DOCUMENT RESUME

ED 123 037 SE 019 522

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TITLE Analytic Concepts and the Relation Between Content and Process in Science Curricula.
INSTITUTION Southwest Regional Laboratory for Educational Research and Development, Los Alamitos, Calif.
REPORT NO SWRL-TN-72-56
PUB DATE 4 Dec 72
NOTE 37p.

EDRS PRICE MF-$0.83 HC-$2.06 Plus Postage
DESCRIPTORS *Curriculum; *Curriculum Development; Elementary School Science; Instruction; *Primary Education; *Process Education; Science Course Improvement Project; Science Education; Scientific Concepts; Skill Development
IDENTIFIERS Southwest Regional Laboratory

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SOUTHWEST REGIONAL LABORATORY
TECHNICAL NOTE

DATE: December 4, 1972

NO: TN-2-72-56

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Edward L. Smith

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# ANALYTIC CONCEPTS AND THE RELATION BETWEEN CONTENT AND PROCESS IN SCIENCE CURRICULA

Edward L. Smith

What relative emphasis should be placed on the learning of content (concepts, definitions, principles, etc.) as opposed to processes (strategies, procedures, etc.) in elementary science education? The major projects developing elementary science curriculum materials in the last decade illustrate the spectrum of opinion on this question.

Several projects, such as the *Conceptually Oriented Program in Elementary Science* (COPES, 1967) and the *Cornell Elementary Science Program*, (CESP, 1969) placed major emphasis on content. The content oriented programs were influenced by Bruner's argument that any knowledge can be taught to anyone at some intellectually valid level (Bruner, 1966), by Ausubel's argument for the importance of meaningful reception learning (Ausubel, 1963, 1968), and by efforts of the National Science Teachers Association to develop a consensus on the major conceptual schemes of science (NSTA, 1964, 1966). These programs reflect the view that mastery of basic concepts and principles is the basic requirement for further learning and problem solving.

Taking quite another position was *Science: A Process Approach*, a program sponsored by the American Association for the Advancement of Science (AAAS, 1967). Content was viewed as temporary or unstable, changing with the rapid development of new knowledge, and as not being broadly generalizable. A more enduring and general foundation was sought in basic processes of science. The program was heavily influenced by theoretical views of Gagné on skills and task analysis.

Although considerable emphasis was placed on tryout and revision (formative evaluation) of all of these programs, most assessments have been concerned with the achievement of rather specific objectives. To date there is insufficient data concerning the relative impact of the programs (summative evaluation) to provide an empirical answer to the question of the optimal emphasis to place on content and process in the long-range development of general science skills. Despite enthusastic argumentation by proponents of each side, there is no evidence to suggest that either approach should be discarded entirely. Every scientific field necessarily involves elements of both content and process. If science education is to reflect anything of the nature of science, some contents, some processes, and some relations between them must be included.

Such a balanced approach should not be simply a potpourri of objectives from each side. Rather, an analytic base having its own integrity should be employed as a means of coordinating content and process. Thus, the main question debated by science educators should concern the relation between content and process, not merely the degree of emphasis to be given to each.

The ideas presented in the following paragraphs provide a preliminary answer to this question and indicate how an appropriate analytic base for a science program can be designed. The approach described below has been found similar in several respects to that implicitly employed by the Science Curriculum Improvement Study (SCIS, 1966, 1968a, 1968b, 1968c). By making the analytic base explicit, precision can

be increased, and inconsistencies and other problems can be discovered and solved at the design level (see Smith & McClain, 1972; Smith, 1971).

Three levels of program content are distinguished: the analytic, the systemic, and the particular. The most general and stable aspects of science are the analytic concepts such as variable, operation, system, relation, hypothesis, etc. Analytic concepts are abstractions from the systems of content of particular disciplines. They reflect the structure or form of that (systemic) content, rather than its substance. Mastery of analytic concepts provides a basis for organizing investigation into new areas, whether first hand or through secondary sources. Sets of analytic concepts organized into networks can provide the framework for curriculum design. One such network, built around the concept of a variable, has already been developed (Smith & Van Horn, 1971) and applied to the analysis of outcomes of an extant primary science unit (McClain & Smith, 1971; Smith, 1971).

