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AN ANTHROPOCENTRIC VIEW OF SCIENCE AND THE TEACHING OF SCIENCE

O. Roger Anderson

Teachers College and the Biology Division of the
Lamont-Doherty Geological Observatory of Columbia University
New York, N.Y. 10027
U.S.A.

Introduction

Discussions and theorizing about modern science and moral values will effect change in social action to the extent that our best theoretical models of unified science are matched by equally potent and commensurate methods of communicating science as a human enterprise susceptible to moral judgment. Toward this end, a new view of the teaching of science, particularly to the young, is needed that will emphasize a human-centered approach to the analysis of science and hence result in a human-centered method of communicating science knowledge and processes. I use the phrase "human-centered view of science" to mean that science is considered as a human endeavor amenable to analysis in terms of cognitive and affective processes. Moreover, to view science as a human endeavor brings the processes and products of science within the domain of value judgment and thus allows us to admit science as a process to the realm of moral evaluation. I call the model of science processes presented here an anthropocentric view of science since it is constructed from a psychological base that includes concepts of human values and cognition in addition to the more traditional concepts of the epistemology of science. The model has been developed with the particular aim of providing a rationale for construction of science curricula at the precollege and college levels. The model contains selected psychological and science process dimensions suitable for curriculum use. The model, therefore, is not necessarily the most general form that a philosopher of science might prefer. It is clear that future generations will need to be more keenly aware than their predecessors of the possibility of rendering moral judgments about the processes and outcomes of science. Toward this end we will need science curricula that emphasize the psychological factors in the performance of science in addition to the study of scientific processes.

This paper contains two sections. The first section presents background information on current philosophical and psychological models that are used in curriculum construction. The second section presents an overview of an anthropocentric model of science and the teaching of science. Comparisons are made between the new model and some contemporary models as cited in section one.

Contemporary Models

The philosophical works of Margenau (1959), Kuhn (1968), Schwab (1966), and Suchman (1966) have had strong influence on curriculum development particularly in the United States. The application of these kinds of models to curriculum innovation has resulted in the inquiry or process approach to science teaching. Inquiry-oriented curricula focus on the epistemology of science. A brief overview of some contributions of philosophy to curriculum construction is presented.

Margenau has contributed a brilliant analysis of the nature of physical reality. In his view scientific knowledge is neither invariant nor absolute, but rather is a system of constructs derived from a logical analysis of sensory experience.

What we hold to be reality at a particular point in time is the combined product of sensory data reception and interpretation. Thus our conception of reality can change as new sensory data are acquired or as our interpretations are changed to better account for and predict environmental events.

According to Margenau's model as presented in Figure 1, the construction of physical reality occurs at several levels of cognitive complexity. At the most immediate level is the perception of sensory experience. This is represented as the P plane. The P plane is the interface of a person with his environment. All external sources of sensory data are called Nature or the P field. The result of immediate sensory experience is the construction of abstractions or cognitive constructs (C field) that are the symbolic representations of sensory experience. Various rules for passage from sensory experience to constructs are posited and are called rules of correspondence. These rules represent the means whereby scientists consistently interpret sensory experience. According to Margenau, a set of constructs (a set of logically connected abstractions representing an interpretation of sensory data) is validated by demonstrating accuracy in predicting natural phenomena. Thus in Figure 1 the process of predicting phenomena and testing the prediction is shown by a set of arrows. In the process of verification, a sensory experience P_1 arouses a representation of experience shown as a circle within the C field. A set of logical connections is made through a network of constructs and a prediction P_2 is made. If the predicted phenomenon is observed to occur, the circuit of verification is complete and the set of interconnected constructs that yielded the prediction is temporarily accepted as being valid.

