnosis and evaluation).

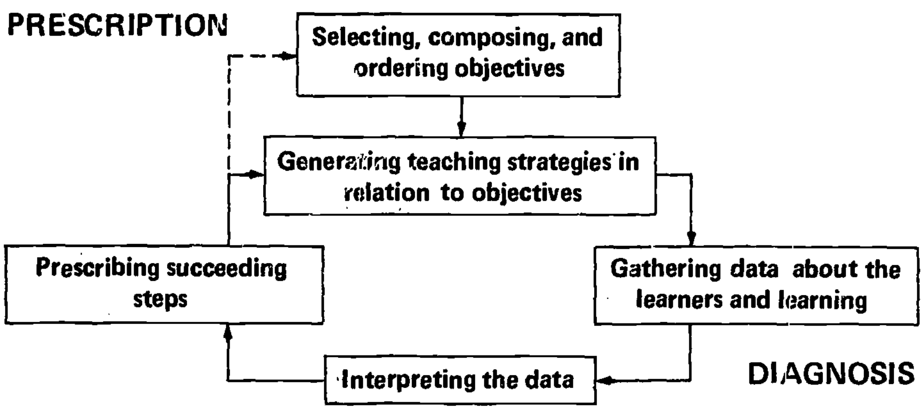


Fig. 13. A Diagnostic/Prescriptive Teaching Model

[4] Arthur L. Costa, "Strategies for Developing Autonomous Learners," *Audiovisual Instruction,* XIII (October, 1968), 832.

This and other attempts to systematize teaching help to identify the many decision-making junctures that constantly confront the teacher. Without a strategy in mind, few rational decisions can be made as to what techniques and tactics can be employed during the interaction of the teacher, the learner, and the media.

The diagnostic side of this closed-loop feedback system involves the gathering and interpreting of data. The prescriptive side includes selection of learning-step objectives, generation of appropriate strategies for accomplishing each objective, and planning succeeding steps. The procedures involved are as follows.

1. Selecting, composing, and ordering objectives. The necessity for generating specific learning-step objectives from broad goals and long-range objectives has already been emphasized. A course of study, for example, might include the following terminal objective under the goal of developing rational thinking processes: **When confronted with several conflicting hypotheses, the student searches for data to support or reject the hypotheses before accepting or rejecting them.**

2. Generating teaching strategies in relation to objectives. Although the sample objective is stated in behavioral terms and indicates what to look for to determine whether or not the desired behavior is manifested, it does not describe what the teacher should do in order to have the student confront, practice, and incorporate the behavior into a total action pattern. Also, it does not describe the conditions under which the student is expected to exhibit the behavior. Therefore, the teacher must decide what to do to have the student perform in the desired way.

In generating teaching strategies, the teacher obtains and considers relevant data about the learner, available instructional materials, the science concepts and generalizations included in the knowledge objectives suggested in his course of study, the developmental level of the learner, the teacher's own theoretical knowledge of how learning takes place, and his own experience. Given the sample behavioral objective and after considering the relevant data, a teacher might decide, for example, to confront his students with three similar but somewhat conflicting hypotheses explaining the causes of thunder. He might then have the students work in groups to gather data from films, books, or other sources supporting or refuting each of the hypotheses. After the students have gathered, recorded, and compared their data and reached some tentative conclusions, the teacher, through discussion, might bring to the awareness of the learners the *processes* they used and emphasize the necessity for seeking and using reliable information to substantiate or refute ideas. Having made these decisions, the teacher is now in a position to state the desired student behavior in more specific terms; for example: **When confronted with three teacher-stated hypotheses relative to the causes of thunder, provided with suitable reference materials, and asked to gather and report data to support or refute each hypothesis, the student will find and report at least one bit of data that seems to support or refute each hypothesis.** Other specific objectives related to this learning situation might be generated and evaluated.

3. Gathering data about the learners and learning. As indicated under subfunction 4.3 (define position regarding place of diagnosis and evaluation), data gathering may take place prior to, during, and after the instructional act. Referring to Figure 13, we see that in planning the lesson just described, the teacher has already gone once around the diagnosis/prescription cycle. As he implements his selected teaching strategies, he is constantly gathering and interpreting additional "bits" of information obtained by observing the students and the ways in which they interact with materials, each other, and himself. The teacher uses perceptions of what appears to be going on in this milieu to make inferences about the learning that is or is not taking place and as bases for making decisions relative to modifying his strategy and tactics and for prescribing succeeding steps. He can also determine from the pupils' actions whether each has achieved the desired objectives under the specified conditions. After the instruction sequence has been completed, the teacher structures conditions in which he can observe how the learners would react in another, similar situation. This time the teacher says nothing; he searches for behaviors that indicate that the learners seek data to support or refute one or more of the hypotheses.

4. Interpreting the data. Data alone are useless. They must be processed, acted upon, interpreted, or evaluated in some way that provides meaning and direction. Directly observed behaviors are compared with the range of behaviors that are thought to be congruent with the desired objective. If they "match," the teacher may be inclined to think that some learning has occurred and, therefore, that the learning can be reinforced and practiced. The teacher also seeks explanations for data that conflict with his expectations.

5. Prescribing succeeding steps. If a student's overt behaviors indicate that the desired learning has taken place, the teacher then decides what next higher level of objective should be selected, what reinforcement should be provided, and whether the concept or skill being developed should be applied to a practical situation of interest to the student. If a student's overt behaviors indicate that the desired learning has not taken place, the teacher must decide what to do next. Should he gather more data about the student? Should he modify his teaching strategy in terms of a different theory of learning? Should he go ahead with the next lesson and come back later to this one?

A Concept and Process Development Model

The model presented in Figure 14 shows how optimal achievement of the basic goals of science education and the specific behavioral objectives stated for each learning step are attained. Major emphasis

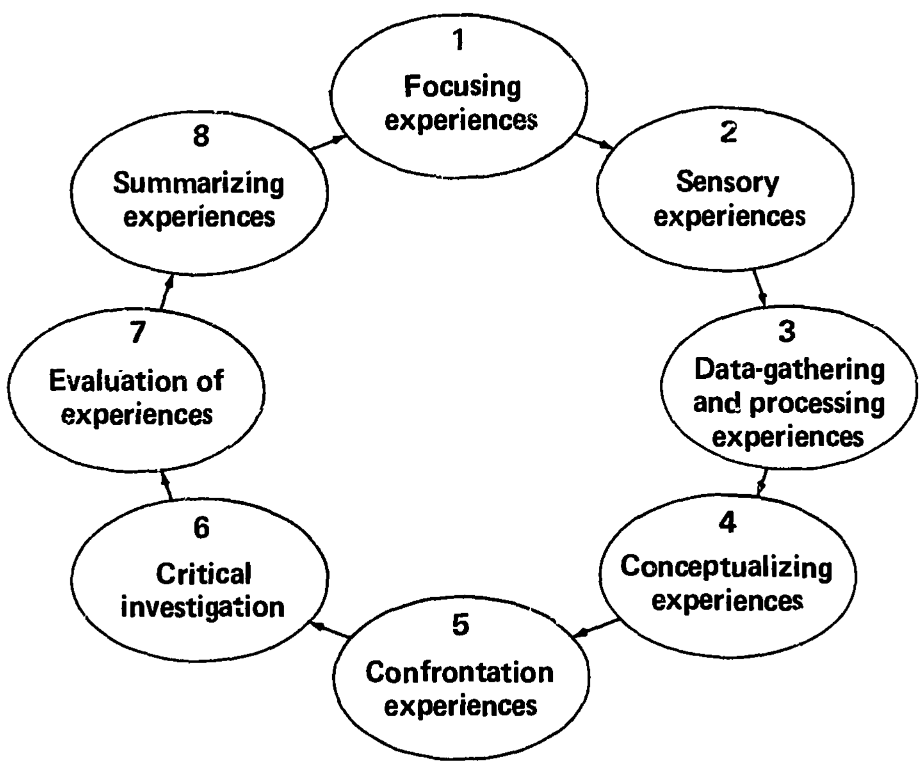


Fig. 14. A Concept and Process Development Model[5]

[5]Adapted from ***Planning a Continuous Science Program for All Junior High School Youth.*** Edited by Adrian N. Gentry. Riverside, Calif.: Office of the Riverside County Superintendent of Schools, 1967, p. 101.

is placed on the processes by which students learn science as well as on their formation and application of basic science concepts. This model is considered most appropriate for use in intermediate grades and above.

The arrangement of teaching strategies and the sequences of learning experiences concomitant to each strategy form a sequence of processes designed to expedite learning. The sequence follows in a general way the hierarchy of cognitive behaviors described in Bloom's *Taxonomy of Educational Objectives.*[6] Each learning sequence (indicated by completion of the eight kinds of learning experiences in the closed-loop model) is intended to develop or deepen comprehension of a particular concept. A series of several loops may be devoted to related concepts that broaden the learner's comprehension of a single conceptual system; e.g., **energy exists in a variety of convertible forms.**

In actual practice, every learning sequence need not include instruction in each learning step. If, for example, preinstruction diagnosis indicates that a particular student or group of students demonstrates the expected comprehension level of a particular concept, the teacher may decide to confront him or the group immediately with a discrepant event that challenges comprehension of the concept or generalization.

The order in which the various categories of learning experiences generally are presented is indicated by the model. Types of activities that may be included under each category are as follows:

1. *Focusing experiences* are activities designed to help the teacher determine the extent to which the learners already exhibit the behaviors that make up the specific objectives for this sequence; experiences that help the students connect the concept or generalization with their own experience and tie the new learning sequence to sequences that have preceded it; and experiences that arouse interest and motivate student involvement in the new situation.

2. *Sensory experiences* help students develop needed manipulative skills and provide opportunities for them to further develop sensory perception and observation skills relevant to investigations they will conduct later in the sequence. Some of these

[6] ***Taxonomy of Educational Objectives – Handbook I: Cognitive Domain.*** Prepared by Benjamin S. Bloom and Others. New York: David McKay Co., Inc., 1956.

experiences may involve "messing around" with materials and equipment.

3. *Data-gathering and processing experiences* involve experiences with materials and situations that enable students to obtain information relative to the concept being studied and experiences designed to develop student competencies in quantifying, recording, organizing, and communicating in conventional scientific form.

4. *Conceptualizing experiences* assist students to formulate and/or deepen their understanding of a concept or generalization. Such experiences involve translating data from tabular and graphic form into algebraic form and interpreting, extrapolating, and generalizing data. These skills may be developed through questioning, discussing, demonstrating, and investigating in the field or laboratory.

5. *Confrontation experiences* are those that confront the students with discrepant or related objects or events contrived by the teacher or arising naturally when students obtain data that are in real or apparent conflict with their mental models of some aspect of their environment.

6. *Critical investigation* refers to investigations that are designed and carried out by the students to explain the discrepant or related objects or events. The designs for testing should include a statement of the problem, solution strategies (hypotheses), and ways and means of testing the hypotheses by means of firsthand observations or research.

7. *Evaluation of experiences* involves activities that encourage students to evaluate their perceptions, data, hypotheses, processes, and conceptual understanding. Evaluation in this context involves making personal judgments about the value, for some purpose, of ideas, solution strategies, methods, materials, and the like.

8. *Summarizing experiences* are activities designed to enable students to summarize and apply what they have learned and to set it into a larger framework, discussions that bring out the tentative nature and limitations of newly gained concepts, independent study activities, activities that lead into the next learning sequence, and activities that assess the extent to which learning-sequence objectives have been attained.

FOCUS: To check preliminary statements against philosophical position, objectives, performance requirements, and constraints

DECISION: To tentatively accept or modify tentative position on optimal conditions for learning

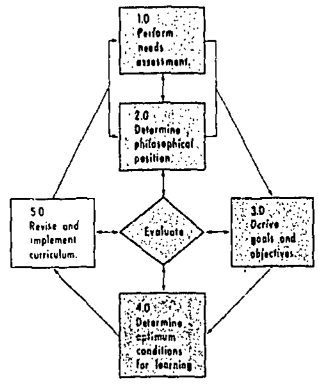
Fig. 15. Evaluation of Statements Regarding Optimum Conditions for Learning

The recent public concern for improving instruction in science and other critical areas has made available many millions of dollars for research on the development of science education. Many new programs and program components have passed through the experimental stage and are now on the market; others are on the way. Various teaching strategies and techniques are exemplified in these new programs. What kinds of criteria may be used by the teacher or curriculum planner to evaluate these new programs, as well as existing programs, in terms of teaching strategies and techniques? As stated in the introduction to this chapter, the Advisory Committee feels that teaching strategies and other conditions will provide optimum situations for learning if they are consistent with (1) the nature of science; (2) learning theories; (3) the needs of society; and (4) the developmental level of the learner. It was further pointed out, in Chapter III, that teaching strategies selected for use in a particular situation should be consistent with the statement of goals and objectives, performance requirements, and any unresolvable constraints imposed on the situation.

In this chapter the Advisory Committee has been concerned, in particular, with optimum conditions for learning derived from learning theories employed by some of the major science curriculum projects and with optimum conditions for learning that are applicable to the four categories of science education goals (attitudes, rational thinking processes, manipulative and communication skills, and knowledge). Although the committee has suggested learning conditions which it feels are generally consistent with its theoretical point of view, other strategies may be derived from this view, and those who hold other theoretical positions may favor a different set of strategies. Educational theory has not yet reached the point where one can say for sure that all strategies must be consistent with any or all theories. In some instances the best criterion may still be, "Does it work?"

In addition to providing internal consistency, teaching strategies and techniques should create conditions that do the following:

1. Focus the learner's attention on the particular nature of the learning task.
2. Motivate the learner.
3. Maintain the learner's interest.
4. Provide immediate feedback to both learner and teacher.
5. Allow the learner to progress at his own rate.
6. Promote transfer of learning to new situations in and out of school.
7. Develop and preserve positive attitudes toward the self, the teacher, the subject matter, and the education process.



CHAPTER V

Revising and Implementing Curriculum

Selecting, testing, adopting, and implementing curriculum and instruction is a complex process. The extent to which a school district can make its own decisions in these matters varies from small to large districts, from elementary schools to high schools, and according to legislative mandates effecting periodic changes in the California Education Code and the California Administrative Code, Title 5, Education. Some decisions, especially those involving a few teachers in a school consisting of a single building or those affecting teaching procedures rather than the course of study, may be made by individual teachers and principals. Decisions relative to the selection and adoption of more extensive changes may involve all school personnel, county courses of study, the State Board of Education, the State Department of Education, and, possibly, the Legislature. It is impractical, therefore, to propose a single procedure for revising and implementing science curricula and adopting new teaching strategies that would be applicable in all situations.

Furthermore, the several existing models for implementing curriculum change are incomplete and have been tested in special situations which may not be generally applicable. This chapter, therefore, is limited to a brief outline of the major steps involved in a systems approach to the selection, assessment, adoption, and implementation of science curriculum and instruction and to a few suggested procedures for carrying out these steps.

Major curriculum changes involve both external and internal participants. Each of these participants has control of certain sources of power and methods of influence. Whether invented inside or outside the system, innovations, in order to become effective throughout a school or school district, must gain the support and approval of teachers, administrators, governing boards, and other influential decision makers.

