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AUTHOR	Klopfer, Leopold E.
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ABSTRACT

A classification scheme for the affective domain in relation to science education is presented in this article to clarify student's affective behaviors and their representative phenomena. Discussion is made in connection with the content-objectives grid in the cognitive domain. An analogous grid for the affective domain is delineated by a two-dimensional presentation. Krathwohl's taxonomy of educational objectives is incorporated along the behavioral objective dimension, and the second dimension is composed of a set of phenomena. The phenomena are grouped into four divisions: events in the natural world, activities, science, and inquiry. Each division is further grouped into subdivisions with some divided into still smaller categories. Sample statements along with the applicable cells of the phenomena-behaviors grid are given as examples. Applications of the present structure to science teaching and educational research are provided. Included are five tables relating to organization of the scientific enterprise, interactions of science with society, scientists as people, processes of scientific inquiry, and nature of scientific inquiry. (CC)

A Structure for the Affective Domain in Relation to Science Education

Leopold E. Klopfer

Learning Research and Development Center

University of Pittsburgh

Pittsburgh, PA 15260

It is easy to assert that the affective domain is important in science education. It's not so easy to say what that assertion means. A good part of the difficulty stems from the fact that it is usually not clear what behaviors we should look for in the student when we are concerned about his feelings, appreciations, attitudes, and values. Compounding the difficulty is the general uncertainty about the definition or specification of the phenomena related to science education that we expect the student to exhibit feelings and attitudes about. This paper seeks to contribute to the discussion and clarification of both the student's affective behaviors and the phenomena which are the focus of these affective behaviors in science education.

In dealing with the cognitive domain, there is relatively little difficulty in specifying desired student behaviors and the phenomena on which they impinge. The phenomena here are simply the subject-matter content of science instruction. It is not too hard to divide science content into various categories and subcategories, and then to arrange these in some form of content structure or classification scheme. This has been done countless times in planning science curricula, courses, textbooks, and tests. Through many years' experience, teachers and researchers have also become adept at specifying the behaviors desired of the student in acquiring and using science content. These desired

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student behaviors are the objectives of instruction. Like content, objectives that represent related or similar behaviors may be grouped into convenient categories, and these may be arranged in some form of structure or classification scheme. Using the strategy just outlined, science educators have been able to encompass the cognitive domain within two dimensions, content and objectives. As usually presented, the several categories of the content dimension and the several categories of the objectives dimension appear along two sides of a content-objectives grid or table of specifications. An X or other mark entered in a cell of the content-objectives grid indicates that a specific type of objective with respect to a specific item of content is part of the design of the science curriculum, course, or test for which the table of specifications has been prepared.

Not long ago, I prepared such a content-objectives grid which was a generalized table of specifications for science education that might serve as a framework for any science program, curriculum, course, unit, or test (see Ref. 1). In this table of specification for science education, the various categories of a classification scheme for science content were listed as the vertical dimension along the left side of the grid. The categories of objectives, expressed as student behaviors, were listed as the horizontal dimension along the top of the grid. The categorization scheme for this dimension was quite unique in that it not only included behaviors pertaining to the student's knowledge, comprehension, and application of science content, but it also included student behaviors with respect to the processes of scientific inquiry, with respect to an orientation about science's relationships with other aspects of culture, and with respect to attitudes and interests. The incorporation of attitudes and interests in the student behaviors dimension of the grid represented an attempt to relate the affective domain to science education. It must be

candidly admitted, however, that this was a weak attempt, since the affective domain was given explicit attention in only one of the nine categories of student behaviors. If our perspective of the affective domain in science education is to be concordant with its importance, we cannot afford to submerge the richness and complexity of students' feelings and attitudes among various other student behavior categories. Instead, just as the cognitive domain of science learning is delineated by a synoptic structure, what is needed is a complementary structure for the affective domain in relation to science education.