Somewhat less general and stable are the systemic concepts, those specialized concepts basic to the conceptual systems of specific disciplines. Force, energy, atom, ecosystem, cost, profit, role, response, need, etc., are important systemic concepts in their respective disciplines. A variety of such concepts is an essential ingredient of a curriculum designed to develop analytic concepts since the systemic concepts exemplify the analytic concepts. Concepts at this level are also required as a basis for assimilation of specific phenomena or information about them. Without an appropriate framework of such concepts the individual must construct his own. In general, naive

inductions are unlikely to be an effective basis for discovery of new relations, or for accurate comprehension of new scientific information. Although less general than the analytic concepts, systemic concepts do have considerable generality in the diversity of phenomena to which they apply.

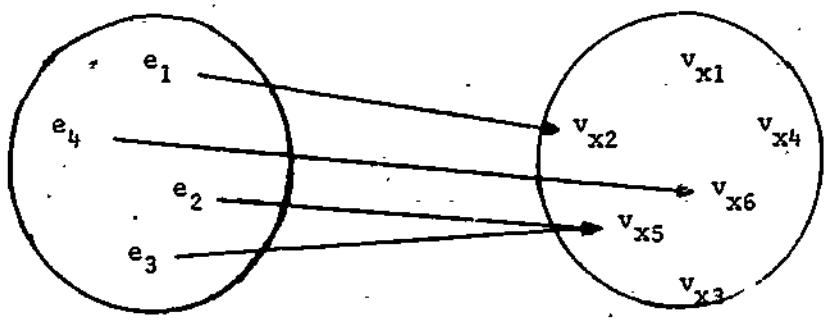
The third level of content is represented by the particular phenomena with which the student deals in the curriculum. The student may encounter the concept of weight in the context of the weights of himself and others in his class, for example. The content at this level can be viewed as a sample of the phenomena with which the student might come into contact. This domain is very large and heterogeneous, varying across individuals as well as over time. Thus, this level of content is the least general and the least stable.

The analytic, systemic, and particular levels of content represent three distinct levels of analysis and decision making. Analysis and subsequent selection of analytic content does not determine the systemic or particular content although it does establish criteria. Analysis of the conceptual systems of various disciplines must then be carried out. Content selections at this level must exemplify the analytic concepts already selected. Finally, particular content which exemplifies the systemic content can be selected. Additional criteria can and should be adopted for selecting among systemic and particular content alternatives which meet the compatibility criterion.

The discussion above reflects what is typically referred to as content. However, the process aspect is not an independent component. Concepts are not static constituents which the individual merely possesses; they are functioning structures with functional consequences in behavior. In this sense processes are implied by the phrase, "mastery of the concept." Particular functional capabilities of the student with respect to a given concept cannot be assumed or left to chance, however. They must be clearly specified, given appropriate instructional attention, and carefully assessed.

At the analytic level, processes are represented by analytic operations defined in terms of the analytic concepts. It is quite probable that these operations can be adequately represented symbolically in a formal system. Initial attempts employing set theory have been moderately successful (Smith & Van Horn, 1971; McClain & Smith, 1971; Smith, 1971). For example, the description operation is defined as a many-to-one mapping of elements (the things to be described) into a set of values for the variable on which the description is made (see Figure 1).

Detailed specifications of tasks to be performed can be prepared at the analytic level by specifying the analytic operations the student must perform, and indicating the analytic concepts for which examples are identified in the task situation and those for which the student must provide appropriate examples for himself. For example, one description task provides the student with the elements and a variable name. The student must contribute the values and the observation/measurement procedure in carrying out the description operation.




Elements Values for Variable x

Figure 1. A mapping formulation of the description operation.

At the systemic level, processes are represented by algorithms or procedures exemplifying analytic operations. At this level the description task above might involve the measurement of weight using a spring scales calibrated in pounds, for example. Although limits on the sets of possible elements may be specified at the systemic level, the final selection of elements (and weight values) represent decisions at the particular level. Thus, the specification of the children in the classroom as elements to be weighed would represent a decision at the particular level.

As formulated above, development of the processes of science is not an alternative to the learning of science content, but rather one aspect of what is implied by mastery of such content. If properly organized, each learning event can serve to develop knowledge of specific phenomena, important systemic concepts, and generalizable analytic concepts. Without such organization, processes become isolated procedures with little meaning, power, or utility. Certainly skill

in measuring weight has no more generality or stability than the concept of weight. Of course, these effects are not automatic results of any arbitrary science activity. Detailed analysis and careful selection are required. Further, instructional techniques which make the relations between the levels functional for the student must be identified. Undoubtedly, verbal mediation will play an important role. However, the optimal time for introducing analytic and systemic concept labels, optimal sequencing of examples, and other instructional problems must be investigated.