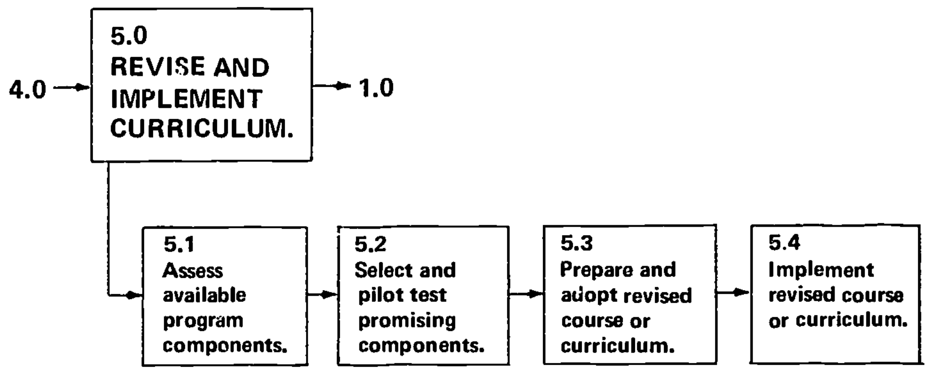


Fig. 16. Analysis of Function 5.0 — Revise and Implement Curriculum

Investigations conducted at the Center for Coordinated Education at the University of California, Santa Barbara, indicate that "the effective installation of an innovation in a school requires three sequential operations, each involving a number of discrete steps: preliminary analysis, strategy selection, and action."[1]

In the preliminary analysis process, science education needs are assessed; a philosophical position is determined; and findings of educational and psychological research relevant to conditions that promote the learner's attainment of the several categories of goals and objectives are stated. Analysis of subfunctions 5.1 (assess available program components) and 5.2 (select and test promising components) provides additional information called for in the preliminary analysis step: review all available relevant curriculum programs and practices (including those currently in use in the school system), and pilot test and evaluate those that seem to be consistent with the school's philosophical and psychological viewpoints and with its goals and objectives for science education.

Information for decision making relative to the second and third operations — strategy selection and action — is generated from analysis of subfunctions 5.3 (prepare and adopt revised course or curriculum) and 5.4 (implement revised course or curriculum)..

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[1]Louis J. Rubin, "Installing an Innovation," in *Educational Change: The Reality and the Promise.* Edited by Richard R. Goulet. New York: Citation Press, 1968, p. 159.

5.1 Assess available program components.

Application of Sets of Criteria to Potential Programs and Practices in Order to Obtain Local Evaluative Data

During the past several years, many innovative science courses, package units, teaching strategies, and learning devices have become available to teachers and other curriculum planners. These new curriculum components range from sequences of courses designed by groups of scientists with the aid of multimillion dollar foundation or federal grants and field tested in hundreds of schools to a package unit developed around a newly invented teaching device or a teaching strategy by a creative teacher. Data obtained from the preliminary analysis phase of a systematic approach to improvement of science instruction provide several sets of criteria that are applicable to the assessment of this vast range of materials and practices.

School district policy statements should be dynamic and subject to modification in the light of new research and special conditions. State or local adoption of textbooks and courses of study should not inhibit teachers from experimenting with new ideas and promising practices nor lead to a district posture of rigid conformity. The school and district educational climate should foster and promote teachers' creativity and initiative. Although the innovative products of curriculum reform movements may provide ways and means for change, the extent to which these products improve learning depends upon the teacher's attitudes about the innovation and upon his instructional procedures. Substantial change in the kind and amount of desired learning occurs when knowledgeable, creative teachers improve their verbal and nonverbal interactions with their students and provide other learning conditions appropriate to the attainment of science education objectives.

Whether major modifications are proposed for dissemination within a particular level or course or throughout the total science curriculum for kindergarten through grade twelve, they are assessed in terms of their consistency with a cooperatively developed set of theoretical and practical criteria.

Theoretical Requirements for Science Curriculum Components

The theoretical positions generated by analysis of the four functions in our flow chart provide one major source for making rational decisions concerning the selection of components for inclusion in a science curriculum that is internally consistent from level to level and externally compatible with other curriculum areas and the organizational structure of the school. By applying this set of theoretical criteria, each component proposed for inclusion in a revised course or curriculum may be assessed in terms of its consistency with the adopting agency's position relative to societal needs for a humanistic and scientifically literate citizenry, special local community needs, the developmental needs of the learners, the nature and structure of science, the major goals and objectives of science education, theories of learning, and curriculum organization.

Practical Performance Requirements and Constraints to Be Considered When Assessing Science Curriculum Components

The answers to questions such as those that follow provide some practical performance requirements and constraints that must be considered by any teacher, school, or school district when a proposed curriculum change will result in modification of needed staff competencies, student behavior, content, materials and facilities, time, school organization, teaching strategies and techniques, staff assignments, and budget. If an innovation that generally meets the adopter's theoretical requirements and performs according to specifications during pilot testing is incorporated into the school or school district science curriculum, the following questions must be considered:

1. What personnel additions and/or changes will be required?
2. What competencies and attitudes should teachers and other personnel have in order to implement the innovation in an effective manner?
3. Are the teaching strategies and techniques advocated in the innovative program compatible with the existing school organization and facilities?
4. Can the proposed innovation be readily coordinated with other components now in the science curriculum or contemplated in the revised curriculum?
5. How much teacher preparation time and classroom time will be required to implement the proposed innovation?
6. What additional equipment and instructional materials will be needed?
7. Is the initial and long-term cost per pupil feasible in terms of currently available or obtainable funds?

8. Is the innovation compatible with the capabilities of the students for whom it is intended?

5.2 Select and pilot test promising components.

The Importance of Local Tryout Prior to Adoption and Dissemination of Innovative Programs and Practices

Among the reasons for local tryout of promising innovations prior to their selection for adoption and installation are the following:

1. Teachers will have better attitudes toward an innovation if they are involved in an experimental tryout program.
2. Administrators, supervisors, and teachers are persuaded to consider and eventually adopt innovations primarily through seeing them succeed in their schools.
3. Although innovative programs may produce excellent results in field tests supervised by the program producers, they may not produce the same results when they are used in situations not connected with the developing agency.
4. Some basically sound programs must be modified because of unique local conditions that were not present in the field testing schools.
5. Local pilot testing provides data relative to teacher competencies, time, materials, and other factors that must be considered prior to adoption and installation of the innovation.
6. Opportunity is provided for teachers and supervisory personnel to develop competencies and experience needed for training other personnel who will be using the innovation.
7. Evaluation of local tryout can provide a variety of information for decision making; e.g., attitudes of local personnel toward the innovation, effectiveness of the program in attaining the desired objectives for the intended learners, and durability of instructional materials when subjected to local classroom conditions.

5.3 Prepare and adopt revised course or curriculum.

Adopting Selected Innovations and Blending Them into the Existing Course or Curriculum

After comparing the actual and intended outputs of the proposed innovative programs or practices in terms of their effectiveness for target populations in the school district, the decision is made to adopt, modify and adopt, or reject each of the locally tested elements of the proposed curriculum revision. Decision making may involve only a few teachers, or it may affect all teachers at a particular level or of a particular course. Major curriculum reforms may involve all teachers of science from kindergarten through high school.

The innovation may require modification of the existing course of study, time schedule, budget allocations, inservice education program, or other conditions that involve a substantial number of teachers. All persons concerned should be made aware of their roles and responsiblities in implementing the new program and should have opportunities to propose changes prior to formal adoption of the revised curriculum. When all involved persons understand the nature and implications of proposed changes, are encouraged to react to them, and have their opinions considered in the final proposal, the general acceptance and success of the new program, once it has been adopted and installed, are ensured.

If cost-analysis data indicate that installation of the revised program will require a budget increase for science education on a temporary or permanent basis, it is important for personnel in other departments to be aware of the effect that budget reallocation may have on their programs.

5.4 Implement revised course or curriculum

Installing the Innovation and Making It Operational

Having made the decision to adopt a curriculum innovation, the adopting agency is faced with implementing its decision in a manner that will result in the desired improvements in instruction. This subfunction might be further broken down as indicated in Figure 17.

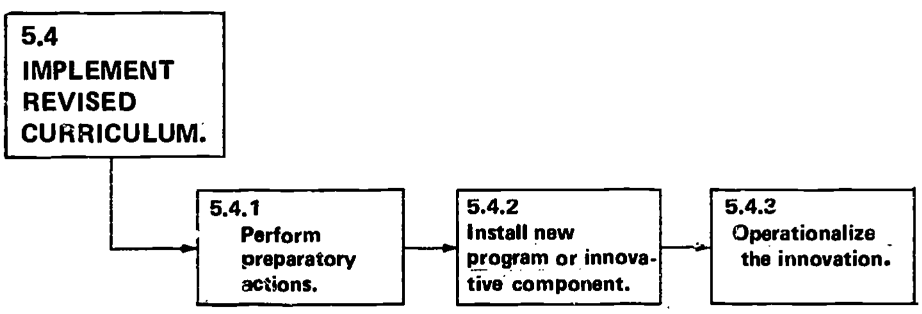

Fig. 17. Breakdown of Subfunction 5.4 — Implement Revised Course or Curriculum

Examples of the kinds of actions within each of the three steps involved in installing and implementing a newly adopted innovation in science education are listed on the following pages.

5.4.1 Perform Preparatory Actions

The following are the preparatory actions to be performed in implementing a revised curriculum:

1. Prepare and adopt budget needed to implement the revised program.
2. Make any necessary adjustments in school organization pattern and/or time schedule.
3. Provide the necessary facilities.
4. Provide inservice education for present personnel and, if necessary, recruit new personnel who have the desired competencies.
5. Inform school personnel and the general public about the innovation.
6. Design an evaluation-feedback system that will assess the effectiveness of the innovation.
7. Select and initiate implementation strategies that seem to be most appropriate for the target group of teachers and other personnel. Introduction of new subject matter calls for different strategies than does installation of an innovative teaching technique. Strategy selection also depends upon the power structure that is advocating and engineering the innovation. Innovations resulting from community pressures, for example, call for different strategies than those required to implement effectively changes for which the community shows little concern or those which a significant body of citizens may resist. However, all of the preceding six items must be considered and acted upon to the degrees advisable for implementation of the innovation.

5.4.2 Install New Program or Innovative Component

The following are the steps to be taken in installing a new program or innovative component:

1. Organize and implement an inservice program based on diagnosis of individual teacher needs and designed to develop the specific competencies each individual needs to implement the innovation successfully.

2. Provide incentives such as extra pay, released time, or salary schedule credit to compensate the target personnel for the extra time and energy required during the first year of installation of a major change and as necessary in subsequent years.
3. Provide the teachers with moral as well as physical and financial support during the transition period.
4. Make sure that target teachers and other concerned persons understand the nature of the innovation, its requirements, and its relation to district objectives.
5. Initiate a continuous evaluation-feedback system.

5.4.3 Operationalize the Innovation

The procedures to be used in operationalizing the innovation are as follows:

1. Blend the innovative program or practice into the ongoing program.
2. Continue evaluation of the revised program, and begin to generate data relative to priorities for the next change cycle.
3. Provide inservice education for new teachers.
4. Budget funds for replacement of consumable materials, for lost or broken equipment, and for purchase of new materials and equipment.
5. Solicit and disseminate creative ideas and practices that are developed by local teachers and which enhance the effectiveness of the innovation.
6. Adjust anticipated minimum performance standards stated for each behavioral objective after second year of implementation of the innovation if feedback data make adjustment or revision necessary.

Evaluation	**FOCUS:**	**To determine effectiveness of innovation or revised science curriculum**
	DECISION:	**To continue or further modify revised curriculum**

Fig. 18. Evaluation of Revised Science Curriculum

An evaluation-feedback-change loop is an integral part of each major function in our proposed model for assessing and improving the science curriculum for kindergarten through grade twelve. The loop for the present function is particularly significant. The objectives it presents are (1) to identify defects in the procedural design or in its implementation and to maintain a record of procedural events related to installating and institutionalizing the innovation; and (2) to relate outcome or product information to the objectives, theoretical requirements, and practical requirements and constraints stated for the innovation.

Methods and instruments for evaluating an innovation or a total science curriculum are effective to the extent that they provide the necessary information for making decisions relative to both the change process and the results or product of the process.

Once a course of action for installing an innovation has been approved and implementation of the plan has begun, ***process evaluation*** is needed to provide periodic feedback to those who are responsible for installing the new program for continuous control and refinement of plans and procedures. Potential sources of failure of the process include interpersonal relationships, communication channels, logistics, understandings of and agreement with the innovation's purposes, adequacy of inservice education, resources, time, and the like.

Product evaluation is used to determine the effectiveness of the innovation after it has completed each cycle. The method of evaluation is to operationally define and measure criteria associated with the objectives of the program, to compare these measurements with predetermined standards, and to make rational interpretations of the outcomes. As far as the change process is concerned, product evaluation provides information for deciding to continue, terminate, modify, or refocus a change activity and for linking the innovation to other phases of the curriculum.

Once the new program has been blended into the total school program, continued process and product evaluation begin to generate data relative to priority needs for the next change cycle.

CONCLUSION

In the period from 1960 to 1970, a major reform movement in science teaching took place. New courses were designed based upon assumptions unlike those in traditional programs. Bruner pointed out the importance of using the conceptual structure of disciplines in planning curricula. Schwab showed the futility of attempting to present a valid interpretation of science in the absence of the inquiry processes that generate scientific knowledge. Gagné fostered the hierarchical concept of curriculum organization and the importance of a proper sequencing of learning materials. Laboratory work in science teaching was reexamined and its values defined in terms of developing intellectual skills rather than techniques of manipulation. The reform movement has given rise to other refinements in modern science curriculum building.

The period from 1970 to the year 2000 will be a time for further examination of the science curriculum. The cultural implications of science have not as yet been written into courses. One aim of science learning is the contribution it can make to the intellectual use of leisure; another is the application of scientific knowledge to humane ends. Neither of these goals was emphasized in the reform movement of the 1960s. For the most part, the subject matter of conventional science courses has been selected for its classical rather than its social values. Students learn the science of historical significance rather than the science useful for resolving contemporary social problems, such as pollution, inadequacy of world food resources, and overpopulation. And there are other problems, which have too often been suppressed in science courses, that have been brought about by the application of science to technological ends. There is also little emphasis on the aesthetic and philosophical aspects of science. A general education in science exists only in a social context, and its goal is to improve the welfare of mankind. The social, economic, and political interrelationships of the scientific enterprise are of increasing importance for designing the future we want in America. The reform movement during the 1960s was directed to modernizing the content of science courses; for the next decade the task is one of making it relevant to human needs.

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Hurd identifies the rationale and conceptual themes of new secondary school science curriculum projects in earth science, biology, physics, and chemistry.

The inquiry goals of each subject are listed, and their implementation in class and laboratory work is discussed.

Hurd, Paul DeHart, and James Joseph Gallagher. *New Directions in Elementary Science Teaching.* Belmont, Calif.: Wadsworth Publishing Company, Inc., 1968.

A description of the new experimental elementary school science curricula, with sample units for each project, including the rationale and goals. There is an extensive bibliography classified according to the curriculum studies.

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APPENDIX A

Conceptual Systems

Facts do not constitute science; science exists only when relationships are discovered. Science is an invention of man which enables him to order information and to conduct systematic search. From such a scientific enterprise, sets of related ideas (concepts) and investigative processes have emerged. These concepts and processes provide the structure on which a science curriculum is built.