Fortunately, the same strategy that has served to encompass the cognitive domain within two dimension can also be employed to delineate an analogous grid for the affective domain in science education. Moreover, the categories of the student behaviors dimension for this grid are already at hand in the classification of educational objectives in the affective domain presented by Krathwohl, Bloom, and Masia in the Taxonomy of Educational Objectives, Handbook II: Affective Domain (Ref. 2). Objectives included in this domain "...emphasize a feeling tone, an emotion, or a degree of acceptance or rejection. Affective objectives vary from simple attention to selected phenomena to complex but internally consistent qualities of character and conscience." (Ref. 2, p. 7) The structure of the affective domain taxonomy is based on the process of internalization, the process through which a phenomenon or value successively and pervasively becomes a part of the individual. Internalization of a phenomenon or value proceeds in stages or levels, which form a continuum. This continuum begins at

> "...a level at which the individual is merely aware of a phenomenon, being able to perceive it. At a next level he is willing to attend to phenomena. At a next level he responds to the phenomena with a positive feeling. Eventually he may feel strongly enough to go out of his way to respond. At some point in the process he

conceptualizes his behavior and feelings and organizes these conceptualizations into a structure. This structure grows in complexity as it becomes his life outlook." (Ref. 2, p. 27)

Five major levels of internalization are identified in the structure of the affective domain taxonomy, and each of these levels has two or three subcategories. The five major levels are:

A. Receiving or attending

B. Responding

C. Valuing

D. Organization

E. Characterization by a value or value complex

These levels and their subcategories provide an appropriate and useful delineation of the student behaviors dimension of a two-dimensional table of specifications, or grid, for the affective domain in science education. The appropriateness and usefulness of this delineation of affective behaviors are illustrated in the following consideration of the second dimension of the grid, the phenomena upon which the student's affective behaviors impinge.

Although the affective domain taxonomy has been available to science teachers and researchers for quite some time, it has not had much impact on either practice or research in science education. A primary reason for this neglect is the lack of clarity and prevalence of confusion regarding the phenomena of concern in science education that the student might have feelings or attitudes about. It would be convenient if the phenomena of concern under the affective domain were merely the same phenomena upon which student behaviors in the cognitive domain impinge, but this is not the case. Science content, which alone is considered in defining the second dimension of the cognitive

domain grid, represents only a part of the phenomena of concern under the affective domain. In order to build a proper synoptic structure for the affective domain in science education, the phenomena comprising the second dimension of the grid have to be satisfactorily defined.

In the vertical dimension of the accompanying Chart 1 is a listing of the full range of phenomena toward which some affective behavior by the student is sought or hoped for in science education. The phenomena are grouped into four divisions:

1. Events in the natural world
2. Activities
3. Science
4. Inquiry

The divisions have been sequenced in an order that suggests increasing formal, structured attention by the student to the phenomena in the successive divisions. In the first division, Events in the natural world [1.0], no formal study of the events is at all necessary. It is simply a question of awareness and emotive response to experiencing such events as frost on a cold morning, an eclipse of the moon, the birth of kittens, a spider capturing prey. Rather arbitrarily, two categories--Biological events [1.1] and Physical events [1.2]--have been designated for division 1.0.

In division 2.0, the focus is on Activities in which the student participates that bear some relationship to the learning of science. The first category, Informal [2.1], includes both voluntary, out-of-school science activities [2.11], such as doing chemical experiments, collecting insects, visiting a science museum; and science-related activities [2.12], such as building a radio, flying model airplanes, protesting air pollution. Category 2.2, Formalized

science learning activities in school, encompasses organized science courses and science classes, as well as the various activities that go on in school science courses and classes, such as reading science textbooks, doing laboratory work, watching films, taking tests.

To illustrate the phenomena included in the first two divisions and to indicate how various affective behaviors impinge on these phenomena, several sample statements of objectives in the affective domain are given below. For each objective, the applicable cell of the phenomena-behaviors grid is indicated, with the code for the affective behavior category listed first and the code for the phenomena category second. In these illustrations, the affective behaviors span several of the categories shown in Chart 1, from Willingness to receive [A.1] to Preference for a value [C.2], and the phenomena are selected examples falling under the two divisions just discussed.

BEHAVIOR CATEGORY, PHENOMENA CATEGORY	
A.1, 1.1	The student is sensitive to the singing of birds.
A.2, 1.1	The student is inclined to stop what he is doing to listen to the singing of birds.
A.3, 1.1	The student carefully attends to the singing of birds and notes some differences in their songs.
B.3, 1.1	The student develops a keen interest in his natural surroundings--in trees, flowers, birds, insects, life processes, and the like.
B.2, 2.1	The student voluntarily reports to his teacher or other students concerning science or science-related information he has read or heard about and science or science-related activities he has seen or done.
B.1, 2.11	The student visits a science museum when told to do so.
B.2, 2.11	The student exhibits a scientific interest through making collections, conducting experiments, going on excursions, or selecting science books to read.

A.1, 2.2 The student is aware of the science classes in the school and that he will be expected to take science.