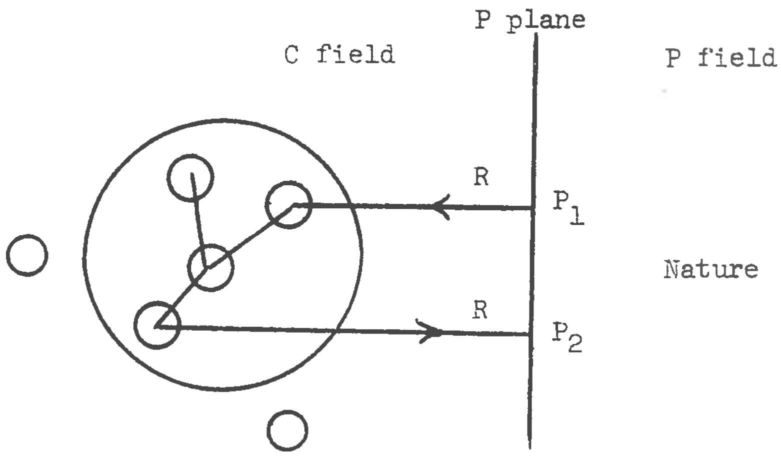

Figure 1

The Circuit of Verification (after Margenau, 1959).

If a prediction based on a constructed interpretation of sensory experience fails to be verified, a revised system of constructs is required until a network of relations is established that yields better predictive validity. Margenau's contribution has influenced science curriculum thought by emphasizing the constructed nature of reality and the need for a non-dogmatic view of scientific knowledge and the processes of acquiring knowledge.

Kuhn has contributed significantly to our understanding of the history of scientific theories. His interpretation of science is much like that of Margenau in the sense that scientific knowledge and the models used to guide research are temporary and indeed sometimes undergo radical change as new data challenge old conceptions thus demanding revolutionary revisions in scientific theory. These paradigms that guide scientific research are not therefore static and ultimate truths, but rather temporary interpretations that guide research until more accurate or useful models are produced.

Schwab and Suchman can be considered simultaneously in so far as they have contributed to science curriculum development. Both of these philosophers have elucidated scientific inquiry processes and presented models of inquiry that have been used to construct science curricula.

The major contribution of the aforementioned philosophers has been their brilliance in explaining science inquiry processes. It is becoming clear however, that in modern society, the moral implications of science and the role of human decision-making in scientific research will need to be examined if we are to be fully in control of the technological applications of scientific findings. This pressing need suggests that new models of science inquiry are required that include psychological, moral and human emotive factors in addition to the already recognized scientific processes of data gathering and interpretation.

B.F. Skinner (1971) has proposed a psychological solution to the dilemma of efficiently inculcating moral values. His model called operant conditioning is remarkable for its predictability in changing behavior patterns, but is equally alarming for the potential mechanistic life style produced by the conditioning process. According to Skinner, behavior patterns can be shaped or built up by systematically applying a psychological reinforcer each time a desirable behavior is emitted or an approximation toward the desired behavior is exhibited. Although this empirical method yields a high degree of precision in controlling overt behavior patterns, the tacit psychological processes of valuing and goal selection so central to human moral judgment are neglected. Unless Skinner's mechanistic approach to behavior modification is supplemented with training in tacit psychological processes, we may foresee a generation of adults who perform many morally correct actions, but who lack a mature interpretation of why they behave as they do.

I therefore propose the following model that contains a synthesis of psychological and philosophical interpretations of science processes.

Anthropocentric Model

There are three dimensions in the model: (1) psychological orientation of an individual toward the natural and social environments, (2) psychological orientation of an individual toward scientific inquiry processes, and (3) a set of scientific inquiry processes. The dimensions will be defined and their relationships will be presented in a three-dimensional model. (Figure 2 here)

The psychological orientation of an individual toward his environment is the set of attitudes, beliefs, and values that a person holds about the environment. This dimension is divided into two subcategories: orientation toward the natural environment and orientation toward the social environment. One's orientation toward the natural environment is the set of attitudes, beliefs, and values that one holds about the non-human environment. For example one may assume that the natural environment is chaotic or that it is susceptible to being ordered. One may assume that the natural environment is complementary to human technological advance or that it is to be exploited for human advance. The substance of this category is how one perceives the environment as a phenomenon and its relation to his own purposes. Orientation toward the social environment is one's philosophy about the purposes of society and the individual's role vis a vis those purposes. For example, a person can perceive society as subservient to individual personal goals or as a cooperative group where the individual adjusts his goals to be consonant with the goals of society at large. Society can be seen as existing to advance its purposes without regard to their cost to the natural environment or it can be perceived as an organization of individuals who manage the natural environment with prudence and wisdom.