## IMPLICATIONS FOR THE DESIGN OF A SCIENCE PROGRAM

The above remarks have several implications for the design of a science program.

1) A set of analytic concepts should be selected before final selection of content at the systemic level. Systemic content can be used as raw material for analysis to identify or assess the generality of analytic concepts. However, if the systemic content is to serve as a vehicle for the development of analytic concepts, the final selections and organization at the systemic level must be based on decisions made at the analytic level.

2) General terms such as deduction, observation, prediction, etc., which suggest operations must be defined precisely in terms of analytic concepts before they can become useful as a basis for decisions at the systemic and particular levels. Precise definitions also make prerequisite relations

among such operations more apparent, thus facilitating their selection and sequencing.

3) Criteria for the selection of analytic content must be established. These might include:

   a. Readiness of children to master as indicated by empirical and theoretical literature.

   b. Generality of application to systemic and particular content of interest and/or significance to the students.

   c. Time and effort required to develop a suitable level of mastery.

   d. Relevance to other, higher level analytic content.

ANALYTIC CONCEPTS FOR THE PRIMARY SCIENCE CURRICULUM

A preliminary set of analytic concepts for use in the primary science curriculum is described below. The concepts were identified as broadly applicable in analyses of extant instructional programs (Smith & McClain, 1972). Revisions may be made as tasks are defined and instructional strategies for their development are designed.

Most analytic concepts are defined in terms of their relation to other analytic concepts and derive their utility from those relations. It seems appropriate, therefore, to describe networks of interrelated analytic concepts. Although almost all such concepts may be related in the context of at least some systemic content, there do seem to be clusters which often function independently. The networks described below reflect the lowest level at which the concepts seem to function independently. Interactions among the networks will be defined at a later time.

ELEMENT-VALUE-VARIABLE NETWORK OF ANALYTIC CONCEPTS

A very basic network of concepts involves the entities whose nature is the subject of study and the features of those entities which are used to describe, compare, order, and classify those entities. These analytic concepts have been described in considerable detail elsewhere along with analytic operations and tasks defined in terms of them (Smith & Van Horn, 1971; Smith, 1971). Brief definitions of these concepts are presented below:

Elements--The entities (objects, events, systems, constructs, etc.) which are being studied.

Variable Name--Name of an aspect of elements which may vary either from element to element or for one element across time.

Values--Terms representing particular element characterizations distinguished with respect to a given variable.

Observation/Measurement Procedure--Rule or algorithm which, when applied to an element, results in the specification of the value of the corresponding variable which applies to the element.

Description--A set of values consisting of one value for each of a set of variables.

Comparative--Term representing the relation between the values of a single variable (or descriptions on a set of variables) which characterize two or more elements (or an element at different times).

Correlational Rule--Rule or algorthm which, when applied to a value of one variable, results in the specification of a value of a different variable.

THE CLASS-MEMBER NETWORK OF ANALYTIC CONCEPTS

A broadly applicable and widely studied network of concepts is based on the notion of class membership. This network also includes the concept of element. Other concepts involved are defined as follows:

Class--A particular set of elements.

Class Member--An element which is in a particular class.

Class Definition[1]--A decision rule which when applied to a description of an element, specifies whether or not the element is a member of the corresponding class.

Class Name[2]--Label applicable to any element which is a member of a given class; also used to refer to the class as a whole.

WHOLE-PART NETWORK OF ANALYTIC CONCEPTS

This analytic network is based on a special relation between elements. Each element in the relation is viewed simultaneously at two levels. Each is viewed as an element. At the same time, the "whole" is viewed as being divisable and the part as a result of a division. In other contexts, each may be viewed simply as elements.

Part--An element which is an integral portion of another element.

Complex Element (whole)--An element which is regarded as having two or more parts.

Activity--A characteristic functioning or behavior of a complex element (activity implies complexity, i.e., parts).

Function--The action or contribution a part makes toward an activity of a complex element of which it is a part.

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[1]Definitions of classes are a form of correlational rule since they relate values on one variable (the alternative classes) to those of one or more other variables (those on which the descriptions are based). They are true by definition, however, since there is no independent means of assigning values.