The learning of related sets of concepts (conceptual systems), such as the following, should be the basis for the development of content in science instruction because (1) it is the very nature of science to be a continual search for greater and greater generalizations; (2) conceptual systems provide a foundation for the understanding of how certain facts are related; and (3) conceptual systems provide education for the future because they offer a perspective by means of which future discoveries may be correlated and understood.

A. Most events in nature occur in a predictable way, understandable in terms of a cause-and-effect relationship; natural laws are universal and demonstrable throughout time and space.

This first conceptual system is an overall summation of the other 12 systems described in this appendix. The other conceptual systems are extensions or elaborations of the general theme that is stated in this first, summarizing conceptual system. The principal ideas contained in this system may be restated in greater detail in the form of the following four points:

1. Events in nature are the result of a cause-and-effect relationship. The laws and theories of nature — as they apply to motion, energy, change, conservation, and atomic structure — are simplifying generalizations in which a cause and an effect are related. These laws and theories are based on experience and verified by experiment. To state a thesis that cannot be tested by experiment is to state no thesis at all. The quantitative experiment is essential to valid scientific research.

2. Knowledge of cause and effect allows prediction of events. Knowledge about the motion of the earth and moon allows predictions of the sunrise and sunset and of the time and magnitude of the tides. Knowledge about chemical bonding allows prediction of the heat that will be liberated when an acid is added to an alkali. The validity of a prediction based upon cause-and-effect relationships is determined by the reproducibility of experimental results that have been obtained through a variety of experimental approaches.
3. Cause-and-effect relationships are universally applicable. The goal of the scientist is to discover laws of nature that are applicable to any part of the universe at any time. He thus seeks laws of motion that apply to planets as well as to electrons and laws of chemical equilibrium that apply to oceans as well as to humans.
4. Predictions based on cause-and-effect relationships can also come out of randomness and uncertainty. Some events in nature occur in such random fashion that predictions concerning individual events can be made only with great uncertainty. However, predictions concerning many occurrences can still be made with a high degree of certainty by applying statistical theory as well as the principles of cause-and-effect relationships in the study of such random events. For example, we can predict the fraction of atoms that will disintegrate in a given mass of radioactive atoms, but we cannot predict when any one atom will disintegrate. The same is true of predictions regarding the energy in molecules — we can predict what fraction of them will have a particular energy, but we cannot predict the amount of energy that will be found in any one of them. Again, in the field of genetics, we can predict what proportion of children will be boys, but we cannot as yet predict the sex of a particular unborn child.

Predictions that are not verifiable by experiment lead to reexamination of scientific hypotheses and to changes and improvements in them in an effort to account for all observations. This procedure represents a break with superstition and with the idea that natural phenomena cannot be explained by the laws of nature. Even if the cause-and-effect relationships are not understood immediately, persistent pursuit of answers will eventually lead to understanding as knowledge increases.

Prediction of scientific phenomena is, at one and the same time, a statement of faith in a natural law and of hope in the fertility of its applications. Although a prediction may be based on a century of experience, it must still meet the requirement of experimental verification or proof before it can be accepted as valid. Proof means demonstrable validity in every test and not mere acceptance by consensus or by vote.

B. Frames of reference for size, position, time, and motion in space are relative, not absolute.

This conceptual system deals with the measurable attributes of things and events. It can be developed from the following two points of view:

1. Objects are weighed and measured to determine their magnitudes. The position of an object is determined by measuring its distance and direction from other objects or from fixed basepoints. Events in time are measured by means of clocks marking off intervals from a reference point in time. The motion of an object can be characterized in terms of its changes in position with reference to time.

   All these measurements are made with appropriate scales; for example, weight may refer to pounds, grams, or kilotons, and distance may be expressed in inches, meters, or light-years. The latter units of measure also imply direction and distance from other objects or from fixed basepoints.

   Indirect measurements, such as the measuring of a child's shadow to deduce the sun's position, are used to measure the relative positions of objects we cannot reach. Clocks measure time in seconds, minutes, and hours; calendars indicate days, years, and centuries. Living things have biological clocks set, for example, to daily light-and-dark schedules and to the temperatures of seasons.

   Motion in space is a combination measurement — a change in position with reference to time (the measurement just mentioned). The greater the distance traveled from a fixed point in a given length of time, the faster the motion; the slower the motion, the longer the time required to travel a given distance.

   The most difficult quantitative concepts are those that are well beyond the level of intellectual comprehension: the numbers of atoms, stars, or insect populations and atomic or astronomical dimensions.

2. These measurements seem rigid and constant — a pound is a standard unit of weight, valuable because of its constant

dependability. Transfer the pound to an environment outside the earth's gravitational field, however, and this standard unit of weight loses its rigid, constant, earthbound value. The weight values of objects measured by earth standards on the moon or Jupiter or in an orbiting space capsule would be less or more than their weight values as measured on the earth. Consider also an astronaut's measure of a day as rapid revolutions spin him through several "day-night" experiences during one earth day. Scales can be more definitive if the frame of reference is expressed, that is, an earth day or an earth pound.

The situation becomes more abstruse when motion in space is considered. The velocity of a vehicle speeding towards Mars, such as Mariner II, has one rate of motion relative to Earth, another relative to Mars, and still another relative to the sun. Earth, Mars, the sun, and Mariner II each travel at different velocities and in different directions.

The principles of relativity can be stated simply in terms of relative positions. For example, on the playground the movements of children may be observed relative to the fixed position of the observer or his movements. The complexities of Einstein's general theory of relativity need not be considered in such a situation. The frame of reference within which various physical or biological properties are considered determines the level of complexity of a given situation. Measurement within relative frames of reference challenges the student to interpret observations by quantitative means. The numbers derived from measurement data can be processed with the developing tools of arithmetic, algebra, geometry, and calculus — an increasingly compelling and efficient logical system. Thus, the conceptual system that is concerned with the role of an observer relative to his experimental environment provides a connection between science and mathematics, through which the two disciplines can develop in harmony and to reciprocal advantage. For science, most of the "elementary processes" relate to the measurements subsumed in this concept; for mathematics, the "strands" take substance in the definition and application of this conceptual system.

C. Matter is composed of particles which are in constant motion.

Different kinds of matter can be classified according to their particulate natures and according to the energetic movements of the particles within them. The model in which matter is composed of moving particles has been used to explain many natural phenomena, such as the physical states of matter (the solid, liquid, and gaseous states).

According to the model, for example, water is made up of many moving molecules. In the solid state the molecules are tightly bound and vibrate about fixed points. When energy in the form of heat is applied to these molecules, they vibrate more energetically, but they still vibrate in the same relative positions. The normal molecular pattern or structure of the solid remains intact until the heat energy applied is sufficient to change the substance from a solid into a liquid. In the liquid state, the molecules are less tightly bound and are free to roll around and over each other. If still more heat energy is applied to the substance, the liquid changes into a gas. In the gaseous state, the molecules have sufficient energy to overcome their mutual attraction and, consequently, are free to move about in a completely random manner.

Molecules are not simple particles; they are made up of smaller units called atoms. Atoms are sometimes called the "basic building blocks of matter" because they determine the properties of the basic elements. Again, a particulate model for the molecule explains various observed phenomena, such as the breaking up of water into oxygen and hydrogen according to a definite and constant ratio by weight.

Though atoms behave in many circumstances like single particles, they, too, are composed of smaller, subatomic particles such as electrons, protons, and neutrons. Thus, there is a particulate model for the atom in which electrons move around a nucleus, which is a collection of protons and neutrons confined in a very small space. This model accounts for many properties of the atom, such as atomic radiations, and also for some properties of the nucleus. Further study of the nucleus, however, has led to the discovery of many more subatomic particles contained within it, and their interrelationships are not as yet fully understood. It is expected that present ideas about the nature of matter will change as new experiments lead to new knowledge.

Looking at more complex forms of matter, we find that the particle concept is not just a theoretical model, because particles can sometimes be observed directly with the aid of a microscope. In the case of living matter, the basic unit is the cell, which is composed of complexes of compounds called organelles. These in turn are composed of molecules formed by the joining together of atoms.

Knowledge about the constant motion of individual constituents within the cell is important in explaining how the cell continually takes in new substances and discards manufactured products. Thus, knowledge about the particulate nature of matter is essential to an understanding of the complex, as well as the basic, natural events.

D. Energy exists in a variety of convertible forms.

Energy and its conversion is a common strand that runs through all sciences, from physics to biology and from geology to cosmology. The rate of man's rise from being his own beast of burden to developing modern technology has been in direct proportion to his ability to find and convert energy to replace muscle power. A direct measure of a nation's progress and material well-being is the average amount of energy consumed per citizen per year. Man's ultimate downfall, however, may be his pollution of the atmosphere by his conversion of energy from fossil fuels or by the catastrophic release of the energy locked within the nucleus of the atom.

The origin of most forms of energy on Earth can be traced directly or indirectly to radiant energy from the sun. The earth receives only one-half billionth of the sun's total output of energy; yet, much more or much less radiant energy from the sun would destroy all life as we now know it. This small fraction of the sun's energy remains on earth temporarily before it continues outward in space, changed only in direction and spectral distribution. One by one, the multitude of forms of potential and kinetic energy that man requires can be traced back to their thermonuclear birth on the sun.

The law of conservation of energy is based on many observations which support the conclusion that energy cannot be created or destroyed but can only be converted from one form to another. With reservations concerning the interchange of matter and energy, the total amount of energy in a system remains constant. Therefore, there can be no perpetual motion machine or any other device whose energy output exceeds its energy input.

The principle of energy conversion underlies almost every major scientific discipline. The physicist sees a swinging pendulum as an example of the transformation of energy from potential to kinetic and vice versa. He interprets sound as the transfer of energy from the vibration of a solid material to wave motion in the air, to another vibration within the ear and, finally, to an electrical impulse in the auditory nerve. The chemist observes that energy is transferred between molecules when they collide and that the potential energy of atoms and molecules decreases when electrical forces bind them together and increases when these bonds are broken. The nuclear engineer now converts some of the energy of the atomic nucleus to heat through nuclear fission and fusion and is seeking more direct and efficient methods of conversion. The meteorologist and the oceanographer consider their domains as parts of a heat engine driven by solar energy and modified by such factors as the earth's rotation. The astronomer collects electromagnetic energy that comes from the far reaches of the universe. The geologist observes the forces of erosion that are shaping our earth and speculates upon radioactivity as a possible source of the earth's central heating system. The biologist understands that all changes in living organisms, from simple cells to human beings, involve a flow of energy to and from the environment.

The energy transfer of the photosynthetic process is the basic source of energy for all living things. Photosynthesis, in turn, is based mainly on the conversion of the thin band of radiant energy which comes to man as light. The solar energy captured by chlorophyll enters living systems and is used with amazing efficiency to organize matter. Only bit by bit does the solar energy used in photosynthesis emerge as heat energy.

Living things are receivers, organizers, and distributors of energy in space and time. All of man's activities depend on his ability to obtain and make efficient use of energy resources. All motion and all change involve energy transformations. Falling water, a bouncing ball, metabolic processes, a penetrating gamma ray, a 100-foot geyser, a spinning radiometer, a plasma engine, and a comet are all explainable in terms of energy conversions. The problems of harnessing geothermal forces, confining nuclear fusion by magnetohydrodynamics, and setting foot on the moon require energy conversions for their solution. Fundamentally, meeting the energy needs of the world's expanding population means finding more energy sources and more efficient energy conversion devices.

E. Matter and energy are manifestations of a single entity; their sum in a closed system is constant

In our ordinary day-to-day experiences, the law of conservation of matter and the law of conservation of energy seem to be universally applicable. Investigations of certain subatomic and cosmic phenomena show that the relationship between matter and energy can be expressed by Einstein's famous equation, $E = mc^2$. Two important characteristics of this relationship are (1) that the amount of energy (E) appearing or disappearing is proportional to the amount of matter (m) that is destroyed or created; and (2) that c (the proportionality constant) is a large number (the speed of light). Thus, a small amount of mass is equivalent to a huge amount of energy. These points may be illustrated by the following examples:

1. In ordinary chemical reactions — decomposition of limestone by hydrochloric acid, for example — there is no measurable difference between total mass of reactants and total mass of products. Also, quantitative measurements show that energy liberated is not "created" but is simply the result of changing the chemical energy stored in the atoms and molecules into some other form of energy such as heat. On the other hand, during decay of radioactive elements such as radium or when uranium 235 decomposes into lighter elements in the explosion of an atom bomb, there is a loss of matter resulting in the creation of energy. Furthermore, the energy gained is proportional to the amount of matter lost, as predicted by the equation, $E = mc^2$
2. In the burning of a candle or any common fuel, both matter and energy are conserved. But in the fusion reactions that take place in the sun and in the hydrogen bomb, matter is destroyed and energy is created. Again the relationship is $E = mc^2$, and a huge amount of energy results from a small loss of matter.
3. The amount of matter in a stationary object is not changed measurably by putting it in a fast-moving airplane; none of the energy gained when speed is increased is converted into matter. However, man-made devices make it possible to accelerate electrons and some other subatomic particles to velocities that approach the speed of light. Under such extreme conditions, some of the kinetic energy of the fast-moving electron is converted into matter. At 18,600 miles per second (one-tenth the speed of light), the increase in mass is only one-half of 1 percent, but at 90 percent of the speed of light, the particle's mass is more than doubled.
4. When two automobiles collide, much of their kinetic energy is transformed into heat energy, but the total mass does not change; that is, there is no measurable conversion of energy into matter. But when high-speed protons collide, their loss of energy results in the creation of matter in the form of particles that did not exist before the collison.
5. When a piece of flint is struck with a piece of steel, sparks result. Kinetic energy of the moving steel is changed into heat

and light energy, but matter is not converted into energy, and there is no measurable change in the total mass of the system. In subatomic systems, however, it is possible to have collisons or combinations resulting in the complete annihilation of matter and the consequent creation of energy. For example, if an electron and a positron collide, they both disappear, and a photon of radiant energy is created. A similar phenomenon occurs when a proton and an antiproton combine. The energy of the photons so created is dependent upon the energy and masses of the disappearing particles.

Throughout the universe matter is constantly being transformed into energy, and matter is simultaneously being created from energy. A currently popular belief is that the two processes are in balance, but it is not definitely known that such a state of equilibrium has actually been attained. However, all available evidence tends to confirm the validity of the conclusion that the sum of matter and energy in the universe remains constant.

F. Through classification systems, scientists bring order and unity to apparently dissimilar and diverse natural phenomena.

The philosophers of ancient Greece asserted that from *Chaos* — a state of complete disorder, utter confusion, and lawlessness — evolved *Cosmos,* the perfectly arranged and ordered universe. This strong belief in an ordered (or orderable) universe has persisted in Western thought and today serves as a basic foundation for modern empirical sciences.

Through observation and analysis, scientists sort and identify the distinguishing characteristics or properties of natural phenomena that may lead to their interpretation and prediction. They search among these characteristics or properties for generalizations or principles that might serve as unifying themes or principles upon which classification systems or taxonomies could be developed.

Apparently diverse phenomena have been ordered or classified according to the principle of degree of simplicity or complexity of organization in natural systems. The taxonomy of plant and animal kingdoms, the periodic tables of elements, and the electromagnetic spectrum are examples of classification systems based upon underlying principles or unifying themes.

Recognition of diversity in the universe, accompanied by attempts to relate these differences, is the very process by which order is established. Differences in the characteristics of stars, ranging from spectral contrasts to dissimilarities in radio-wave emissions, allow the astronomer to suggest remarkable groupings f. ɔm which theories of stellar evolution emerge.