B.3, 2.2 The student enjoys his work in the science laboratory.

B.3, 2.2 The student exhibits personal satisfaction when he completes his science lessons.

B.3, 2.2 The student takes pride in doing careful work in his science lessons and laboratory activities.

C.2, 2.2 The student consistently prefers to take a science course over taking courses in other areas whenever he has a free choice.

Division 3.0, Science, of the phenomena dimension is much larger than either of the preceding divisions, and it encompasses four very large and important categories. Category 3.1, Science as a source of knowledge about the natural world, has to do with the subject-matter of science, with science content. When the student's view of science content is not differentiated, i.e., when he just sees science content in one lump, the phenomenon is designated by subcategory 3.11, science in general. But, the student may focus on only a part of the content of science, perhaps a very small part. This phenomenon is designated by subcategory 3.12, any content area in science. (Should one with to do so, the particular content area focused on could be additionally identified by entering the code number assigned to that content area in the "Table of Specifications for Science Education" given in Ref. 1, pp. 562-563.)

The phenomena included under category 3.2, Science as an enterprise organized to gain understanding of the natural world, are concerned with the institutional aspects of science, its "ethos," and its internal communication system. Since the meaning of these elements may not be altogether clear, an outline of the phenomena included in this category is given in Table 1, Organization of the Scientific Enterprise. A much broader category is 3.3, Science in its interrelationships with society, which includes the whole gamut of interdependencies

of science, technology, and society; the multifaceted influences which scientific ideas have on the general culture, on literature, on philosophy; and the influences of society on science. These are outlined in Table 2, Interactions of Science with Society. It is within category 3.3 that many of the contemporary dilemmas about the values of society in a scientific-technological age are located. The last category of this division, Scientists as people [3.4], is concerned with the personal characteristics of scientists as individuals and as a group, with the abilities possessed by men and women who are scientists, and with science as a professional career (see Table 3).

Insert Tables 1, 2, and 3 about here

Illustrative statements of affective domain objectives for the several categories of phenomena division 3.0 are presented below. As before, the applicable cell in the behaviors-phenomena grid is indicated by the two codes preceding each objective.

BEHAVIOR CATEGORY, PHENOMENA CATEGORY	
A.1, 3.11	The student recognizes that the primary activity in science is study of the natural world.
A.2, 3.11	The student accepts the learning of science as beneficial to himself.
C.2, 3.11	The student consistently prefers to study science over studying in other areas whenever he has a free choice.
A.1, 3.12	The student realizes that organic chemistry is important in understanding living processes.
A.3, 3.2	The student is sensitive to the importance of the study of the natural world as the primary activity in science.
A.1, 3.3	The student is aware that there is an interdependence of science, technology, and society.

D.2, 3.3 The student begins to form judgments as to the major directions for the integration of science and public policy.

A.1, 3.4 The student displays awareness of some differences among scientists as individuals and in what they study.

A.2, 3.4 The student increases his sensitivity to differences among scientists as individuals and in what they study.

A.3, 3.4 The student is alert to differences among scientists as individuals and in what they study.

C.1, 3.4 The student feels a sense of kinship with people who are scientists.

D.1, 3.4 The student reexamines his own ethical standards and personal goals in the course of his reading of biographies of scientists.

The elaboration of division 4.0, Inquiry, of the phenomena dimension is somewhat different from that of the other three divisions. While the categories in the divisions already discussed are little more than suitable boxes into which related and similar phenomena can be placed, the three categories of division 4.0 are arranged in a progressive order. Their ordering represents the progression generally followed in science education to enable the student to utilize inquiry as his way of thought. For many science educators, this is the most significant purpose of science education, even though it goes beyond the bounds of science education itself, and perhaps because of that very reason.

Category 4.1, Processes of scientific inquiry, includes observing, measuring, hypothesizing, theory-testing, and all other procedures that are used in scientific inquiry. I have described these various processes previously (see Ref. 1, pp. 568-575), and a summary of them is given in Table 4. In contemporary science education programs, it is customary to introduce the student to these processes of scientific inquiry early in his school career, even during the elementary school years. At a later stage, the student is often encouraged to conceptualize about different ideas concerning the nature of scientific inquiry,

and the phenomena of interest here are included in category 4.2, Scientific inquiry as a way of thought. An outline of relevant ideas is given in Table 5, Nature of Scientific Inquiry. With such a large number of ideas before us, it seems fitting to remind ourselves that, since we focus on feelings and attitudes in the affective domain, the main concern here is not with the student's knowledge and understanding of the ideas. Knowledge and understanding of the ideas is necessary, of course, to develop informed attitudes, but it is the student's internalization of the ideas and values described under the Processes of Scientific Inquiry and Nature of Scientific Inquiry headings that the affective domain is primarily about.