[2]Class names serve as values in statements asserting class membership for elements or relating class membership to other characteristics.

PROCESS-STAGE-EVENT ANALYTIC NETWORK

None of the analytic concepts described above deal explicitly with the temporal aspect of phenomena although the values and comparatives can be employed in describing changes. This aspect seems basic and important enough to warrant specilized treatment. The following concepts deal explicitly with the temporal aspect of phenomena while relating it to the structural or spatial aspect.

Change--A change is the applicability of two different values of a variable to an element at two different points in time.

Event--The occurrence of a change or set of coincident changes in an element.

Process--A set of temporally ordered changes in an element on a given set of variables.

Stage[3]--Part of a process consisting of (a) a sequential subset of events, or (b) a period of time bounded by specific events.

APPLICATION OF ANALYTIC CONCEPTS IN CURRICULUM DESIGN

The role of analytic concepts in the design of a science program is illustrated by the application of the analytic concepts defined above to a list of proposed content for a kindergarten science program (see Appendix A). The list was specified and organized at the systemic level. The reorganization resulting from the application of the analytic concepts (Appendix B) provided the basis for the following discussion and recommendations. These comments consider

[3]Sometimes the form an element takes during a stage is referred to as a stage. This is considered to be an implicit statement of "the form x takes during stage y." The stage may be identified by the form taken during that stage, e.g., larva stage.

only the relation between the analytic and systemic concepts and do not reflect evaluation of the systemic concepts themselves.

In considering such recommendations, it is important to keep in mind the assumption, developed above, that the primary contribution of systemic concepts is the development of the analytic concepts which they exemplify. It is the analytic concepts which provide a mediating device for the facilitation of learning of new systemic content (parallel transfer) and the development of generalizable inquiry strategies. It should be recalled that this does not eliminate the necessity for mastery of systemic content, however. To the contrary, mastery of systemic concepts is essential for it is these which exemplify the analytic concepts.

1. When viewed from the analytic level, several gaps are revealed in the proposed lists of systemic content. For example, several lists of parts on page 24 do not have any functions specified. Only a few of the class concepts on pages 26 and 27 have any values specified which serve as definitions. Gaps at the systemic level will result in gaps at the analytic level. They also reduce the power and usefulness of the systemic content in the assimilation of particular content. <u>It is recommended that systemic content be added to fill in these gaps</u>.
2. In some cases, sets of systemic concepts did not fit any analytic network very well. The phenomenon of burning, for example (see page 31), could be treated with whole-part

concepts or with process-stage-event concepts. However, the proposed list of systemic concepts does not seem to completely fit either. Such mismatches might be due to inadequacies in the analytic networks or to inconsistencies in the systemic content. Whatever the reason, difficulties in learning could result at both the analytic and systemic levels. Systemic content, particularly at the primary level, should exemplify specific analytic networks. It is recommended that where unreasolvable mismatches occur, the systemic content be postponed until a later time.

3. The proposed list is probably too extensive to allow adequate development of all the systemic concepts in a single kindergarten program, particularly if the first recommendation above is heeded. The number of systemic concepts can be reduced by using fewer examples of each analytic concept or by adopting fewer analytic concepts. Development of concepts in primary children requires experience with a number of examples.[4] While the optimal number of examples is not known, it would seem wise not to cut the margin too thin on the first pass. Thus, in order to allow time for a sufficient number and variety of particular examples of each systemic concept, it is

[4]Examples are not necessarily real world objects and events. Linguistic usage of concept labels can also function as examples. Although some real world examples are undoubtedly necessary at the primary level, appropriately structured linguistic examples can probably make a considerable contribution.

recommended that the number of systemic concepts be reduced by adopting fewer analytic concepts for emphasis in the kindergarten program.

4. Although analytic concepts are the most broadly generalizable, many systemic concepts do have considerable generality in the variety of particular content to which they are applicable. Systemic concepts applicable in several of the particular subject matter areas covered in the list are sometimes employed only in one. For example, the variables "time of day" and "number" (page 29) could easily be employed in the living things areas as well as the universe area. To increase the probability of adequate mastery, it is recommended that the systemic concepts be explicitly employed in more than one subject matter area whenever possible.