In any classification devised to bring order to our concepts of the universe, there must be an awareness that the system is, after all, made *by* man and *for* man. The human intellect has superimposed upon nature a system in order to better understand the universe. It is not surprising, therefore, that certain objects do not fit into man's classification system. Man is, in a very real sense, limited in his understandings and descriptions of natural phenomena to and by his mental processes and patterns. He is also limited, in part at least, by the modes by which he acquires knowledge.

F-1. Matter is organized into units which can be classified into organizational levels.

Structure within the natural order is observed in classifications from the smallest subatomic particles to the matter within huge galactic masses. Basic units of matter, small or large, are found in every organizational level in the physical and biological structures of the natural order. Scientists attempt to bring order to the world they investigate by grouping and classifying matter according to its properties. The basic unit selected varies with the particular field of inquiry. The cell, which represents an elemental unit to the biologist, is a highly complex system in the view of the chemist; similarly, entities that are conveniently considered fundamental by the chemist are intricate from the standpoint of the nuclear physicist.

There is a need within each organizational level for further distinction among forms of matter that resemble one another in terms of complexity but differ with respect to function.

Forms of matter that cannot be divided into simpler entities by chemical means are called elements, of which the basic unit is the atom. Combinations of atoms give rise to more complex forms of matter called molecules. Molecular constitution ranges from the very simple, such as is found in hydrogen gas, to the highly complex, as typified by a protein.

Aggregates comprising different types of molecules result in even greater complexity. A special and important class of such combinations is matter that has the ability to reproduce itself at the expense of its surroundings.

Even as the atom represents a fundamental organizational unit for the chemist, the cell fulfills much the same function for the biologist. An analogous increase in complexity occurs as aggregations of cells are considered, ranging from the relatively simple (tissue) to the highly complex (living organisms). As with the atom, the cell itself is composed of several types of matter, each of which possesses a unique complexity.

F-2. Living things are highly organized systems of matter and energy.

The forms of life and their interactions within various systems may be described as an immense hierarchy or organization ranging from atomic and molecular interactions to the interactions of plants and animals within the vastness of the biosphere.

The biosphere is the layer of living matter spanning the earth from within its crust to its upper atmosphere. All the plants and animals of the world are inhabitants of the biosphere, and all these organisms are in constant interaction with each other and with their environment. For this reason, the biosphere may be viewed as an integrated whole. For other purposes of study, however, the biosphere may be taken as a group of subsystems called ecosystems.

The ecosystem is composed of units known as communities. A community is a "web" of plants and animals that has adapted to a particular environment. Thus, a community might exist in a pond, in a vacant lot, or in an intestine. Regardless of the level of organization, an interaction of matter and energy must be maintained, or the community will become unbalanced and the system will deteriorate.

The specifically related animals or plants in a community constitute a population, such as a population of mice, tapeworms, ferns, or amoeba. Each individual within a population is considered an organism. Although this is the level commonly associated with life, it would be a mistake to presume that a single organism can exist in isolation. Each organism is dependent on other forms of matter for continuity of energy.

Organisms are interacting units within a population; they, in turn, are composed of cells. Cells are the smallest living units (excluding the virus) of organized matter and energy. Studies of certain units of the cell in isolation from the organized cellular structure have determined that these units hold the secret of life itself. These parts of the cell are called organelles.

The organism is a highly ordered, independently functioning system of large energy-producing molecules and cells, but the continuance of its life is dependent on the organism's contribution and on the contribution of other living things to the population-community ecosystem and to the biosphere.

F-3. Structure and function are often interdependent.

On every organizational level of matter, scientists have used the interdependence of function and structure as a useful tool. In most cases, if the function of a unit of matter can be observed, the scientist can make informed guesses as to its structure. Conversely, if the scientist can observe the structure of a unit of matter, he will have a good idea of its function.

A classic example of the use of this concept is found in the work of William Harvey, the English biologist. By studying the portion of the circulatory system that he could observe, Harvey determined that the flow of blood must be continuous. This enabled him to predict the existence of capillaries, which were structures too small for him to see. Thus, Harvey made inferences regarding structure from his observations of function.

Another example of the interdependence of structure and function is found in evolution. Cause-and-effect evolutionary theories were at first misinterpreted by Lamark when he predicted that function gave rise to structural adaptations. Experimental research indicates that structures evolved that made some organisms more adaptable to their environment than others. Organisms that evolved parts that did not successfully function within their environment did not survive.

Still another example is found in genetics. Geneticists observed that inheritance seemed to follow certain patterns, and they searched for the kind of physical structures that might hold the key to inheritance. They first realized the significance of chromosomes, then of genes, and eventually of even the molecular structure by searching for functional relationships.

G. Units of matter interact.

The properties and behavior of every unit of matter in the universe are dependent upon its interactions with other units of matter. In analyzing the behavior of a particular unit of matter, some of its significant interactions with other units of matter are selected for study. In this way, different types of interactions are investigated, and the changes in form, properties, or position that they produce in the unit of matter being studied are analyzed. At all levels of organization, the interactions of units of matter provide evidence to determine not only the relationships between units but also the basic properties of individual units. Thus, the study of interactions constitutes a large part of scientific investigation, and such studies have led to the formulation of a number of closely related concepts.

G-1. The bases of all interactions are electromagnetic, gravitational, and nuclear forces whose fields extend beyond the vicinity of their origins.

In every interaction it is found that forces come into play. These forces seem at first to be of many types, but at the present time the three types that stand out as being the bases of a great many interactions are electromagnetic, gravitational, and nuclear forces. All three of these basic forces have the rather amazing property of acting at a distance; that is, they permit interactions to take place without any direct contact between the units of interacting matter. The electromagnetic force is sometimes analyzed in terms of two separate forces, the electrical force and the magnetic force. Each of these forces can be described by corresponding laws of physics, but they are intricately related and thus can best be classified as two parts of a simple force field called the electromagnetic field.

Most of the interactions that are observed in everyday life, such as the interaction between a ball and a bat, do not seem to result from action-at-a-distance forces, since they require at least a surface contact between the bodies. A closer look at such interactions on a microscopic level, however, leads to a quite different conclusion. It is now believed that all contact interactions are basically due to the electromagnetic forces that bind electrons to nuclei to form atoms, and atoms to atoms to form molecules. What appears to be a direct contact between the surfaces of two interacting bodies is actually only a relatively close proximity between molecules, calling into play the attractive and repulsive action of electromagnets.

Many examples can be given in which electromagnetic forces between atoms or molecules are found to be the basis for what appear to be contact interactions. When a piece of paper is torn apart, the electrical bonds between like molecules are disrupted. The viscous forces that resist rapid motion through a fluid can be traced to electrical forces between the molecules of the fluid. A chemical reaction changes the electrical bonds between atoms making up a molecule and rearranges the atoms by different electrical bonding into a new molecule. Sound is the movement through the air of a compressional disturbance, and again it is the electrical force between molecules of air that causes them to resist the compression and thus pass along the disturbance to nearby molecules. Light is now known to be an electromagnetic field that moves through space, sometimes interacting with a responsive device such as the eye, a photographic film, or a photoelectric cell.

Thus, by looking at interactions on the atomic level, it can be seen that even the so-called contact interactions are based on action-at-a-distance forces. These forces are closely related to the electrical and magnetic forces that can be observed on a larger scale with charged bodies and magnets. On the atomic level the forces have properties that depend upon the dynamic nature of the atom or molecule. However, these forces are still basically attributable to the electrical charge possessed by the interacting particles. Magnetic forces caused by the motions of electrical charges are also present and sometimes play an important role, but the electrical forces have been emphasized here because they dominate in most atomic interactions. Gravitational attractions between individual atoms or molecules are also assumed to be present, but they are negligible in comparison with the other forces. Only for large bodies do the gravitational forces become observable.

When it was discovered that the nucleus is made up of particles (protons and neutrons) that have electrical and magnetic properties, it was thought that perhaps the nucleus was held together by electromagnetic force. It was soon found, however, that this could not possibly by the case, for not only are those forces far too weak to produce the observed binding but also the electrical forces push the protons apart rather than bind them together. Gravitational forces are much too weak to have any effect whatsoever on the binding of protons and neutrons together in the nucleus. Thus, it must be postulated that there is at least one other type of force, the nuclear force. It is now believed that there are actually two kinds of nuclear force, one of which is considerably weaker than the other.

Nuclear forces also act without direct contact between the interacting particles, but, unlike the other forces, the strength of the nuclear forces does not vary inversely with the square of the distance between particles. The nuclear forces are much stronger than the other forces, but they are effective over very short distances (roughly equal to the diameter of a nuclear particle). Studies of radioactivity, high energy collisions, and interactions of elementary particles have led to considerable progress in understanding the two nuclear forces. They are not yet fully understood, however, and they are therefore the object of intensive study today.

G-2. Interdependence and interaction with the environment are universal relationships.

Interaction and interdependence are found in the smallest subatomic particles and in the most gigantic astronomical bodies. Nothing in the universe exists in isolation, for every object that exists is either dependent upon an interacting event for its origin or is in the process of change due to interactions.

Units of matter interact when forces are applied to them; basic forces are electromagnetic, gravitational, and nuclear. Energy may pass from one body to another by direct contact or by radiation. Interactions within an atom hold its various parts together and establish the energy levels of the electron configurations. Interactions of the orbital electrons of one atom with those of another establish the bondings of molecules. These molecules in turn are held together in interacting systems, such as crystals or varieties of gaseous, liquid, or solid matter.

Living things and the parts of living things react with their environments. The environment consists of both living and nonliving things and may be external (surrounding the organism) or internal (found within the organism). These interactions result in a balanced equilibrium whose limits determine the continued existence of the organism or its parts. The components of a living cell are integrated by interactions, and the cell as a whole dynamically interacts with its environment by exchanging matter and energy across the cell surface. At the higher organizational levels of organism, population, community, and ecosystem, the components within any given unit interact with each other, and the unit as a whole exchanges matter and energy with its environment.

Each body in the universe influences and is influenced by all other bodies in the universe. Many of the actions observed on the surface of the earth are the direct or indirect result of the effect of the sun and the moon. For example, the weather and the tides result from solar and lunar interactions with the earth.

Many interdependent events that occur in the natural order are cyclic in character. There is a pattern of sequential events, which gives rise to a repetitive chain of events. These cyclic phenomena are therefore a series of predictable events in which one link of the chain is dependent upon its preceding link. Food cycles, water cycles, and life cycles are a few examples of dependent cyclic interactions.

A food chain links members of an ecosystem together. Green plants begin the chain (phytoplankton in the marine ecosystem). The green plants, using light from the sun for energy and water and carbon dioxide, manufacture food. A first-order consumer comes along and eats the plant. A second-order consumer eats the first-order consumer. We can even have a transfer of food and energy from the producer to a third-order consumer or to an even higher level.

Another order of interactions is that of evolutionary events, which produce predictable changes in certain kinds of objects over long periods of time. One theory claims that atoms, interacting with one another and evolving over eons of time, gave rise to the present assemblage of various kinds of elements. Another evolutionary thesis describes the progress of stars all the way from young gaseous nebulae to pulsating dying stars. Still another interacting series of events has produced the evolution of rocks from igneous to sedimentary and metamorphic.

All scientific evidence to date concerning the origin of life implies at least a dualism or the necessity to use several theories to fully explain relationships between established data points. This dualism is not unique to this study but is also appropriate in other scientific disciplines, such as the physics of light.[1]

While the Bible and other philosophic treatises also mention creation, science has independently postulated the various theories of creation. Therefore, creation in scientific terms is not a religious or philosophic belief. Also note that creation and evolutionary theories are not necessarily mutual exclusives. Some of the scientific data (e.g., the regular absence of transitional forms) may be best explained by a creation theory, while other data (e.g., transmutation of species) substantiate a process of evolution.[2]

Aristotle proposed a theory of spontaneous generation. In the nineteenth century a concept of natural selection was proposed. This theory rests upon the idea of diversity among living organisms and the influence of the natural environment upon their survival. Fossil records indicate that hundreds of thousands of species of plants and animals have not been able to survive the conditions of a changing environment. More recently, efforts have been made to explain the origin of life in biochemical terms.

G-3. Interaction and reorganization of units of matter are always associated with changes in energy.

The relationships among all things and their environments can be compared to a spider's web consisting of many interwoven threads that form a complicated pattern. An interplay of matter and energy holds the "web" together. There is, however, an orderly pattern to the total process.

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[1]This statement was prepared by the State Board of Education as an explanation of its position and inserted in this copy in lieu of two sentences which were deleted. This statement does not meet with the approval of the State Advisory Committee on Science Education, nor does its inclusion in this manuscript have the approval of the Committee.

[2]*Ibid.*

Interactions of matter and energy are consistent and describable in terms of natural laws. The study of thermodynamics considers the laws of energy change and makes possible the prediction of many physical, chemical, and biological events. The following two concepts are concerned with the changes in energy that accompany changes in the organization or state of matter:

1. In a closed system, when units of matter interact, the system tends toward a condition of equilibrium in which free energy is at a minimum.
2. In an open system, units of matter may interact in such a way as to maintain a steady state or condition of homeostasis.

Both these concepts are concerned with the changes in energy that accompany changes in the organization or state of matter.

The First Law of Thermodynamics is a statement of conservation of energy (see conceptual system D), including the interchange of heat and mechanical energy with the system. With this law, predictions can be made concerning how much energy is converted from one form to another when a system undergoes energy changes. However, the First Law of Thermodynamics does not determine the direction in which the energy exchanges in an isolated system will normally take place. For example, it does not indicate the tendency for most forms of energy to be converted to thermal energy, from which form the energy cannot be completely reconverted to more useful forms. The universality of this degradation of useful energy to thermal energy has led to a Second Law of Thermodynamics. This law can be stated in many ways but it is perhaps best stated in terms of a thermodynamic quantity called entropy, a quantity that is closely related to the degree of disorder that exists within the system. In terms of entropy, the Second Law of Thermodynamics states that in every process taking place in an isolated system, the entropy of the system either increases or remains constant. This implies that all the natural processes within the universe (considered as a single isolated system) are increasing the entropy of the universe, that is, tending toward maximum disorder.

When the First and Second Laws of Thermodynamics are applied to relatively simple systems, the changes that will take place in those systems can often be predicted. For example, when a closed system is left alone, processes operating in that system tend to bring it to a state of equilibrium. This is very useful in the study of chemical reactions where equilibrium is reached when the average number of molecules changing from one form to another is the same as the number changing back again to the original reacting elements. If the system is opened, however, and matter or energy is added or removed, the equilibrium point can be shifted in such a way that the reaction may go completely in one direction or the other. Household ammonia (NH_4OH) is formed when ammonia gas (NH_3) reacts with water (H_2O) and all three substances are in equilibrium as long as the container is closed ($NH_4OH \rightleftharpoons NH_3 + H_2O$). If it is opened, the ammonia escapes and the reaction can proceed to completion ($NH_4OH \longrightarrow NH_3\uparrow + H_2O$).

It is essential to living organisms that their biochemical reactions remain open and do not attain equilibrium or all the life processes would soon cease. Biochemical reactions usually occur in a series of orderly steps proceeding in one direction and not reaching equilibrium, because the products of each reaction in the sequence are removed as they become the reacting materials for the succeeding reaction. The maintenance of such an organized system requires a constant supply of free energy to the living organism. This constant flow of matter and/or energy in and out of a system is called the steady state or homeostasis. This constant or steady exchange is not equilibrium because there is continual gain (as food for the organism) and loss (the giving off of heat and wastes by the organism).