Insert Tables 4 and 5 about here

The same consideration applies with equal force to the third category of the dimension, Inquiry as a way of thought [4.3]. Underlying this category on the cognitive side is the development of the student's ability to inquire, but the concern in the affective domain is, once again, for internalization--the extent to which engaging in inquiry becomes a part of the student's responses, commitment, values, and make-up. Category 4.3, Inquiry as a way of thought, has been labeled in other contexts with such terms as critical thinking, reflective thinking, problem solving, the method of intelligence, and others. Two common denominators in all these formulati. s are an adherence to some principles of logic and an expectation of objectivity, accuracy, open-mindedness, criticalness, and other similar safeguards. It is beyond the scope of this paper to attempt a comprehensive formulation of inquiry as a way of thought, which is not confined to science by any means. For the purpose of completing the phenomena dimension of the affective domain grid, it must suffice to make

the point that the student's affective behavior may bear on Inquiry as a way of thought without any association to particular phenomena or problems [category 4.3], or in association with phenomena and problems in science [subcatetory 4.31], or in association with phenomena and problems not in science [subcategory 4.32].

The following illustrative statements of affective domain objectives pertain to the several categories of phenomena dimension 4.0, Inquiry.

BEHAVIOR CATEGORY, PHENOMENA CATEGORY	
A.1, 4.1	The student is conscious of the fact that experimental work in science is often lengthy, tedious, and arduous.
A.3, 4.1	The student is alert to the distinction between observations and interpretations of observations.
B.1, 4.1	The student makes interpretations of observations and data obtained in experiments when he is asked to do so.
B.2, 4.1	The student complies with suggestions to make careful observations when he is working in science.
B.3, 4.1	The student enjoys the challenge of formulating a theory to explain observations.
C.1, 4.1	The student has a continuing desire to develop his ability to test scientific hypotheses by designing and carrying out experiments.
A.1, 4.2	The student realizes that one function of a scientific theory is to explain observations.
A1., 4.2	The student realizes that scientific knowledge is manmade and that the ideas which make up scientific knowledge are always subject to revision.
E.1, 4.2	The student generally relies upon scientific inquiry in finding answers to questions about the natural world and about society.
A.3, 4.3	The student looks for questions to ask as a means of initiating inquiry.
A.3, 4.3	The student is sensitive to the importance of making decisions about means of answering posed questions in order for inquiry to proceed.

C.3, 4.3 The student has faith in the power of reason and in the methods of experiment and discussion.

E.1, 4.3 The student views problems in objective, realistic, and tolerant terms.

A.3, 4.31 The student looks for ways of extrapolating from his experiences in investigating one problem in science to planning an inquiry into a similar, yet different problem.

A.3, 4.31 The student is alert to finding an alternative [illegible] for investigating a problem in science as a possible [illegible]cribution to the progress of inquiry.

B.2, 4.31 The student consistently collects accurate data in carrying out science experiments.

B.3, 4.31 The student is proud of the accuracy of the data he collects in his science experiments.

C.2, 4.32 The student deliberately examines a variety of viewpoints on controversial issues with a view to forming opinions about them.

E.1, 4.32 The student changes his opinion on controversial issues when an examination of the evidence and the arguments calls for revision of opinions previously held.

E.2, 4.32 The student develops a code of behavior based on principles derived from his own inquiries.

In a necessarily brief paper such as this, it is not possible to explore the many ramifications of the synoptic structure for the affective domain that has been presented. I can only hope that the reader will thoughtfully examine the several definitions and illustrations that form the greater bulk of this presentation, so that he may become familiar with this synoptic structure. Then our discussion can well proceed toward utilizing the structure for focusing instruction and stimulating research on the affective domain in relation to science education.

References

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Table 1

Organization of the Scientific Enterprise

OVERVIEW:

Scientific Work is carried out within the context of a cooperative, internally-regulated social institution.

A. The institutionalized goals of science are the extension of knowledge and the explanation of natural phenomena.

1. The primary concern of science is the understanding of nature; the extension of this knowledge to practical applications is an important by-product.