The second dimension, orientation of an individual toward scientific processes is the set of psychological variables that determines how a person uses scientific processes. This dimension is divided into four categories (1) sensation, (2) predisposition, (3) recognition, and (4) operation. The categories are deliberately ordered in a sequence beginning with those psychological variables related to immediate sensory data acquisition and extending toward those variables related to active cognitive application of scientific processes.

Each category is defined.

1. Sensation is immediate sensory data acquisition through mediation of sensory modalities. Here included is (a) the preferred kind of sensory modality, that is a preference to use one of the five senses in gathering sensory data, (b) the intensity of sensory data acquisition - the sensitivity enhibited in using a sensory modality, and (c) the duration of use of a sensory modality. Sensation is the most immediate form of data processing. It is the primary step in selective gathering of stimuli from the environment.
2. Predisposition is a tendency to behave in a certain way. This is a non-verbalized inclination toward a set of behaviors. It is a tacit psychological state of readiness and a confidence sufficient to sustain activity. This category is akin to what laymen call intuitive understanding. For example a person may be aware that a certain pattern of plant growth is present in a field observed from a hill but cannot express the pattern in words. At this level of perception the awareness is non verbal and hence is labeled a predisposition. As another example an inclination to assume that causal relations exist in experience and a confidence to seek instances of them is

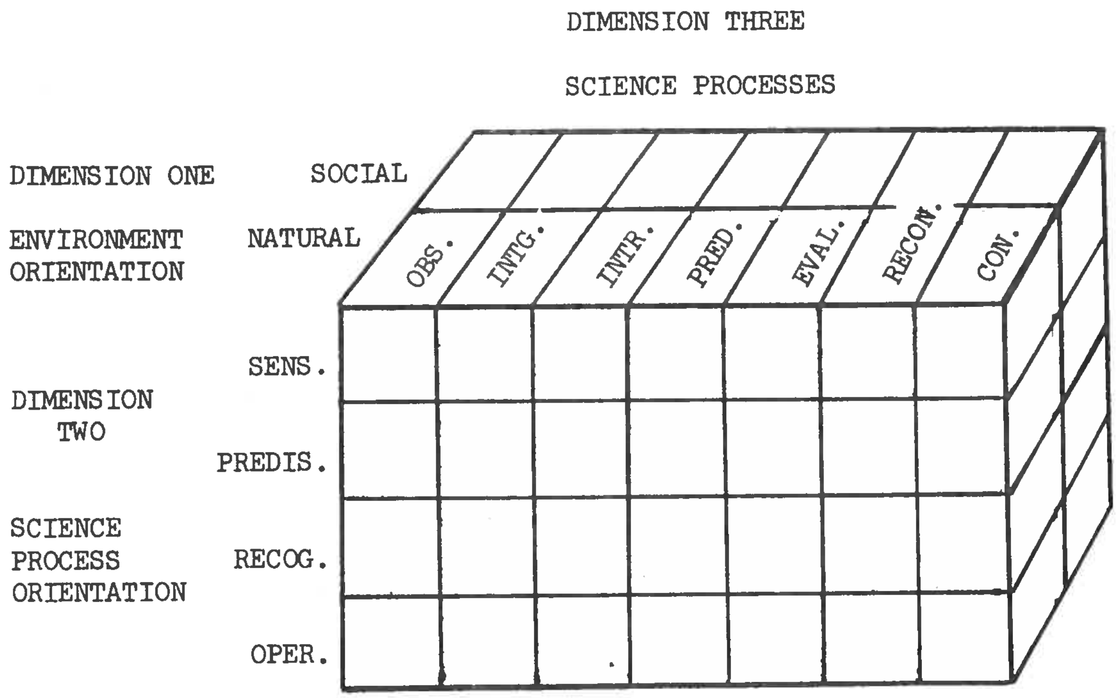

Figure 2

Anthropocentric Model of Science Processes

Legend: Dimension two, SENS. (SENSATION), PREDIS. (PREDISPOSITION), RECOG. (RECOGNITION), OPER. (OPERATION); Dimension three, OBS. (OBSERVATION); INTG. (INTEGRATION), INTR. (INTERPRETATION), PRED. (PREDICTION), EVAL. (EVALUATION), RECON. (RECONSTRUCTION), CON. (CONSTRUCTION).

labeled predisposition. Predisposition is one of the most fundamental psychological variables in this dimension since it is the requisite primary step toward higher cognitive processing of data. Unless one tacitly accepts the possibility of understanding certain things through experience and unless the necessary confidence is present to sustain such activity, there is a low probability that one will perform higher levels of symbolic rational data processing.