The constancy of energy-matter relationships is fundamental to the existence of order in nature. Equilibrium and the steady state are conditions dependent upon a regulated and predictable flow of energy and the changes produced by energy within a given system.

Since the whole universe is moving toward maximum disorder (minimum free energy), and since outside free energy must be utilized to create and maintain the order of a system (such as a living system), it follows that creating order in one part of the universe necessarily involves creating greater disorder in some other part. Future decisions about pollution control, use of atomic energy, and overpopulation must be made on the basis of where disorder can be tolerated in order to bring about order where it is needed for survival.

Fundamental concepts of energy changes may be found in the study of a balanced aquarium unit in the lower grade levels, as well as in the study of molecular equilibrium in the senior high school.

APPENDIX B

Competencies of Teachers

Agencies that provide preservice and continuing education for teachers may use the systems-analysis process described in the Science Framework in conducting and evaluating their programs. The same steps stated in the main body of this document may be utilized by these agencies to assess needs, generate goals, describe teacher behaviors, determine the optimum conditions for teachers to learn the behaviors, and evaluate teachers' growth toward the objectives.

The intention of the Advisory Committee in this appendix is to assist teacher education institutions and other agencies engaged in teacher education to initiate such a systems-analysis process for themselves. Participation in this process will help these institutions and agencies educate teachers so they will be capable of leading students toward the goals of science instruction: scientific attitudes, rational thinking processes, manipulative and communication skills, and knowledge. The following statements of philosophy, lists of competencies and behaviors, and descriptions of conditions are in the nature of suggestions only and may serve as points of departure for further development.

Needs Assessment

The changes in the science curriculum described in this document require a fundamental shift in emphasis from the facts and products of science to the conceptual organization and cognitive processes of science. This change in emphasis calls for a corresponding change in the role of the teacher of science. In his new role, the teacher at each grade level creates the conditions in which the student discovers what the universe is about.

The qualifications of such an instructor of conceptual learning and process development are quite different from those of the traditional teacher who views his role as a transmitter of factual information. Implied in the requirements for this new role is the necessity for a reassessment of the program of preservice and continuing education for both elementary and high school teachers. Changes must occur in all areas of the teacher's preservice preparation — in science, the liberal arts, and professional education. Provisions must be made in programs of continuing education for teachers who are in service to develop the strategies of teaching appropriate to this new role.

Philosophical Position

The Advisory Committee believes that teachers who value and are able to lead students toward the goals listed in this document must participate in experiences based upon these same goals.

Goals and Behavioral Objectives of Teachers of Science

A program of preservice or continuing education can be developed only after the desired attributes of the teacher have been specified. What should a teacher be able to do in order to demonstrate that he has a functional understanding of the stated goals of science education? The following lists suggest four general areas of competency: science, liberal arts, instructional methods and techniques, and professional education. Specific behaviors are derived from each of these areas.

Competencies in Scientific Attitudes, Thinking Processes, Skills, and Knowledge

A complete description of competencies in scientific attitudes, thinking processes, skills, and knowledge is given in Chapter III of this publication. Generally, it is felt that a teacher must first acquire these competencies himself if he is to develop them in his students. A science teacher, therefore, should be able to do the following:

1. Demonstrate his recognition and recall of information selected as basic and indispensable in his field(s) of science.
2. Pronounce correctly and define terms and phrases commonly used in his field(s) of science.
3. State a number of major scientific concepts and demonstrate or explain their significance.
4. List some significant or insoluble problems or paradoxes in science today and demonstrate or explain what makes them significant.
5. Exhibit the scientific attitudes of open-mindedness and suspended judgment.
6. Derive satisfaction and excitement from pursuing scientific investigations.

7. Describe the interrelationships between various fields of scientific endeavor.
8. Demonstrate proficiency in the manipulative skills of science.
9. Perform mathematical calculations appropriate to his field(s).
10. Present evidence of having carried through a piece of research and/or describe research done by someone else, indicating processes used and problems encountered.
11. Identify and utilize the processes of experimentation, verification, analysis, synthesis, evaluation, hypothesis formation, and prediction when confronted with discrepant events in his environment.

Competencies in the Liberal Arts

In addition to having developed scientific attitudes, thinking processes, skills, and knowledge, the teacher must be competent in the social sciences, the arts and humanities, and in the use of the English language. He must be able to:

1. Use the skills and attitudes of the educated man in observing and interpreting the world about him.
2. Interpret the present in terms of the past.
3. Use the skills of oral and written communication effectively.
4. Interpret the relationships between science and other aspects of human endeavor.

Competencies in Instructional Methods and Techniques

Translating knowledge about how students learn into the specific instructional behaviors that will elicit the desired learning is the unique function of the teacher. He must be able to:

1. Select materials and equipment that will lead to the learners' development of scientific attitudes, thinking processes, skills, and knowledge and be able to explain or justify his selections.
2. Construct instruments of evaluation and follow other evaluative procedures to measure the learners' progress toward the stated objectives.
3. Provide a rich environment of data sources, materials for experimentation, sources of ideas, phenomena to observe, and reference materials necessary for the development of scientific attitudes, thinking processes, skills, and knowledge.
4. Use instructional time efficiently.

5. Lead the students through a range of cognitive operations in arriving at a generalization inductively.
6. Demonstrate ability to utilize psychologically sound techniques of reinforcement, transfer, and motivation.
7. Formulate questions, design experiences, and select materials that will elicit in the students those cognitive processes identified in Bloom's ***Taxonomy***[1] and/or those processes identified in Chapter III of this publication.
8. Make revisions of teaching strategies and classroom environment to make them more consistent with the nature of science, learning theories, or the learners' levels of development.
9. Identify or construct situations that motivate inquiry in the learners.
10. Use available data about each learner's conceptual level, cognitive style, interests, and abilities to process information from such data sources as the learner himself, parents, previous teachers, and the learner's cumulative record.
11. Identify the growth of each learner toward autonomous inquiry, self-directed learning, self-evaluation, and increased interest in science.

Competencies in Professional Education

The professional educator draws heavily on other disciplines — sociology, psychology, anthropology, and philosophy — as a basis for deciding what to teach and for the methods of instruction. The professional educator is one who is well-grounded in these foundation areas and draws upon their theoretical constructs as bases for his behavior. He must be able to:

1. Describe the social and cultural functions of the school.
2. Explain the psychological bases for specific teaching techniques.
3. Demonstrate observable attitudes of professional responsibility in personal behavior.
4. Answer questions pertaining to the legal and financial operations of the school.
5. Keep abreast of new developments in teaching and devise new techniques for effective teaching strategies in the light of new developments.

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[1] ***Taxonomy of Educational Objectives — Handbook I: Cognitive Domain.*** Prepared by Benjamin S. Bloom and Others. New York: David McKay Co., Inc., 1956.

6. Work with other staff members to improve curriculum and instructional practices.
7. Relate and involve the work of the classroom with the community, thereby expanding the classroom and contributing to the community.

Optimum Conditions for Attaining Goals

The next step is to devise strategies and conditions in which teachers will manifest the desired behaviors. Although the following list is not prescriptive, it suggests situations that are intended to develop teacher behaviors that are consistent with the teacher's new role in science education:

1. Experiences should provide opportunities for investigatory procedures in field and laboratory to develop the processes that the teacher will be expected to elicit, identify, and evaluate in the work of his students.

2. Experiences should provide whatever degree of depth is needed to ensure both concept and process learning, even if the scope or breadth of instruction must be reduced. The concepts taught at the high school level are more comprehensive and the processes are more refined than at the elementary level. This implies a need for both breadth and depth in subject matter background for the high school teacher. Subject matter preparation or supplementation should be made on the basis of how much it increases understanding of the conceptual structures and inquiry processes of science rather than how successfully it surveys the field.

3. Experiences should provide opportunities for development of individual teacher potential. This may be accomplished through the use of programmed materials, open-ended activities, varied reading lists, and individual laboratory investigations.

4. Experiences should emphasize practical and social implications, the impact of science on society and culture, and the history and philosophy of science.

5. Opportunities should be provided for investigation in fields of knowledge outside the teacher's specific subject area so that he can relate other fields to science and use science to interpret other fields.

6. Opportunities should be provided for teachers to see demonstrations of the national science programs in action and to practice the strategies of these programs.
7. Experiences should be provided in learning to write behavioral objectives and in planning teaching strategies that will develop conceptual understanding and thinking processes in students.
8. Opportunities should be provided in learning new evaluation techniques and in developing evaluation procedures that are consistent with the stated objectives of science instruction.
9. Opportunities should be provided for teachers to become familiar with the new developments in and the availability of the wide variety of instructional media and resource materials, including films, pamphlets, journals, laboratory materials and equipment, television equipment, videotape recording systems, and projectors.
10. Opportunities should be provided for each teacher to plan, record, view, analyze, and revise samples of classroom interaction between himself and his students, between students and students, and between students and instructional materials.

Selection and Implementation of Teacher Education Curricula

Meeting the conditions just outlined can be achieved in the undergraduate and fifth-year college programs of the preservice teacher. Courses in the major, liberal arts subjects, methodology, and professional education should be selected or specifically designed to meet the criteria for teacher competence as set forth in this document. Prospective teachers should be encouraged to study with instructors who understand and agree with the stated objectives of science education and who structure their courses to reflect these objectives.

School districts and offices of county superintendents of schools bear the major responsibility for providing classroom teachers with the opportunities to improve their competencies. The following are some suggestions for implementing such programs:

1. Through the cooperative efforts of all educational personnel (administrative, supervisory, and instructional) within the school districts, determine the needs of teachers within the districts. Assessment of needs should determine what behav-

iors teachers are currently using and identify the disparity between what is current teaching behavior and the behavior required to teach for the goals stated in this document.

2. Plan and conduct both long- and short-range programs, which should include a wide but specific choice of alternative activities designed to improve teacher competencies in science curriculum and instruction.
3. Capitalize on available resources, and cooperate with other agencies sponsoring programs for improving the effectiveness of science teachers.
4. Make continuing programs attractive to teachers through released time or paid summer time.
5. Provide teachers with many sources of information (newsletters, bulletins, progress reports, and periodicals) for their continuing education.

APPENDIX C

Analyses of Teaching Strategies

The lessons analyzed in this section exemplify the type of instruction that can result when the goals, objectives, strategies, and techniques discussed in the previous pages form the framework of science education. The following lessons have been used successfully in classrooms. They reflect ingenuity, imagination, and an awareness of the principles and philosophy of sound science education. The uniqueness of each lesson is a reflection of the unique personality of each teacher and of each child or student and also reflects the uniqueness of each teacher-student relationship. The lessons are not to be imitated in content; rather, they are meant to show actual classroom experiences in which teachers have attempted to encourage, through their instruction, the attainment of the goals set forth in this framework: scientific attitudes, rational thinking processes, manipulative and communications skills, and knowledge.

Lesson 1: What Can Magnets Pick Up?
Grade level: First
Source: Arthur L. Costa, Associate Professor of Education
Sacramento State College

Here is a sample of some classroom interaction. It occurred in a first grade class taught by Mrs. Eugenia Bernthal of the Pasadena Unified School District. It is presented here to illustrate teacher technique in diagnosis. The teacher is gathering information about concepts of magnetism held by each pupil in her class. Using this information, she will make decisions about the kinds of learning activities most likely to produce desired behaviors in the children.

This fragment is not a complete lesson; only enough of the lesson to show a technique has been transcribed. Several aids to analysis follow the dialogue.

Teacher: Gregory, would you please tell us what is so especially interesting about this book and what this picture is all about?

Gregory: It's about magnets, and a boy is in the garage picking up things with a magnet, and he is trying to learn something. He has a whole bunch of nails on a magnet there, and it also looks like it is his daddy's magnet.

Teacher: Why do you think they have all these things over here, Gregory?

Gregory: Probably because the magnet can't pick them up.

Mike: It can pick some of them up, Gregory; it can pick a lot of them up.

Teacher: Which ones?

Mike: Well, it could pick a pail up, and a spoon, and a screwdriver.

Gregory: It could not pick up a spoon.

Mike: How do you know what kind of spoon that is, Gregory?

Gregory: Spoons are all the same kind except for play spoons.

Mike: Yes, but they are not made of the same thing always. Sometimes they are made out of copper.

Kathy: There are wooden spoons and plastic spoons and all that and plastic forks.

Teacher: Jennie, how can we solve this problem between Mike and Gregory and Kathy as to the spoons? Mike, you listen and see if you think this sounds good.

Jennie: You can get a spoon and try it.

Teacher: What kinds of spoons do we need to try this with a magnet?

Jennie: Metal or steel.

Teacher: What kinds of spoons are there, Gregory?

Gregory: There are lots of kinds of spoons. At home I have a real strong magnet, and it can't pick them up.

Teacher: What kind of spoons do you have at home?

Gregory: They are metal and iron.

Teacher: Do you think you could possibly bring one of your spoons to school if we are very careful with it and you take it home with you again when we're through with it?

Gregory: Okay; maybe. I'll ask my mother.

Gary: There's a spoon in Brian's lunch pail.

Teacher: Brian, will you please get the spoon from your lunch pail? Gary, will you get the magnet please? Now because this is Brian's spoon, what do you think is the fair thing to do?

Gregory: Let him do it with his own spoon.

Teacher: Do what?

Gregory: Try and see if he can pick it up with a magnet.

Teacher: Brian, you go ahead; here's the spoon.

Gary: It's probably copper.

Gregory: I told you so because a magnet won't pick it up.

Teacher: The magnet doesn't . . . .

Gregory: Cause the magnet . . . .

Teacher: Anyone know why the magnet won't pick up the spoon?

Mike: The spoon isn't the kind of stuff that magnets can pick up.

Gregory: You mean the right kind of steel.

Mike: I don't mean the right kind of steel.

Gregory: I told you a magnet couldn't pick up a spoon.

Teacher: Are there some kinds of spoons that you think it might pick up? Susan has a spoon; let's see if the magnet can pick up Susan's spoon.

Gregory: Of course it can't; it can't because the spoon is plastic.

Teacher: Do you think that maybe there are some . . . .

Gary: I think the most powerful magnet in the world might be able to pick it up.

Gregory: An electromagnet, I think, is the strongest magnet that was ever made by the earliest scientist.

Teacher: Gregory, do you want to get the electromagnet and try it on the plastic spoon?

Now that you have read the sample of interaction between the teacher and the pupils, how would you evaluate it? Does it conform to the principles and procedures of this framework? Has this teacher, in fact, taught any science? Have the children learned anything? Why would we think so? Why would we think not?

How shall we proceed to analyze this lesson? There are several questions that might be asked as we think back over the lesson:

1. From what behavioral evidence can we infer that the goals of science education are being achieved?
   a. Development of attitudes
   b. Use of rational thinking processes
   c. Development of manipulative and communication skills
   d. Development of concepts (knowledge)
2. From what teacher behaviors can we infer a consistency of teaching strategy?
   a. Consistency of her actions with what a scientist does
   b. Consistency of her actions with learning theory
   c. Consistency of her actions with principles of child development
3. What behavioral evidence can we use to measure each child's level of development?
   a. Attitudinal
   b. Conceptual
   c. Cognitive
4. From what behavioral evidence can we infer that the children are developing autonomy?
   a. Self-direction

b. Self-evaluation
c. Use of processes and concepts with minimum or no teacher help

5. From the behaviors exhibited in this episode, what should be prescribed as the next learning activities for these pupils to lead them towards what goals and objectives? What teacher behaviors would be appropriate to elicit this behavior?