2. In the search for knowledge and understanding, science is a process-oriented, dynamic activity.

3. To further the goals of science, scientists collaborate in their efforts on an international scale.

   a. The origin of a contributor to science is unimportant; it is his contribution that counts.
   b. Validation of ideas is an international endeavor: there is no proper place for nationalism in science.

B. The guidelines regulating scientific activities constitute an unwritten set of values (an "ethos") for the scientific community.

1. The validity of ideas must be subjected to critical appraisal by other qualified investigators. Careful validation of ideas makes it possible for researchers to build on previous work with considerable confidence.

2. The substantive findings of science are a product of community collaboration and are part of the public trust.

3. Scientists are expected by their peers to achieve their self-interest in work-satisfaction and in prestige through direct service to the community of scientists.

4. Institutional pressures on scientists.

   a. Many of the noble characteristics attributed to scientists are more a reflection of the nature of the scientific enterprise than of the personalities of scientists. What are generally known as "scientific attitudes" are better described as professional standards. The nature of scientific evidence is such that observations and experiments can almost always be checked or

Table 1 (continued)

duplicated by other scientists, so that frauds and sloppy operators are rapidly detected. In the laboratory, therefore, the scientist will be as accurate, honest, self-critical, and open-minded as he possibly can. If he isn't, he will soon lose the respect of his colleagues.
   (1) A scientist expects his ideas to be challenged.
   (2) Validation of ideas eliminates quacks and charlatans from scientific work.

b. Another institutional pressure on scientists is to be creative. The scientist cannot be merely a recorder of observations, for a large task in science is the development of new ways of thinking about what is observed and new techniques for observing. Thus, a definite creative effort is demanded of the scientist. This demand accounts for the appearance of certain personality tendencies among scientists, since creativity is a function of certain personality attributes, and non-creative people do not stay active as scientists.

5. Controversies in science are resolved in the open forum (either in meetings or through publications) of the professional group. A scientist's views are always subjected to the informed criticism of his colleagues, and it is expected that he should present all relevant evidence, appeal to experimental and observational data, and rely on logic, not rhetoric.

   a. Scientists communicate with one another through meetings, journals, books, personal contacts, correspondence. Informal and formal contacts among scientists are equal in importance. Ideas, opinions, and speculations are clarified and grow through informal give-and-take, letters, discussions.

   b. Publications make it possible for a scientist's work to be critically scrutinized by his colleagues and to be subject to repeated tests.

Table 2

Interactions of Science with Society

OVERVIEW:

The interactions of science with society are reciprocal: science has marked influences on the culture in which it exists; at the same time, the cultural environment of the society-at-large influences the development of science.

A. Interdependence of Science, Technology, and Society.

1. Science is dependent upon technology for tools and techniques and, frequently, for the formulation of basic questions.

a. Technology is not the same as science: technology involves the means of building and doing useful things; the aim of science is the development of knowledge and understanding.

b. The boundary lines between science (sometimes called "basic science" or "pure science") and applied science, between applied science and technology, and between science and technology are not always clear.

(1) In some fields, the separation between science and technology is relatively non-existent. At different times, the activities of an individual scientist may contribute to science, applied science, or technology.

(2) Inventors and designers of useful devices or machines are not scientists, even though the making of a device or machine frequently involves the application of scientific knowledge.

2. Technology depends upon basic science for the development of new knowledge and understanding.

a. The ability to generate new scientific knowledge and to apply it in technology is a major factor in the economic growth of all nations throughout the world today.

b. Social and political changes may need to be made in a nation for it to keep pace with scientific and technological advances.

3. Many contemporary social, economic, and political problems have rational solutions only in the context of science and technology.

B. Influences of Science and Society.

1. The evolution of scientific ideas and scientists' achievements in understanding the natural world have greatly affected, and will continue to affect, the conditions of people in a society:

a. The influence of scientific ideas on human thought are reflected in changes in orientation and in the content of literature and philosophy. Science contributes to man's common-sense view of the world.

b. Applications of scientific laws and principles accelerate, and often make possible the development of an efficient technology. Expanding technology, in turn, produces many economic readjustments and opportunities with their concomitant sociological changes.

(1) Increased population, "automated unemployment," and nuclearphobia are only a few of the societal problems created by science and technology.

(2) There are vocational and leisure implications of scientific discovery and technological development.

c. Applications of scientific ideas to problems of human health and disease help to alleviate people's suffering and often produce significant changes in demographic characteristics of society.