3. Recognition is a verbalized awareness of sensory experience and of scientific processes that can be used in obtaining and processing sensory data. Whereas predisposition is a tacit, non-verbalized state, recognition is a verbalized awareness of data processing. It includes the ability to explain scientific processes but not the ability to actually perform them.

4. Operation is the ability to use scientific processes. This is the highest level of cognitive activity among the categories in this dimension and represents an ability to apply scientific processes with various degrees of sophistication. The degree of sophistication of operation is determined by the extent to which an individual can explain the purposes of an operation, differentiate when an operation is appropriate or inappropriate and modify an operation when the situation demands it.

The science processes dimension contains seven categories. These categories include activities used by scientists in both the physical and biological sciences. The activities are ordered in sequence beginning with those activities related to immediate sensory data acquisition and progressing toward those kinds of activities that represent higher order data processing. The categories of activities in this dimension are (1) observation, (2) integration, (3) interpretation, (4) prediction, (5) evaluation, (6) reconstruction, and (7) construction. Each of the scientific process categories is described.

1. Observation is a process of acquiring immediate sensory data. Although it is the most fundamental category among those in the science processes dimension, it is nonetheless psychologically very complex. It includes the kind and range of stimuli to which one attends, the boundaries that one places on what is to be observed in gathering sensory data, and the kind of organization that one immediately identifies in sensory experience. These attention factors are regulated by complex psychological variables. Among these variables are (1) prior experience that determines the potency and valence of the stimuli, and (2) previously acquired schemas (organized ways of viewing the world) that guide selective attending and determine the range of stimuli attended to and the immediate organization one imposes on sensory data.

2. Integration is a process of relating newly acquired data to prior-gained information. This is a transition category between observation and interpretation. Integration is a process of associating immediate experience with prior gained information without performing elaborate logical analyses about the kinds of relationships that exist. Integration includes first order associations such as identifying an instance of something previously encountered. Higher levels of integration include classification of data in previously formed categories. To identify a spider as belonging to a particular genus is an act

of integration. To see a larger than normal specimen of an animal and thus to realize that a prior formed category of living things contains a wider range of sizes than previously understood is a high-level act of integration that approximates the next higher category of interpretation.

3. Interpretation is a process of deducing relations within immediate sensory data or between presently acquired data and prior knowledge. The relations go beyond simple associative relations and assignment of data to prior formed classification categories. Included here are the following kinds of processes:
   (a) invention of new classification systems or categories used to order sensory data,
   (b) application of mathematical data interpretation systems such as statistical methods and graphical methods of data analysis,
   (c) synthesis of temporal or spatial relations among sensory data (this includes explanations of observed forms and functions), and
   (d) statements of correlation or cause and effect among variables that are not merely memorized data relations. This last instance comes close to the next higher category of prediction.
4. Prediction is a statement of events that are expected to occur or a statement of cause and effect that can be subjected to a test of verification. At the lowest level, this category includes simple extrapolation -- an extension of a trend beyond acquired data. At the highest level of prediction stands an hypothetical statement containing clearly defined independent and dependent variables whose causal relations are set forth with due attention to contributory variables that are to be controlled or

accounted for during a test of the hyphothesis.

5. Evaluation is a judgment of the accuracy of a prediction or the quality of sensory experience in relation to a criterion. The criterion can be a standard of quality, a value statement of what is good or acceptable, or an objective that was to be accomplished.

6. Reconstruction is a process of reorganizing or otherwise refining a theoretical explanation or model in the light of newly acquired data. This category presupposes the existence of a set of ordered constructs and that newly acquired data present evidence requiring reorganization of the constructs to better accomodate the data. It is presumed that part of the theory will remain constant and that the changes made do not represent a radical revision to the extent that the theory would be classified as overthrown.