The following models are intended to help teachers plan and analyze a classroom discussion-type lesson in science. The lesson draws upon the contributions of such instructional strategists as Bellack, Bloom, Flanders, Minnis, and Taba as a basis for interpretation. It is based upon the notion that a teacher basically performs three functions in a classroom discussion: (1) the soliciting and initiatory function; (2) the reacting and responsive function; and (3) the role-definition, direction-giving, and structuring function. Many teachers perform these functions without realizing their own intentions or the effect of what they are doing. Each time the teacher performs one of these functions, he is in a decision-making position. It is hoped that these lesson-planning devices will help teachers make more rational decisions.

1. Concept Formation Model

One aspect of science instruction is concerned with concept formation and the development of cognitive processes. Therefore, this model, borrowing from Taba,[1] is based on three levels:

Level 1. Concept formation: recalling, labeling, enumerating, identifying, and so forth

Level 2. Data processing: interpreting, synthesizing, classifying, analyzing, generalizing, comparing, and so forth

Level 3. Applying concepts and processes: predicting, evaluating, hypothesizing, experimenting, and so forth

The behavior the teacher uses will determine which cognitive operation the student will perform. If teaching is to encourage the development of cognitive processes, then teachers must become more aware of their own behavior as a tool to create good learning conditions.

[1] Hilda Taba, ***Teachers' Handbook for Elementary Social Studies.*** Palo Alto, Calif.: Addison-Wesley Publishing Company, 1967, p. 9.

Chart 1

Planning or Analyzing a Discussion Strategy — General

Teacher behavior (planned/observed)	Student response (anticipated/observed)	Teacher reaction (planned/observed)
I. Concept formation. Teacher asks: "What things will a magnet pick up?" (Questions or instructions elicit in the student a cognitive task; in this case, recall.)	The student responds by recalling: "A pail, a spoon, a screwdriver."	At this point the teacher can either reinforce the correct answer: "Good," "Correct," and so forth. Or, he may proceed to another student or another question at a higher level of thinking.
II. Data processing and interpreting. The teacher's questions cause the student to perform the cognitive operations of showing relationships, synthesizing, classifying, comparing, and so forth: "Why won't the magnet pick up the spoon?"	The student responds by giving his hypothesis, which shows a relationship between the magnet and the particular metal.	The teacher maintains the level of inference by accepting all hypotheses and explanations, clarifying, elaborating, feeding in data, and so forth. The teacher responds to the student's statements at the same cognitive level or proceeds to a higher level.
III. Application of concepts and processes. The teacher's questions cause the student to predict, evaluate, or apply a concept: "Do you think there are some magnets that would pick the spoon up?"	The student responds by predicting, hypothesizing, and substantiating his ideas with previously gained concepts, and so forth.	The teacher accepts, probes for clarification, elaborates an idea, contributes data to support or question hypotheses, or asks further questions.

Chart 2
Planning or Analyzing a Discussion Strategy — Specific

	Examples of teacher questions	Student response	Teacher reaction
Level 1. Concept formation	What kind . . . ? How many . . . ? Do you remember . . . ? What are the names of . . . ?	Identifying Enumerating Recalling Labeling	Reinforce correct answer. Correct wrong answer. Seek clarification. Accept correct answer. Provide data. Initiate next higher level of thinking.
Level 2. Data processing and interpreting	How are these similar to or different from . . . ? What do we need in order to . . . ? How many kinds of . . . ? Can you describe what you saw? Can you explain what you saw?	Comparing Analyzing Classifying Interpreting Synthesizing	Accept all responses. Seek clarification or elaboration. Provide data. Respond at same level of thinking — comparing, interpreting, analyzing syntheses or classifications. Initiate next higher level of thinking.
Level 3. Appreciation of concepts and processes	How shall we go about . . . ? What would happen if . . . ? Why do you think . . . ? How can you find out . . . ? Which do you think would be better . . . ?	Experimenting (process) Predicting Hypothesizing Verifying (process) Evaluating	Provide materials for experimentation and data collection. Provide data. Seek clarification or elaboration. Accept all responses. Diagnose concept formation.

Chart 3

Analysis of Science Lesson — First Grade

Name	Statement/response	Teacher behavior	Cognitive operations
Teacher:	Gregory, would you please tell us what is so especially interesting about this book and what this picture is all about?	Structuring	
Gregory:	It's about magnets, and a boy is in the garage picking up things with a magnet, and he is trying to learn something. He has a whole bunch of nails on a magnet there, and it also looks like it is his daddy's magnet.		Analyzing and interpreting picture (level 2)
Teacher:	Why do you think they have all these things over here, Gregory?	Initiating application of concepts and processes—"Why" question elicits hypothesis.	
Gregory:	Probably because the magnet can't pick them up.		Hypothesizing (level 3)
Mike:	It can pick some of them up, Gregory; it can pick a lot of them up.		Synthesizing (level 2)
Teacher:	Which ones?	Initiating concept formation—"Which" question elicits enumeration.	
Mike:	Well, it could pick a pail up, and a spoon, and a screwdriver.		Enumerating (level 1)
Gregory:	It could not pick up a spoon.		Synthesizing (level 2)
Mike:	How do you know what kind of spoon that is, Gregory?		Analyzing (level 2)
Gregory:	Spoons are all the same kind except for play spoons.		Generalizing (level 2)
Mike:	Yes, but they are not made of the same thing always. Sometimes they are made out of copper.		Analyzing (level 2)
Kathy:	There are wooden spoons and plastic spoons and all that and plastic forks.		Classifying (level 2)
Teacher:	Jennie, how can we solve this problem betwen Mike and Gregory and Kathy as to the spoons? Mike, you listen and see if you think this sounds good.	Initiating application of concepts and processes—"How can we solve" question elicits experimentation (structuring, evaluation).	

Chart 3

Analysis of Science Lesson — First Grade (Continued)

Name	Statement/Response	Teacher behavior	Cognitive operations
Jennie:	You can get a spoon and try it.		Application of processes—experimenting (level 3)
Teacher:	What kind of spoons do we need to try this with a magnet?	Initiating concept formation—"What kind" question elicits identification.	
Jennie:	Metal or steel.		Identifying (level 1)
Teacher:	What kinds of spoons are there, Gregory?	Initiating concept formation—"What kind" question elicits identification.	
Gregory:	There are lots of kinds of spoons. At home I have a real strong magnet and it can't pick them up.		Generalizing (level 2) Recalling (level 1)
Teacher:	What kind of spoons do you have at home?	Initiating concept formation—"What kind" question elicits identification and recall.	
Gregory:	They are metal and iron.		Recalling, identifying (level 1)
Teacher:	Do you think you could possibly bring one of your spoons to school if we are very careful with it and you take it home with you again when we're through with it?	Structuring	
Gregory:	O.K.; maybe. I'll ask my mother.		
Gary:	There's a spoon in Brian's lunch pail.		Recalling (level 1)
Teacher:	Brian, will you please get the spoon from your lunch pail? Gary, will you get the magnet, please? Now because this is Brian's spoon, what do you think is the fair thing to do?	Structuring	
Gregory:	Let him do it with his own spoon.		
Teacher:	Do what?	Initiating application of concepts and processes (experimentation)	

Chart 3

Analysis of Science Lesson – First Grade (Continued)

Name	Statement/Response	Teacher behavior	Cognitive operations
Gregory:	Try and see if he can pick it up with a magnet.		Experimenting (level 3)
Teacher:	Brian, you go ahead; here's the spoon.	Structuring	
Gary:	It's probably copper.		Synthesizing (level 2)
Gregory:	I told you so because a magnet won't pick it up.		Synthesizing (level 2)
Teacher:	The magnet doesn't		
Gregory:	'Cause the magnet		
Teacher:	Anyone know why the magnet won't pick up the spoon?	Initiating data processing—"Why won't the magnet" question elicits interpretation or hypothesis.	
Mike:	The spoon isn't the kind of stuff that magnets can pick up.		Interpreting (level 2)
Gregory:	You mean the right kind of steel.		Interpreting (level 2)
Mike:	I don't mean the right kind of steel.		Synthesizing (level 2)
Gregory:	I told you a magnet couldn't pick up a spoon.		Synthesizing (level 2)
Teacher:	Are there some kinds of spoons that you think it might pick up? Susan has a spoon; let's see if the magnet can pick up Susan's spoon.	Initiating data processing—"Are there some kinds" question elicits analysis; structuring.	
Gregory:	Of course it can't; it can't because the spoon is plastic.		Predicting (level 3)
Teacher:	Do you think that maybe there are some	Initiating application of concepts and processes—"Do you think that maybe" question elicits hypothesis.	
Gary:	I think the most powerful magnet in the world might be able to pick it up.		Predicting (level 3)
Gregory:	An electromagnet, I think, is the strongest magnet that was ever made by the earliest scientist.		Generalizing (level 2)
Teacher:	Gregory, do you want to get the electromagnet and try it on the plastic spoon?	Structuring	

2. Behavioral Objectives Model

Another way of analyzing this lesson is to recall or record behaviors that match the specific behavioral objectives under each of the four goals of the science program as indicated in this framework: (1) scientific attitudes; (2) rational thinking processes; (3) manipulative and communication skills; and (4) knowledge.

Chart 4

Specific Pupil Behaviors That Indicate Achievement of Goals or Objectives

	Attitudes	Rational thinking processes	Manipulative and communication skills	Knowledge
Gregory	Demonstrates interest in event: Description of picture in book.	Application-hypothesis: "It won't pick it up because it's plastic."		Understands magnetic attraction on some materials but not others: "It could not pick up a spoon."
Mike	Demonstrates interest in event: "They can pick some of them up."			
Jennie		Experimentation: "You can get a spoon and try it."		
Gary	Demonstrates interest in event: "There's a spoon in Brian's lunch pail."			Does not comprehend magnetic attraction on some materials: "I think the most powerful magnet in the world might pick it up."
Brian			Handles magnets in correct manner.	

3. Science Lesson Planning Model

The analytical processes demonstrated in Model 2 may also be used in the preparation of a science lesson. The advantage of such planning is that it enables the teacher to think through his behaviors prior to the lesson and to anticipate the effect his behaviors will have on the pupils. The following model may be helpful in planning such a lesson. Does the teacher's behavior achieve the desired effect?

Chart 5

Detailed Plan or Analysis of a Discussion Strategy

Objectives of pupil	Activity	From what conceptual system is the activity drawn?	Initiatory teacher behavior	Anticipated pupil behavior	Appropriate teacher responses
When conducting investigations to test inferences, hypotheses, and theoretical models, the pupil reorganizes and reports data that are not consistent with the statements being tested.	Working with magnets to determine what materials magnets will attract and what materials they will not attract	**System A:** Most events in nature occur in a predictable way, understandable in terms of a cause-and-effect relationship; natural laws are universal and demonstrable throughout time and space.	**Level 1:** What will a magnet pick up? What kind of material will a magnet pick up? (labeling).	**Level 1:** Listing or enumerating, labeling	**Level 1:** Does not respond to incorrect or correct statements; initiates higher-level cognitive behavior.
		System D: Energy exists in a variety of convertible forms.	**Level 2:** Why did the magnet not pick it up? Can you explain why not? In what ways are the things magnets pick up alike?	**Level 2:** Comparing, classifying, hypothesizing, interpreting	**Level 2:** Responds at same cognitive level or initiates higher level of cognitive behavior; clarifies.
		System G-1: The bases of all interactions are electromagnetic, gravitational, and nuclear forces whose fields extend beyond the vicinity of their origins.	**Level 3:** Do you think there might be a way. . .?What would happen if you used . . . ? How would you go about . . . ? How would you find out if . . . ?	**Level 3:** Predicting, experimenting	**Level 3:** Responds at same cognitive level; clarifies.

Lesson 2: Different Rates of Mixing (Diffusion of Liquids)[2]
Grade level: Sixth
Source: John L. Ryan, Science Teacher-at-Large
San Francisco Unified School District

The subject of Lesson 2 is the effect of temperature on the diffusion rate of liquids. In this lesson the teacher attempts to encourage the progress of his pupils toward the goals of science instruction, in addition to helping them attain the specific objectives of this lesson.

Principal Goals of Lesson 2

The principal goals of Lesson 2 are scientific attitudes and rational thinking processes.

Goal 1: Scientific attitudes. Each pupil should prefer to investigate a problem through analysis and verification rather than accept a conclusion without analysis or verification.

Goal 2: Rational thinking processes. Each pupil should be able to (a) analyze variables; (b) formulate a hypothesis; (c) design an investigation to test a hypothesis; and (d) draw a logical conclusion based on the outcome of his investigation.

Secondary or Incidental Goals of Lesson 2

The secondary or incidental goals of Lesson 2 are manipulative and communication skills and knowledge.

Goal 3: Manipulative and communication skills. Each pupil should be able to (a) manipulate apparatus in a safe manner; and (b) communicate with others orally in a manner that is consistent with his knowledge of scientific conventions and that facilitates the learning of his listeners.

Goal 4: Knowledge. Each pupil should be able to (a) demonstrate a knowledge of specific facts; and (b) define a hypothesis operationally.

Specific Lesson Objectives
(Learning-Step Objectives)

In Lesson 2 each pupil should learn to do the following:

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[2]This lesson extends Hy Ruchlis' "Investigation 5: Motion of Molecules," in ***Teacher's Manual for Classroom Laboratory 6*** (Concepts in Science 6). New York: Harcourt, Brace & World, Inc., 1967, 1966, p. 42-3. Although initial materials and procedures are similar, the designs and objectives of the two lessons differ significantly.

1. Investigate problems through analysis and verification and show his desire to do this by means of verbal or facial communication.
2. Identify temperature of water and source of dye as variables in this investigation.
3. Hypothesize either (a) the difference in rate of mixing is due to the difference in water temperature; or (b) the difference in rate of mixing is due to the difference between the dyes.
4. Plan and execute an investigation of either hypothesis by holding one variable constant and manipulating the other variable.
5. Either accept hypothesis (a) or reject hyposthesis (b) as a logical conclusion of his investigation.
6. Manipulate the vials, water, and dye without spilling anything and move about the classroom without running or bumping into things.
7. Communicate clearly what he has done and why he accepts hypothesis (a) or rejects hypothesis (b).
8. Understand that dye mixes more rapidly in hot water than in cold water.
9. Use the term "hypothesis" correctly in describing his research design to his listeners.

The following lesson and running commentary describe the teacher's rationale and teacher-student interaction and illustrate how the teacher encourages student initiative at all stages of the learning process. They also describe techniques for presenting problem situations, obtaining participation, and encouraging careful analysis before drawing conclusions. Diagnosis of student behavior is in terms of the lesson's goals and specific objectives and the developmental level of cognitive processes.