C. Influences of Society on Science.

1. Science is, in large measure, a product of the prevailing culture of the society in which it exists.

a. Factors which determine how well science will flourish in a particular society include:

(1) the conduciveness of the general climate of opinion to the kind of inquiry which scientists pursue;
(2) the maintainance of an adequate educational system to train scientific investigators and supporting personnel;
(3) the provision of sufficient financial backing for science personnel, materials and institutions;
(4) the state of development of supporting industries which supply instruments, equipment, and materials needed in scientific work.

b. Since the factors mentioned in paragraph a. vary from country to country and from time to time, the extent of scientific activity and achievements vary from one nation to another and throughout the history of any one nation.

2. The needs and interests of a nation often determine the kinds of problems scientists will investigate.

Table 3

Scientists As People

OVERVIEW:

Men and women possessing a variety of personal characteristics and abilities carry out the diverse tasks in the science professions.

A. Personal Characteristics of Scientists.

1. Like any group of people, scientists differ with respect to their personal characteristics. They differ, for example, in how they approach and handle personal problems, in how they relate to their wives or husbands and their families, in their interests in fields of endeavor outside science (e.g., music, politics). Hence, there is little factual basis for some of the popular stereotypes of scientists.

2. Many generalizations about scientists are tendencies of successful professional people in general (e.g., dedicated to his or her work, extremely hard-working).

3. As a group, scientists are above-average in general intelligence.

4. Scientists do not necessarily display "scientific attitudes" when they are not engaged in their work. As human beings, scientists are subject to the same human weaknesses, temptations, and emotions as are people in other lines of work.

B. Abilities of Scientists.

1. Since the activities of different scientists vary over a wide range, it is not possible to define a single set of specific abilities needed by all scientists. A. scientist will need different abilities, depending on the field he works in and on whether he is primarily a theoretician or an experimenter.

2. Some scientists, who are primarily theoreticians, rarely, or never, perform experiments: their principal activity is the synthesizing of scientific knowledge and the construction of theories.

3. Some general abilities often needed by scientists are:
   a. ability to communicate effectively;
   b. ability to think critically;
   c. ability to observe and record accurately;
   d. ability to design experiments and apparatus;
   e. manipulative skills;
   f. facility in mathematics;
   g. ability to see problems in a broad perspective.

4. Today, scientific research is so complex that long years of training are needed to prepare for most types of work. This training usually includes several years of formal study after graduation from college.

Table 4

Processes of Scientific Inquiry*

B. PROCESSES OF SCIENTIFIC INQUIRY I: OBSERVING AND MEASURING

B.01 Observation of objects and phenomena
B.02 Description of observations using appropriate language
B.03 Measurement of objects and changes
B.04 Selection of appropriate measuring instruments
B.05 Estimation of measurements and recognition of limits in accuracy of measurements

C. PROCESSES OF SCIENTIFIC INQUIRY II: SEEING A PROBLEM AND SEEKING WAYS TO SOLVE IT

C.01 Recognition of a problem
C.02 Formulation of a working hypothesis
C.03 Selection of suitable tests of a hypothesis
C.04 Design of appropriate procedures for performing experimental tests

D. PROCESSES OF SCIENTIFIC INQUIRY III: INTERPRETING DATA AND FORMULATING GENERALIZATIONS

D.01 Processing of experimental data
D.02 Presentation of data in the form of functional relationships
D.03 Interpretation of experimental data and observations
D.04 Extrapolation, when warranted, of functional relationships beyond actual observations, and interpolation between observed points
D.05 Evaluation of hypothesis under test in the light of the experimental data obtained
D.06 Formulation of appropriate generalizations (empirical laws or principles) that are warranted by the relationships found

E. PROCESSES OF SCIENTIFIC INQUIRY IV: BUILDING, TESTING, AND REVISING A THEORETICAL MODEL

E.01 Recognition of need for a theoretical model to relate different phenomena and empirical laws or principles
E.02 Formulation of a theoretical model to accomodate the known phenomena and principles
E.03 Specification of phenomena and principles that are satisfied or explained by a theoretical model
E.04 Deduction of new hypotheses from a theoretical model to direct observations and experiments for testing it
E.05 Interpretation and evaluation of the results of experiments to test a theoretical model
E.06 Formulation, when warranted by new observations or interpretations, of a revised, refined, or extended theoretical model

*Extracted from behavior categories in Ref. 1

Table 5

Nature of Scientific Inquiry

OVERVIEW:

Man builds his understanding of the natural universe through scientific inquiry, which seeks orderly relationships among phenomena and develops conceptual structures that are self-testing.