7. Construction is the synthesis of a new theoretical statement or model. It is such a dramatic departure from prior explanations or it includes new interpretations of sensory experience of such a novel kind that it can be considered a new statement. Construction is the production of a set of orderly relations among constructs and as such implies an explanation that is more complex than a classification scheme as cited in the category of interpretation.

An assembly of the three dimensions in a cubical model is shown as Figure 2. Some combinations of categories among the three dimensions are explained and the resulting anthropocentric view of science is applied to the analysis of learning experiences.

The limited space available in this paper will allow only an overview of some of the relations contained in the model. An explanation of the relations between categories in dimensions two and three will be given first followed by a description of combinations of categories from all three dimensions. The pattern of combining categories in dimensions two and three will be to identify a row category in dimension two and systematically relate it to column categories in dimension three. As a shorthand expression for the combined categories, the row category will be cited followed by a slash and the column category. Thus, sensation/observation is the first category pair to be considered in row one and sensation/construction is the last category pair to be considered. Selected category pairs will be used to illustrate the kinds of interpretations derived from the model.

Sensation/observation is the dominant sensory modality or range of modalities used by an individual in gathering immediate sensory data. Some individuals may fixate on visual data reception to the exclusion of tactile or auditory data acquisition. The particular context wherein certain modalities are employed can be determined. Does the student tend to use visual data gathering when in the laboratory, but prefers to use auditory data in the field experience? This binary combination represents the simplest level of data processing. The binary combinations sensation/integration, sensation/interpretation, sensation/prediction, sensation/reconstruction, and sensation/construction mean respectively the extent to which a student applies various sources of sensory data in performing each of the science processes in dimension two. Thus integration of data may be largely centered for example in visual data or in auditory data gathering. Evaluation of sensory experiences may be restricted largely to tactile sensory data with little attention to other sensory modalities or may be exhibited among several sensory modalities.

Binary combinations of the predisposition category with various science process categories from dimension two are presented. Predisposition/observation includes an individual's awareness of or inclination to identify patterns of sensory data as opposed to identification of unitary and fragmented instances of phenomena in the environment. Here also is included the mere tendency to use observation as a science process. A sense of confidence in observing phenomena is also indicated. The binary combinations of predisposition/integration through predisposition/construction indicate an individual's tacit inclination to be aware of and have confidence in his ability to perform the various science processes. There is no requirement that the individual exhibit performance capability with the processes.

The binary combinations of the recognition category with science process categories include the extent to which an individual can verbalize an explanation of the purposes of and steps to be performed in a scientific process. For example the binary combination recognition/interpretation is the extent to which an individual can describe how a classification system is constructed and used to organize and interrelate sensory data. Recognition/construction is an individual's ability to describe the organization of theory and how theories and models of natural phenomena are constructed. There is no requirement that the individual actually construct a theory or model.

Binary combinations of the category operation with science process categories is the extent to which an individual exhibits performance capability with a science process. For example the combination operation/observation includes an individual's ability to gather sensory data by sustained use of a sensory modality; here is also included the kind of organization in stimuli identified by the observer. The tendency to consistently identify complex patterns or to identify only unitary or fragmentary instances of phenomena is included here. The difference between unit and pattern identification in observation is illustrated by the following example. When presented with a survey map of a river basin area adjacent to a mountain containing vegetative cover over the entire area up to a timberline on the mountain, a student may identify only instances of kinds of trees and herbaceous plants growing in the range. This is an example of unit identification. An example of pattern identification would be a statement that softwood trees grow along the river edge and grade into hardwood deciduous trees near the mountain base followed by a gradient into conifer trees up the mountain side toward timberline. Using this same geographical example, the binary combination operation/interpretation indicates that the individual can state the relations that exist among the various components in a pattern. Thus an example of interpretation is a statement that softwood trees grow near the river's edge since they are mesophytes well adapted to water laden soil and require abundant water resources to live, whereas conifers grow on the mountain slopes since they are wind and drought resistant due to leaf mechanisms that prevent excessive water loss. This operation/interpretation category pair is to be contrasted with an operation/integration combination. The latter usage indicates that the student is able to identify prior-gained instances of the pattern or units observed and state the conditions of relationship that exist between prior knowledge and the newly acquired data. For example to state that a vegetative pattern of growth presently observed in Nebraska was previously seen in a grassland in Idaho is an instance of integration. The simple classification of upland conifer trees as belonging to the class Gymnospermae is also an operation of integration. The limited space available will not allow further examples of binary combinations of categories in dimensions two and three. Therefore, I proceed to a survey of instances of ternary combinations among categories in dimensions one, two, and three. The addition of dimension one allows us to include human value systems, norms, and beliefs as a component of the scientific enterprise. In our previous discussion of dimensions two and three, the model was anthropocentric to the extent that dimension two contains cognitive variables related to human experience -- namely the orientation of an individual toward scientific processes. The admission of dimension one allows one to make value judgments about the impact of science on society and the role of the individual in performing scientific inquiry and its impact on the natural environment. Selected exemplars of ternary category combinations are presented.