Chart 6

Analysis of Lesson 2: Different Rates of Mixing (Diffusion of Liquids)

Teacher's strategy and rationale	Class in action	Diagnosis of student behavior[3]
In my role as a teacher, I assume the following: 1. Learning, in the final analysis, is a personal operation. 2. Cognitive learning consists of one of two operations: a. Assimilating (incorporating) information into one's already-formed referent system (mental structure) b. Accommodating (adjusting) one's own referent system to new information. 3. An individual does not adjust his own referent system until he is psychically involved with new information. 4. An individual becomes psychically involved when he makes a personal commitment. Therefore, I often employ the teaching strategy of contriving situations in which students first participate and then make personal commitments, thereby becoming psychically involved and ready to learn. I handled the hot water used in this lesson in order to minimize danger to the pupils.	The class of 32 pupils was divided into six investigation teams. While they were studying their spelling words, two "laboratory assistants," Nancy and Lewis, were assembling, preparing, and distributing materials. The teacher was given an electric hot plate, a pan of water, a plastic tumbler, a ladle, and two bottles of identical green food coloring (liquid). Each team was given paper towels to protect desk tops, two plastic vials (test tubes or small jars would serve just as well), and one rack for the vials. When the spelling period had ended, the pupils cleared their tables while the "lab assistants" filled one vial about two-thirds full of cold water for each team. The teacher heated his water and filled each team's other vial about two-thirds full of hot water.	The sixth grade class in a large urban area was composed of children from a nearby housing project, children from middle socioeconomic-level families living in flats in the community, and Negro children "bused in" from a severely depressed ghetto neighborhood slated for demolition and rehabilitation. Although the bused children ranged from sixth grade level to four years below the norm in verbal ability, they achieved as well or better than the rest of the class when it came to observing, recalling, planning, and executing an investigation in science.

[3]This diagnosis uses the following categories of cognitive development: level 1, concept formation; level 2, data processing; and level 3, application of concepts and processes.

Chart 6

Analysis of Lesson 2: Different Rates of Mixing (Continued)

Teacher's strategy and rationale	Class in action	Diagnosis of student behavior
In order to encourage participation and involvement, I often begin a lesson by asking the pupils to complete simple tasks at which they will probably be immediately successful.	Each team was asked to identify and label the vial containing hot water. The teams were then asked to identify and label the vial containing cold water.	Differentiating, labeling (level 1)
I arranged the situation so that it was possible that the dyes could be different, since they came from two different sources.	A bottle of liquid food coloring was given to each of the two "lab assistants." Nancy was instructed to dispense one drop of "her dye" into each vial of cold water. Lewis was instructed to dispense one drop of "his dye" into each vial of hot water. The class was asked to observe what happened in each vial and to look for differences. After a period time sufficient for observation, discussion, and comparison, each team reported its observations. All teams reported that the color mixed more rapidly and more completely in the hot water than in the cold water.	Identifying, recognizing space-time relationships, observing (level 1) Comparing (level 2) Team participation achieved
I purposely induced the pupils to jump to conclusions before all factors had been analyzed. At this point not enough of the pupils seemed particularly concerned with the teacher-contrived problem. I proceeded to encourage more of them to participate. I was seeking not only participation, but also involvement through commitment.	The class was then asked to explain why the differences occurred. "The hot one mixed first because it's hotter," responded Dennis. About one-fourth of the class nodded or showed by facial and other expressions that they agreed with Dennis' conclusion. The teacher asked for a show of hands of those who agreed with Dennis' conclusion. About half the class now raised their hands.	Defining operationally, inferring (level 2)
By now almost all pupils had made a commitment of one kind or other. Having made a commitment,	The teacher then asked, "How many disagree with Dennis' idea?" About one-fourth of the class raised	

Chart 6

Analysis of Lesson 2: Different Rates of Mixing (Continued)

Teacher's strategy and rationale	Class in action	Diagnosis of student behavior
each was now ready to confront the problem.	their hands. The teacher repeated his questions: "Who agrees?" "Who disagrees?" "Who is not sure?"	
I proceeded to state the problem.	"How do you know that heat was the cause of the difference in the results?" the teacher asked.	
Various answers were forthcoming.	"I read about it in a book," said one.	Recalling, identifying (level I) Pupil uses book to support his opinion.
	"I know, but I don't know how I know what I know," said another.	Forming concepts (level 1) Pupil has come to proper conclusion but is unable to explain how he reached it.
Here was the untested assumption that I had wanted the class to make. The rest of the lesson was designed to teach the pupils the necessity of proving their conclusions. They were taught that they could do this by proving false any other possible solutions to the problem.	"Everything on the table is the same except the temperature of the water, so the heat has to be the only thing that's different," said a third.	Data processing (level 2)
I pressed for another suggestion.	The teacher pressed on: "Are you sure the water is the only thing on your tables that varies?"	
	Kathy seemed perplexed as she replied, "But how could it be anything else? All the rest of the stuff is the same!" Several children agreed.	Untested inference
	"Are you sure?" continued the teacher. More perplexed expressions appeared in the classroom.	No student was able to analyze the factors in this situation without assistance.

Chart 6

Analysis of Lesson 2: Different Rates of Mixing (Continued)

Teacher's strategy and rationale	Class in action	Diagnosis of student behavior
In order to pursue my goals, it was necessary for me to guide the class in identifying and analyzing the factors in this situation.	"Look at the materials on your tables," urged the teacher. "Let's list all the things that are on your tables."	
	The children did this: towel, two vials, vial holder, hot water, cold water, and the dye.	Observing, sorting (level 1)
I wanted the children to realize that the dye, although the same color, might be different in the two vials and thus be a variable, since the dye came from two different bottles. I therefore asked leading questions.	"Is the dye the same in both vials?" queried the teacher.	
	"Sure," retorted Harry and some of the others.	Variables not yet identified
	"Where did the dye in the cold water come from?" the teacher asked.	
	"From Nancy," the class agreed.	
	"Where did the dye in the hot water come from?"	
	"From Lewis' bottle," they all agreed.	
	"Are the dyes the same?" the teacher asked again.	
	"Yes," they answered.	No one had yet become aware of the difference in source of the dyes. Some signs of confusion appeared but one student persisted.
	"How do you know?" the teacher pursued.	
	"Because they are the same color," came the reply.	
	"Does that make them the same?" the teacher asked again.	
	"Sure, they are the same," argued Raymond. "They have the same color."	Pupil does not differentiate (level 2).
I tried to have Raymond differentiate.	"Do two things having the same color have to be the same thing?" the teacher asked.	
Another student began to offer a suggestion.	"No!" replied Kathy. "In art we can make the same green by using water color, or tempera, or oils."	Generalizing (level 2)

Chart 6

Analysis of Lesson 2: Different Rates of Mixing (Continued)

Teacher's strategy and rationale	Class in action	Diagnosis of student behavior
	"Well, they look the same!"	
	"But maybe they are different?" (These were typical responses now.)	Identifying a problem (level 2)
	Melody asked to examine both bottles. "They're both the same to me!" she exclaimed.	Interpreting (level 2) By this time each pupil is aware of the problem as one he or she wants to solve.
To lead the pupils to look for possible clues for differentiation of the dyes, I began to look at the underside of each bottle. I had served as the agent to confront them with the problem.	"It's a trick! It's a trick!" Danny announced. "They aren't the same kind of dye." The teacher neither agreed nor disagreed, but asked, "How do you know?"	Data processing (level 2) Conclusion needs to be proved either true or false.
I wanted to lead the pupils to propose a hypothesis.	Dennis went to the board, drew a diagram, and argued that the rate of mixing had to be due to either the difference in temperature of the water or to a difference between the dyes.	Analyzing, interpreting, hypothesizing (levels 2 and 3)
I used the term "hypothesis" without explaining its meaning to the class. The children seemed to understand its meaning through the context.	At this point the teacher helped the class write two hypotheses on the board: Hypothesis (a): The difference in rate of mixing is due to the difference in water temperature. Hypothesis (b): The difference in rate of mixing is due to the difference between the dyes.	
I believe science experiences in the elementary school should be consistent with the nature of science itself. Team investigations are an economical and efficient method whereby students develop valid scientific attitudes, modes of	After identifying the four factors that might need further investigation (hot water, cold water, "Nancy's dye," and "Lewis' dye"), the teams were asked to do the following:	

Chart 6

Analysis of Lesson 2: Different Rates of Mixing (Continued

Teacher's strategy and rationale	Class in action	Diagnosis of student behavior
inquiry, skills, and information. The most difficult problem in team investigations is getting sufficient materials on hand.	1. Accept either hypothesis (a) or (b). 2. Design an experiment to test the hypothesis selected. 3. Check the research design with the teacher for safety factors. 4. Carry out the investigation to test the hypothesis. 5. Report the results to the class when asked to do	
The next step was to have the pupils design an experiment to test the hypothesis. The assignment contained ample provision for individual differences. The criterion for success was individual participation rather than achievement of any predetermined level of sophistication.	After much huddling and conferring, the six teams developed their own designs for the experiment as follows: Teams 1 and 3 decided to dispense one drop of dye into the vial of hot water and another drop from the same bottle into the vial of cold water.	Experimenting, controlling variables, holding dye constant, using hypothesis operationally (level 3)
In the meantime, I circulated among the six teams and noted the wide range of ideas and the skill of the teams in working together and of individuals in handling materials.	Team 2 decided to repeat the experiment and then reverse the dyes, i.e., the dye added to the hot water in the first trial was added to the cold water in the second trial and vice versa.	Predicting, experimenting, using dye as control, controlling variables (level 3)
I had not anticipated that any team would decide to ask for a substitute for the dye, but naturally I encouraged Team 4 to pursue its investigation.	Team 4 decided to repeat the experiment, but to substitute ink from Ann's pen for the dye. Carla argued, "If the hot water makes the dye mix faster, it should also make the ink mix faster."	Not only predicting and experimenting, but also applying generalization to new situations (level 3)
	Team 5 decided to use cold water in both vials and place "Nancy's dye" in one vial and "Lewis' dye" in the other. After recording the result, the pupils repeated the experiment using hot water.	Repeating procedure while manipulating variables (level 3)

Chart 6

Analysis of Lesson 2: Different Rates of Mixing (Continued)

Teacher's strategy and rationale	Class in action	Diagnosis of student behavior
	Team 6 argued over procedure and underlying logic. Dennis wanted to hold the temperature constant and vary the dyes in order to prove his hypothesis that the difference in rate of mixing was due to the difference in temperature of the water.	Dennis seems to have an operational understanding of an essential characteristic of scientific investigation, namely, falsification (level 3). He is unable to communicate this understanding to Michael. Michael's level of development is less sophisticated than Dennis'. Michael needed encouragement.
	Michael, on the other hand, argued that if they were testing for difference due to heat, they would have to use water of different temperatures. Michael finally gave in, and Dennis went ahead to prove his hypothesis true by trying to see if his investigation could prove it false. When Dennis could not prove his hypothesis	
I had to encourage Michael to follow his own research design.	false (therefore proving it true), Michael tried out his design.	Experimenting (level 3)
I encouraged the teams to report and share their conclusions.	During the discussion period after the experiment, all teams reported that they had accepted hypothesis (a): the difference in rate of mixing is due to the difference in water temperature. Hypothesis (b) was rejected.	Although a formal definition of "hypothesis" was not provided, each team is able to apply a hypothesis in planning and executing a scientific investigation. (level 3).
	Dennis contributed: "We really cannot tell if the dyes are the same or not from our experiments. We can only tell that they do not act differently when the water in both vials is about the same temperature."	Evaluating (level 3) Dennis' state of cognitive development is atypical.

Evaluation and Prescription

By the end of the lesson, each child observed was able to state, according to his particular level of development, that it is better to analyze and investigate factors in a given situation before accepting a conclusion. Each child showed that he enjoyed being able to analyze and investigate the variables that might have been the "cause" of the phenomenon under investigation.

To varying degrees, each child had a working understanding (operational definition) of the role of a hypothesis in a scientific investigation. No child was able, however, to formulate a hypothesis independently. Each child observed was able to contribute to the planning and execution of his own "experiment" through processes of observing, communicating, inferring, predicting, defining operationally, controlling variables, and interpreting data. No child was able to identify all the possible variables in the problem without the teacher's assistance.

Each child learned that dye mixes more rapidly in hot water than in cold water, i.e., that the difference in rate of mixing was due to the temperature factor. Furthermore, each child had undergone a first-hand experience, which should help him later to understand such abstract concepts as molecular motion and kinetic theory. The experience should also provide background for his later awareness that in the natural world (1) events in nature occur in a predictable way, understandable in terms of a cause-and-effect relationship; (2) natural laws are universal and demonstrable throughout time and space; (3) energy exists in a variety of convertible forms; (4) the bases of all interactions are electrical, magnetic, gravitational, and nuclear forces whose fields extend beyond the vicinity of their origin; and (5) interaction and reorganization of units of matter are always associated with changes in energy.

A follow-up lesson should be designed to enable each child to act independently in analyzing critical factors in a new situation and in formulating hypotheses.

Lesson 3: Hypothesis Testing Lab Analysis
Grade level: Seventh, eighth, ninth
Source: Edward Shevick, Science Instructor
Portola Junior High School, Tarzana

This lesson follows other investigations in which student teams have developed basic manipulative skills and have practiced cooperative problem solving. The students may or may not have had background experiences in the concepts of gravity, inertia, and pressure involved. The primary thrust is to encourage the process skills of predicting and hypothesizing by the use of potentially discrepant events. The initial predictions and hypothesizing are done at an intellectual level based upon the drawings and observation of the equipment placed around the room. Students are required to draw upon their experiences and background to make their decisions. They are not allowed to handle the materials until their work on parts a and b for all five problems has been examined by the teacher.

As the teacher signs for each team, no attempt is made to correct "wrong" answers but illogical reasoning is pointed out. Each problem in respect to which the students rate themselves "nongenius" requires a new hypothesis based upon their observations. Team members often cannot agree. When this happens, "minority" reports are submitted giving opposing predictions and hypotheses. During the following day's discussion periods, enough students have thought through or researched the problems so that correct physical concepts emerge without excessive teacher guidance.

Students are evaluated on the basis of the logic of their hypotheses and on their ability to develop new hypotheses based upon observations of what actually occurs. The lesson could be followed up if desired by the students by planning variations in the equipment to test other alternatives. The weight-balancing and baloon problems lend themselves well to testable student variations.

SAMPLE OF STUDENT WORK SHEET

Hypothesis Testing Lab — How Right Can You Be?

Captain ____________
1. ____________
2. ____________
3. ____________

A. The Scientific Method

A scientist considers the forming of hypotheses as one step in the scientific method. His hypotheses are educated guesses that lead him into experimental situations in which his hypotheses can be tested. Testing can support, disprove, or lead to changes in the hypotheses.

In this investigation you are going to join the great scientists of the world in hypothesizing and testing. Your team will be given five scientific problems which you will have to tackle mentally before you are allowed to put them to an actual test. These problems have been chosen because their solutions are not obvious and because it will require all your brainpower to solve them. Doing your best is more important in this lab than being 100 percent correct in your predictions.

B. Materials Needed

All materials needed will be provided by your teacher. There should be at least two sets of each of the following basic materials:

Problem 1. **Weight balancing:** one pencil, one number six or larger one-hole rubber stopper

Problem 2. **Pie pan orbit:** one metal pie pan, one-third of which has been cut away; one ball bearing

Problem 3. **Downhill coffee:** two 1-pound coffee cans, two 100-gram weights, masking tape, one 200-gram weight

Problem 4. **Buoyancy special:** one platform balance; beaker or jar (about 250 milliliters); block of wood, minimum 1" x 2" (must fit into the beaker or jar); one set of weights

Problem 5. **Balloon competition:** two balloons, one 8-centimeter section of 6-millimeter glass tubing, two small one-hole rubber stoppers

C. Procedure

1. Your team will be expected to hypothesize on and test all five problems. Put down the opinion of the majority of your members.
2. All hypotheses must be initialed by your teacher before you will be allowed to do any testing.
3. Use the materials that have been placed around the room to test your hypotheses. You may do the problems in any order but your team is to do only one at a time.
4. Teams will have to share the equipment but try not to show other teams your results.
5. Check "genius" for every problem whose outcome you predicted correctly.
6. If your prediction was wrong, check "nongenius" and develop a new hypothesis in the space provided to explain what really happened.