I. Vocabulary of Scientific Inquiry:

A. Hypothesis: a tentative statement, sometimes merely an informed guess, which expresses a scientist's conjectures about certain phenomena, or which predicts the outcome of an experiment.

B. Law: a generalized statement concerning relationships between phenomena which has been repeatedly verified by reliable observations.

C. Theory: a broad generalized statement, or group of statements, that seeks to correlate and explain a large number of related phenomena.

D. Experiment: an operation, or series of operations, designed to test a hypothesis or gather data under controlled conditions.

II. Scientific Knowledge

A. Scientific knowledge consists of ideas (concepts, laws, theories) about the natural world. These ideas deal primarily with what the natural world, its components, and its inhabitants are composed of and how they function and interact.

B. Scientific knowledge is tentative:

1. The ideas which make up scientific knowledge are always subject to revision.
2. At present, the ideas in many areas of science are changing rapidly.
3. When a concept or theory is found not to conform with observation or experience, the concept or theory must be modified or replaced to bring it into accord.

C. Scientific knowledge is man-made:

1. Created by human minds and efforts, scientific ideas grow and are modified as scientists expand their information and vision.
2. Scientific concepts and theories bear the imprint of the man who created them and involve his personality.
3. Individual scientists and scientists in groups cooperate to develop the ideas of science.

D. Scientific knowledge is cumulative: today's scientists build on the work of those of the past, and the achievements of the future will be based upon the accomplishments of the present.

E. Scientists do NOT claim that their theories describe an "ultimate reality".

F. The principal aim of scientific inquiry is the development of an understanding of natural phenomena in terms of verifiable laws and theories.

III. Unity and Diversity in Scientific Inquiry

A. There is unity in science due to a common purpose, similarity of methods, and the fact that all scientific disciplines study systems in which at least one component is biological-the observer, man.

1. Scientific inquiry always involves the application of human intelligence to the understanding of phenomena. "If there is a method in science, it is doing your damnest with your mind no holds barred." (Bridgman)
2. Scientific inquiry involves thought (--planning, analyzing, interpreting, evaluating--) as well as action (--setting up experiments, performing manipulations, making observations--). Carrying out experimental tests and making observations to check his predictions are the scientist's way of asking questions of nature.
3. A scientist's work never ends: the solution of one problem leads invariable to new problems.

B. There is diversity in scientific inquiry due to the fact that different scientific disciplines study different systems (--i.e., different objects and phenomena are investigated by different disciplines--) and employ different theoretical structures.

1. Scientific disciplines can be classified into two major, relatively distinct types:

a. those having a strong temporal or historical element and for which both reductionist and compositionist theories are needed--principally evolving sciences, e.g., ecology, psychology.
b. those for which the temporal or historical element is largely ignored and for which reductionist theories seem adequate--the so-called exact sciences, <u>e.g.</u>, physics, chemistry.

Table 5 (continued)

2. In any scientific discipline, there are two different forms of scientific inquiry: the "stable" form and the "fluid" form. One form of inquiry or the other, or sometimes both, may be proceeding in a discipline at any particular time.

   a. When scientific inquiry proceeds without altering the theoretical structure of the discipline, it is said to be normal, stable, or completive inquiry. The great bulk of scientific inquiry is of this form.

      (1) stable inquiry - "constructing an edifice without questioning the plan" (Schwab)
      (2) knowledge is cumulative in the simple sense of accretion.

   b. When scientific inquiry makes necessary or forces a change in the theoretical structure of the discipline, it is said to be extraordinary, fluid, or generative inquiry. This form of inquiry produces what are called "revolutions" in science. In certain disciplines, these revolutions have recently become quite frequent.

      (1) fluid inquiry - "a mode of investigation which rests on conceptual innovation, proceeds through uncertainty and failure, and eventuates in knowledge which is contingent, dubitable, and hard to come by." (Schwab)
      (2) Since scientists are seeking explanations of natural phenomena in terms of abstract ideas, it is inevitable that different interpretations of a group of phenomena will arise. At such times, there will be disagreements and controversies among scientists about the interpretation which best fits the observations. Such controversies provide stimulus to further research, as scientists seek evidence to resolve the conflict.
      (3) Acceptance of a new theory is much like a change in gestalt in which the elements being interpreted are constant but a switch in interpretation occurs requiring abandonment of that previously held in favor of one completely different. Literally, a new world opens up.