Consider the combination natural environment orientation/predisposition/observation. If an individual views the natural environment as being chaotic or controlled by capricious forces beyond the comprehension of man, then there is a low probability that the individual will develop a predisposition to identify order within the natural environment. There is little likelihood that he will have confidence in his ability to gain ordered information from sustained observation.

A full understanding of the predisposition category is useful in preparing science curriculum experiences particularly for those students who have lived in social settings where experience is believed to be capricious or it is believed that natural phenomena are governed by chaotic or wholly incomprehensible forces. Youth from low income backgrounds or from social milieus where superstition prevails often lack an awareness of and confidence in their ability to order sensory data and to construct systematic explanations of natural phenomena.

Another example of a ternary combination including dimension three is one using the social environment orientation category. If one holds a value that the environment is to be used for social technological advancement without regard to environmental impact then we find some interesting combinations of this category with those in dimensions two and three. Consider its combination with operation/evaluation. Suppose the results of a scientific experiment show that addition of nitrate to a depleted cultivated field will enhance crop production but that run off will undoubtedly lead to eutrophication of a nearby estuary which is a central breeding ground for a species of fish highly critical in the food chain. The results of the experiment can of course be evaluated first in terms of the accuracy of scientific design. But in addition, the use of dimension one suggests an evaluation in terms of the impact of the application of the findings on the ecosystem. Criteria can be discussed as to what constitutes sufficient technological gain and relief of human needs to permit a certain level of environmental insult. Additional examples of categories in the model are presented in the Appendix. I have previously published recommendations for the use of psychological theory in the teaching of biology (Anderson, 1972). Work is currently underway at my institution to create science curriculum experiences with a focus on developing psychological orientations relative to science processes as described in this paper. The purpose of these experiences is to allow teachers and students to be aware of the specific cognitive factors that can be developed as one learns science. The anthropocentric model, moreover, subsumes the philosophical models of Margenau, Kuhn, and Schwab. The categories of reconstruction and construction presented in dimension three allow inclusion of Margenau's concept of constructed reality and construct verification, whereas the concept of reconstruction is particularly consonant with Kuhn's view of science as a process of paradigm revision. This model is unique as a curriculum guide in its synthesis of psychological, philosophical and moral dimensions of science processes and thus allows a more comprehensive view of the teaching of science than provided by other contemporary models.

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APPENDIX

I. A Summary of Some Subcategories in Dimension One

A. Natural Environment Orientation

1. Aesthetic Orientation

Some concepts to be used in developing an aesthetic response in science learning are presented. These concepts can be used as themes in studying a wide range of phenomena.

a. Symmetry - the correspondence in size, form and arrangement of parts on opposite sides of a plane, line or point; any form that can be divided into two or more mirror image components. Plane symmetries are those forms that can be divided into two or more corresponding parts on opposite sides of a plane. Rotational symmetries are those forms that can be rotated through angles less than 360° and brought into correspondence with the initial state. For example, the p-orbitals of an atom, the bilateral symmetry of animals, the symmetry of opposite leaf arrangement and the arrangement of certain flower parts are examples of plane symmetry. Rotational symmetry includes as examples the spiral arrangement of protein molecules (α - helix), the form of a flower head in the compositae and whorled leaf arrangements in plants.