D. Scientific Problems

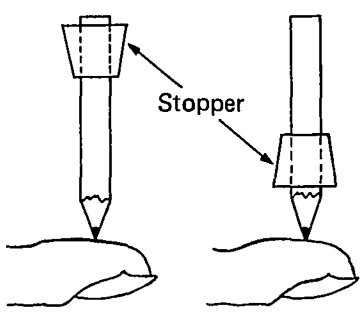
Write your team's hypothesis in the space provided and ask the teacher to initial it before testing.

Problem 1. **Weight balancing:** Which will balance better – a pencil with a one-hole rubber stopper placed on top of it or a pencil with a one-hole rubber stopper placed on the bottom of it? Talk it over with your team and tell what you decided and why. Balance both pencil and stopper on your finger.

a. Your prediction

b. Your hypothesis to back your prediction

c. New hypothesis for the nongenius



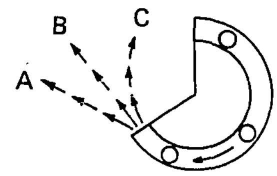
Teacher's initials ______
Genius ______
Nongenius ______

Problem 2. **Pie pan orbit:** What path will a fast-moving ball bearing take after it leaves the cut metal pan shown?

a. Your prediction (path A, B, C, or none of these)

b. Your hypothesis

c. New hypothesis for the nongenius

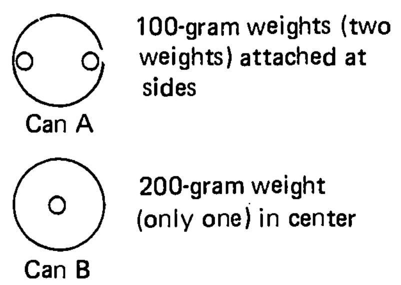


Pie pan with one-third cut away

Teacher's initials ______
Genius ______
Nongenius ______

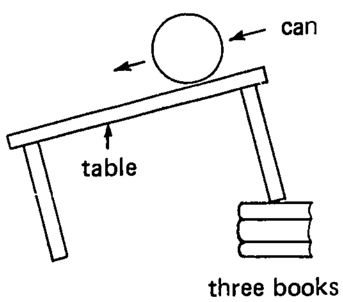
Problem 3. **Downhill coffee:** Which of the weighted coffee cans shown will roll down a tilted table more rapidly?

a. Your prediction



b. Your hypothesis

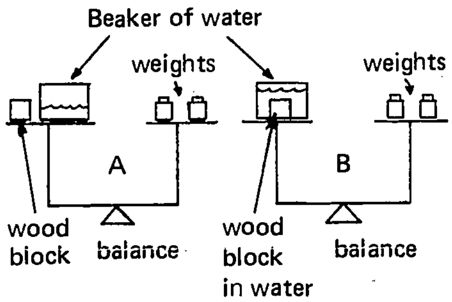
c. New hypothesis for the nongenius



Teacher's initials ____
☺ Genius ____
☹ Nongenius ____

Problem 4. **Buoyancy special:** Will the platform balance arrangement as shown in A still balance after the block of wood is placed in the beaker of water as shown in B? Weigh first, as shown in A.

a. Your prediction



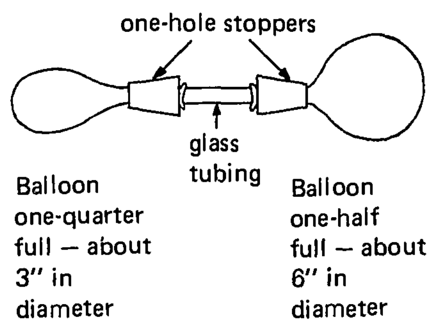
b. Your hypothesis

c. New hypothesis for the nongenius

Teacher's initials ____
☺ Genius ____
☹ Nongenius ____

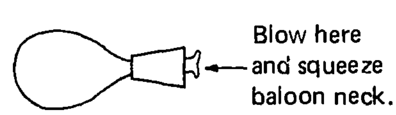
Problem 5. Balloon competition: What will happen when a balloon one-half filled with air is connected by glass tubing to a balloon one-quarter filled with air?
Caution: Be careful putting the glass in the stoppers. It will be easier to blow up the balloons while they are attached to the stoppers.

a. Your prediction



b. Your hypothesis

c. New hypothesis for the nongenius



Teacher's initials ______
Genius ______
Nongenius ______

There will be a discussion period tomorrow to settle your arguments.

STUDENT RESPONSE

The following are samples of student responses to problem 5 involving the balloons. The students were average ninth graders.

Team A

Prediction: The balloons will balance out.

Original hypothesis: The air will distribute itself equally between the balloons.

New hypothesis: The smaller balloon had more outer pressure causing air from the smaller balloon to enter the larger balloon.

Team B

Prediction: The one-quarter-full balloon will be filled with air.

Original hypothesis: The one-half-full balloon has more pressure and therefore pushes air into the smaller one.

New hypothesis: The one-quarter-full balloon will fill up the one-half-full balloon because the air is more compact in the former and has no place else to go.

Team C

Prediction: The big balloon will become bigger and the little one will lose air.

Original hypothesis: The big balloon has more air pressure inside pushing outward because there is more air in it.

New hypothesis: We were right about our prediction but our hypothesis was not so good. The little balloon has more pressure than the big one. The pressure is there because the smaller the rubber balloon, the greater the pressure.

Team D

Prediction: The balloons will stay as they are.

Original hypothesis: The balloons will stay the same because the two air pressures press against each other forming a barrier.

New hypothesis: The air pressure is less on the smaller balloon, so the air inside goes into the bigger balloon.

Team E

Prediction: The balloons will be equally full.

Original hypothesis: The air would try to escape from the big balloon and be forced through the glass into the small balloon.

New hypothesis: When the balloon is small there is a lot more tension, so the small balloon's air would go into the big balloon.

Lesson 4: Inquiry in Three Easy Days
Grade level: Tenth
Source: Harry K. Wong, Biology Teacher
Menlo-Atherton High School, Atherton

The principal goals of this lesson are related to goal 2 of science education, rational thinking processes, and deal specifically with scientific modes of inquiry. Through this lesson, the student should learn to do the following:

1. Sense the existence of a problem.
2. Generate data to support or refine theories.

3. Draw inferences from data gathered.
4. Predict events based upon his theory.
5. Generalize the usefulness of a theory into a broader concept.

When the student attains the operational objectives of this lesson, he should be able to do the following:

1. Given two flasks containing the same material (fermenting sugar), observe differences in appearance (one foamy, one not, and so forth).
2. Offer possible explanations for the differences in appearance.
3. Suggest a method for determining the effect of temperature on yeast growth.
4. Record the results of his experiment in chart form and make a graph of the results
5. Recognize the importance of a control.
6. Interpret the results of his experiment and draw conclusions.

Inquiry Processes

Inquiry is a search for knowledge or truth. No student should be left with the impression that knowledge is true, permanent, and complete. Knowledge is modified constantly. Science affords an excellent opportunity for students to put into practice the processes commonly used to pursue and evaluate knowledge. For this reason, the experiences in a science class should make maximum use of the inquiry processes.

The inquiry model used for this lesson can be illustrated as follows:

Level 5	**Creating, discovering, reorganizing, hypothesizing, questioning, problem stating + level 4**
Level 4	**Explaining, justifying, predicting, estimating, interpreting, inferring, critically judging + level 3**
Level 3	**Comparing, relating, discriminating, reformulating, illustrating + level 2**
Level 2	**Recognizing, identifying, recalling, classifying + level 1**
Level 1	**Imitating, duplicating, repeating**

Strategy

The actual experiment is secondary to the development of the inquiry process. The experiment will be the vehicle through which the inquiry process is developed. The teacher should remember at all times to refrain from talking too much. His role is that of a facilitator, drawing inferences from as many of his students as possible. The teacher is like the director of a show and the class contains his actors and actresses. They do most of the speaking and command stage center. The teacher's job is to stay off the stage and keep the show running toward his desired goals.

Preparation

One day before class (and this should be a Monday or Tuesday to allow for three consecutive days for the lesson itself), mix one package of dry yeast and 150 grams of table sugar (brown sugar is best) into one liter of water. Stir and divide evenly into two one-liter Erlenmeyer flasks. Store one flask in a warm dark place, such as an incubator set at 25 to 37° C., and the other in the refrigerator. On the next day, place both flasks on the front table.

Lesson Analysis

The following dialogue has been reduced to its barest essentials. It is not intended to be a straight teacher-student dialogue; the members of the class should become involved with each other and with the actual experiment.

Chart 7

Lesson 4: Teacher Strategy and Student Responses

Teacher strategy	Typical student reactions	Student behavior
To the teacher: Your entire strategy will be to get the students to notice and wonder why the two flasks are different. This will be followed by suggested hypotheses and the testing of selected hypotheses. Note that your remarks are usually in the form of a question.		
I have two flasks here. What do you notice?	They look different. They do not look alike.	Recognizing (level 2)

Chart 7

Lesson 4: Teacher Strategy and Student Responses (Continued)

Teacher strategy	Typical student reactions	Student behavior
How are they different? Remember, you have learned that scientists try to be good observers.	The contents of one flask are foamier (darker, denser, and so forth). One flask has a watery film on the outside. Material has settled at the bottom of one flask.	Recognizing (level 2) Discriminating (level 3)
Excellent; you have observed well. But what does your list not tell you? Many people see things, but do not wonder about what they see. Are you curious about the flasks? How?	Why are the flasks different? I would like to know what causes the differences.	Questioning, problem stating (level 5)
Good, you have recognized the problem. You want to know what causes the differences. However, before you answer, maybe I can help you. We should attack the problem one step at a time.		
Look at the two flasks again. What is the first thing you should know? (The answer given to the right is the desired answer; however, all other answers are acceptable and should be treated with just as much respect. Perhaps you can put all the answers on the blackboard and then have the class decide which one seems most logical.)	What is inside the flasks?	Questioning (level 5)
How can we decide what is inside the flasks?	We can taste it. Let us smell it. I want to feel it. Let us look at it (microscope).	Identifying (level 2)
(Now let the students examine the material in the flasks.)	It smells like bread. It is slimy. I can hear it sizzle. It tastes bitter. It looks like cells (under microscope).	Discriminating (level 3)
From your observations, what do you predict is in the flasks?	It is yeast.	Inferring (level 4)

Chart 7

Lesson 4: Teacher Strategy and Student Responses (Continued)

Teacher strategy	Typical student reactions	Student behavior
We have used yeast frequently in this course. Many of you have baked bread at home. What else do you think is in the flask?	Water. Food. Sugar.	Recalling (level 2)
With this background, what can you predict may be the cause of the differences between the two flasks?	Maybe you put more yeast in one. There is a difference in age. The material (or food) the yeast is in is different. The flasks were kept at different temperatures. One flask was stoppered to keep out the air. One flask was shaken periodically. There is a difference in pH.	Predicting, inferring (level 4)
What we have listed on the blackboard is a series of guesses as to the possible solution to our problem. The scientist calls these educated guesses hypotheses. If you were a scientist and you had this list of guesses, what would you do next?	Try them out.	Comparing (level 3)
In other words, you would do an ________.	Experiment.	Recalling (level 2)
Each of the predictions on the blackboard is a potential experiment. Would you try them all out at once?	No, because then we would not know which factor caused the difference. We would have too many things going at once. We need to do one experiment at a time.	Explaining, justifying (level 4)
Does anyone know what the fancy scientific name is for doing an experiment with only one factor or difference at a time?	It is called a controlled experiment.	Recalling (level 2)
In order to do a controlled experiment then, we will have to pick one of the hypotheses from the board. Which one do you think is the best guess?	They were kept at different temperatures.	Predicting (level 4)

Chart 7

Lesson 4: Teacher Strategy and Student Responses (Continued)

<table>
<tr><th>Teacher strategy</th><th>Typical student reactions</th><th>Student behavior</th></tr>
<tr><td>(You might want to mention that the most successful scientist is the one who can make the best guess most often.)</td><td></td><td></td></tr>
<tr><td>How are we going to test the effect of temperature on yeast? What will we need? What can we measure to show us that the yeast is affected?</td><td>We can measure the amount of gas given off by the yeast.</td><td>Creating (level 5)</td></tr>
<tr><td>Good! If you know about baking or brewing, then you know that yeast gives off a gas. The gas is carbon dioxide. How are we going to measure the rate of gas produced?</td><td>We can put the yeast in a container and trap the gas that is produced or we can get the gas to push a bubble in a glass tube.</td><td>Creating (level 5)</td></tr>
<tr><td>The suggestions so far have been good, but a critical part is missing. What do we need to make the experiment valid?</td><td>We need a control, another container with everything but the yeast.</td><td>Creating (level 5)
Discriminating (level 3)</td></tr>
<tr><td>How would you design an experiment to measure the rate at which carbon dioxide is produced? (The ideas will vary and different experimental set-ups should be allowed. Afterwards, the limitations of each experiment could be considered.)</td><td>We can pipe the gas into a tube with a drop of ink in it. We can measure the rate of movement of this drop. (Other designs are also possible.)</td><td>Creating (level 5)</td></tr>
<tr><td>If you will all see me, I will help you with the equipment you need. But, before you start, you should plan on a method of recording your results. What do you need?</td><td>We need a table to organize the data.</td><td>Comparing (level 3)</td></tr>
<tr><td>It may be necessary to go into detail with the table. Discuss the length of each reading, the number of readings, and the temperature controls. How would you design your table?</td><td>The Amount of Gas Produced by Yeast at Three Temperatures
<table>
<tr><th rowspan="2">Duration of trials (minutes)</th><th colspan="3">Temperature</th></tr>
<tr><th>12° C.</th><th>22° C.</th><th>32° C.</th></tr>
<tr><td>1</td><td></td><td></td><td></td></tr>
<tr><td>2</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td></td><td></td></tr>
<tr><td>Average</td><td></td><td></td><td></td></tr>
</table></td><td>Comparing (level 3)</td></tr>
</table>

Chart 7

Lesson 4: Teacher Strategy and Student Responses (Continued)

Teacher strategy	Typical student reactions	Student behavior
The experiment is over and the data have been collected. What do the data mean? The data can be analyzed more easily if we draw a picture of the data. What do we mean by drawing a picture of the data?	We mean graphing the results.	Recalling (level 2)
(Explain graphing.) The results of the experiment can be seen more clearly now. What does the graph show us?	As the temperature increases, the rate of gas production increases.	Interpreting (level 4) Discovering (level 5)
(If your students understand their discovery, they should be able to answer the following questions. You are applying their knowledge and evaluating their ability to inquire.) 1. Why do you use yeast when baking bread? 2. Where would you put the bread to allow the dough to rise? 3. What was the purpose of the control?	(Answers will vary.)	Reorganizing, hypothesizing (level 5)
You should not conclude that temperature is the only factor for causing the difference in the contents of the two flasks. (Encourage the students to test the other factors.)	I want to try . . . . What would happen if . . . . I want to know	Creating, reorganizing, questioning, problem stating (level 5)

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