IV. Self-Testing Aspects of Scientific Inquiry

A. The most widespread and conclusive process of self-testing in science is testing by multiplication of relevant observations. Scientists generally test hypotheses in this way.

   1. Relevant observations are those which are potentially capable of disproving the hypothesis.

a. Prediction is only a special form of relevant observation: that for which failure to occur would disprove the hypothesis.
b. Prediction is possible only when the terms being used have been given their operational definitions.
c. Prediction is more difficult in biology which often deals with unique events.

2. When the scientist is satisfied that the results of multiple observations fall within the range predicted by his hypothesis, he will accept the hypothesis as correct. If the results do not fall in the predicted range, he must reject the hypothesis.

B. Observations, laws, or theories may lead a scientist to predict certain phenomena and behaviors in nature, and he must question nature to find out whether his predictions (hypotheses) are correct.

1. The relationship of theory to observation is crucial--without theory, man does not know what to observe.
2. The observations that are to be made in experimental testing must be expressed in terms of specified variables.

a. In experiments where all possible variables cannot be clearly identified, it is desirable to use controls. In a simple control experiment, the control sample is treated exactly the same as the experimental sample except for the experimental variable being investigated.
b. With many phenomena, the whole point of observation is not an exact measurement of determination of occurance but establishment (to some degree of confidence) of a probability.
c. Scientists doing research frequently require specialized instruments and equipment to carry out experiments and make observations.

(1) As experiments become more precise and sophisticated, improvements must be made in the scientific instruments and equipment employed.
(2) Introduction of a new instrument or technique may lead to a new epoch of progress in developing scientific ideas.

C. Falsification is an important process of self-testing in scientific inquiry. Ideas and facts that remain as accepted parts of science have been shown to be not false.

1. The falsity of an alleged face or theory in science can be determined through observation and experiment although the scientist cannot know whether the theory or fact is "true" in an absolute sense. For a scientific fact or theory to be accepted by scientists, it must be shown to be not falsified by evidence that has been gathered.

a. Science has selected, as its criteria for truth, sense data which can be comprehended and checked by everybody with appropriate training.

b. If an alleged fact is false, it will be detected by multiple observations of the same phenomena by different persons. An alleged fact is accepted when multiple observations by different people concur.

2. A theory is held to be valid to the extent that observations check with deductions derived from it. If observations do not check with predictions made from a theory, it may be modified by scientists, it may be held with restricted scope, or it may be discarded in favor of a more adequate theory.

   a. If a scientific theory or some part of it is false, it will predict phenomena that cannot be found through experiments and observations by competent investigators.

   b. To be of value and interest in science, a theory must allow prediction of a large number of apparently unrelated observations.

   c. Simplicity, explanatory power, and growth potential all contribute to the acceptance of a theory.

Chart 1

A STRUCTURE FOR THE AFFECTIVE DOMAIN IN RELATION TO SCIENCE EDUCATION

	BEHAVIORS													
	A.0 RECEIVING			B.0 RESPONDING			C.0 VALUING			D.0 ORGANIZATION		E.0 CHARACTERIZATION BY A VALUE COMPLEX	
	Awareness	Willingness to Receive	Controlled or Selected Attention	Acquiescence in Responding	Willingness to Respond	Satisfaction in Response	Acceptance of a Value	Preference for a Value	Commitment	Conceptualization of a Value	Organization of a Value System	Generalized Set	Characterization
PHENOMENA	A.1	A.2	A.3	B.1	B.2	B.3	C.1	C.2	C.3	D.1	D.2	E.1	E.2
1.0 EVENTS IN THE NATURAL WORLD													
1.1 Biological events													
1.2 Physical events													
2.0 ACTIVITIES													
2.1 Informal (generally outside of school)													
2.11 science activities													
2.12 science-related activities													
2.2 Formalized science learning activities in school													
3.0 SCIENCE													
3.1 Science as a source of knowledge about the natural world													
3.11 science in general													
3.12 any content area in science													
3.2 Science as an enterprise organized to gain understanding of natural world													
3.3 Science in its interrelationships with society													
3.4 Scientists as people													
4.0 INQUIRY													
4.1 Processes of scientific inquiry													
4.2 Scientific inquiry as a way of thought													
4.3 Inquiry as a way of thought													
4.31 in association with phenomena and problems in science													
4.32 in association with phenomena and problems not in science													