b. Complementarity - A relationship of two or more forms such that each form supplies something lacking in the other (a template-product or lock and key relationship). Form is used broadly to mean a solid form or a function found in Nature. Thus complementarity is observed in DNA and MRNA pairing or also in two overlapping environmental niches that do not lead to competitive destruction of the inhabiting species.

c. Balance - a state of equilibrium or equipoise; equal distribution of weight, amount, and so forth. Examples include equal distribution of forces on a line around a point, a pattern of tree growth with equal amounts of limbs on either side of a plane, or a state of an ecosystem when nutrient supply is sufficient for nutrient demand.

d. Periodicity - a regularly repetitive pattern in space or time. Spatial periodicity is exemplified by regularly spaced objects in space such as body segmentation in a worm, insect wing scale arrangement, and stratified horizons in geological formation. Temporal periodicity is a regularly spaced series of events in time. Included here are light and dark cycles, plant and animal life cycles and various rhythms in living things.

e. Pattern-unit relations - a pattern is used here to mean any organizing principle whereby instances of experience can be ordered. A unit is any particular observation that can be subsumed by an organizing principle. A relation is posited when one finds instances that can be subsumed. As an example the concept of "succession" in ecology is a pattern since it can be used to identify various instances of successive patterns of plant growth. The concept of "field" in physics is a pattern since it can be used to identify various kinds of magnetic and electrical phenomena.

2. Organizational Orientation

Order-disorder perception. Perspectives as to the presence of order in the environment and the ability to tolerate variability within observed natural environment data. An understanding of the concept of error in measurement.

B. Social Environment Orientation

Value orientation -

statements of belief about man's obligations as a social being to sustain social organization, plan social progress with consideration for environmental impact, control disease, and alleviate human need.

II. A Summary of Some Subcategories in Dimension three*

A. Observation

1. Unit and Pattern Identification

a. Unit properties - identification of individual objects without concern for relationships to other objects. Individual object properties identified are color, shape, size, weight, density, texture and sound.

b. Pattern properties - identification of an organized

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* Dimension two is not subdivided beyond those categories presented in the main text. Therefore no additional explanations are given here.

or interrelated group of units using the following processes: spatial tracking - visually scanning a set of spatially connected units, grouping - assembly of units into clusters using common properties, inferred function or inferred physical properties, and ordering - assembly of units according to a principle of relative size, shape, inferred importance of functions, and so forth.

2. Visualization of Form and Transformation

   a. Form perspective - visual imagery of an object in various positions vis a vis the observer.

   b. Form transformation - visual imagery of changes in size, color or folding of an object; the translation of microscopic elements (subsumed in a larger object) in to a larger form as though isolated from the whole, and visualization of solid forms as though they were transparent.

B. Interpretation

1. Unit Explanations. A perceived unit (single entity) is analyzed as to its function or role in a natural system.

2. Pattern Explanations. The analysis of functional relationships among units forming a pattern. Included here is inferred form - the deduction of internal structure by an examination of external shape or other topographical or auditory cues, and inferred function - a deduction of function or process based on partial or superficial data. Logical processes of concept

formation, classification, correlation and cause-effect relations are included here.

C. Prediction

1. Pattern Prediction - extending a known set of relationships among units to include new ones.
2. Extrapolation - extending trends beyond known data.
3. Hypothesizing - stating a relationship between independent and dependent variables with due attention to contributory variables that are to be controlled.

D. Evaluation

The quality of an experiment or set of findings is judged in terms of a criterion of research design standard, criteria of significance of results relative to increased knowledge, expanded theoretical understanding, or improved science methodology. Standards of moral acceptability relative to a social value system can also be used.

E. Reconstruction - a previously acquired theoretical explanation is reorganized or expanded as a result of

1. new data that allows the theory to be more general or more logically complete by including relationships not previously included;
2. new data that challenges a part of the theoretical explanation thus requiring a revision.

F. Construction -

A new theoretical explanation for natural phenomena is synthesized. This can result from new data that so severely challenges prior conceptions that a new explanation is required or as a result of newly acquired data that permits a novel theoretical statement.