5. The content list does not include any correlational rules (e.g., animals that eat grass have flat front teeth). It is assumed, however, that some concepts of this type will be included in the program. Specification of the correlational rules in which a variable is used is an important step in selecting variables to include. Thus, it is recommended that correlational rule concepts be specified before selection of variable concepts is made. For example, potentially useful correlational rules might relate kind of habitat and kind of body covering, kind of habitat and kind of part used for moving, kind of motion and kind of part used for moving, and temporal sequence and stage of development.

## CONCLUSION

This paper began with the formulation of the question, "What is the relation between content and process in the science curriculum?" This relation was defined in terms of analytic concepts. The development of generalizable strategies for processing information requires some characterization of the form of the information to be processed. Analytic networks such as those described above provide a basis for consistently organizing systemic content in standard forms. These forms can be gradually abstracted by the students under the guidance of verbal labels and definitions introduced at appropriate levels. This represents mastery of the analytic concepts themselves. The analytic concepts are then available as a mediating device for obtaining and/or organizing new information of the same forms.

Rather than an achievement apart from the mastery of concepts, facility with processes of science is viewed as the operational aspect of the mastery. The processes emerge as operations defined in terms of analytic concepts. As these are repeatedly exemplified at the systemic level, they are brought increasingly under the student's control. Mastery at the analytic level implies the ability to organize new information in an appropriate form employing procedures appropriate to that form, i.e., exemplifying the corresponding analytic operations. The operational aspect of analytic concepts will be treated in detail in subsequent papers.

If a science program is to have an impact beyond the mastery of specific systemic content, the selection and organization of that

content must be based on decisions at the analytic level. However, these decisions are not a sufficient basis for selecting systemic content. Additional criteria such as those proposed by Babikian (listed in Appendix A) are needed. Particularly important from a design point of view are criteria concerning the prerequisite relations with sets of higher level systemic content.

It should be added that no explicit criteria for selecting analytic concepts have as yet been developed. The selections of analytic concepts for the present paper were based on their occurrence in a highly regarded extant program and a subjective evaluation of their reasonableness and generality. The suggestions on page 9 might serve as a starting point for developing such criteria.

APPENDIX A

SUBJECT MATTER CONCEPTS
KINDERGARTEN SCIENCE PROGRAM

Elijah Babikian

November 1971

I. Criterion questions for the selection of K science concepts.

1. Are the concepts consonant with the intellectual maturity of the learners.

2. Can they be taught meaningfully by first-hand experiences.

3. Can they be taught by simple, low-cost, and safe materials.

4. Can they be taught by experiments which guide the learner to discover the concept himself.

5. Do they arouse and/or sustain students' interest.

6. Do they help the children to acquire specified inquiry skills.

7. Are they related to the immediate environment of children.

8. Do they represent all of the five subject matter domains: living things, non-living things, energy, earth, universe.

9. Do they represent all of the five levels of concept abstractions: properties of matter, diversities in nature, interaction in nature, change in nature, and development in nature.

10. Are they expandable, horizontally and vertically, in the upper grades.

## II. Concepts

| Subject Domain | Class Concepts | Attributes |
|---|---|---|
| Living things | Living things: | |
| | characteristics | moving, breathing, eating, growing, having babies. |
| | Animals: | |
| | locomotion | |
| | means | legs, fins, wings. |
| | mode | walking, swimming, flying, hopping, sliding, crawling. |
| | breathing | nostrils, gills. |
| | body covering | hairy, scaly, shell, feather, fur, skin. |
| | size | small/large, smaller/larger, smallest/largest. |
| | food | plant-eater, flesh-eater, plant and flesh eater. |
| | habitat | in water, in air, on land, in ground |
| | reproduction | born alive, hatched from an egg. |
| | development | larva, pupa, adult. |
| | Plants: | |
| | characteristics | not-moving (sessile)*, produce their own food (autotrophs). |
| | roots | going down, cylindrical, branched. |
| | stems | going up, cylindrical, branched. |

* Technical words in parentheses will not be used in instruction.

| Subject Domain | Class Concepts | Attributes |
|---|---|---|
| Living things (cont.) | leaves | flat, green, smooth. |
| | seeds | small, embryo, seed-coat. |
| | development | planting, watering, germination, seedling. |
| Non-living things | Non-living things | |
| | differences from living things. | cannot move, breath, grow, eat, have babies. |
| | Objects: | |
| | weight | light/heavy, lighter/heavier, lightest/heaviest, equal |
| | shape | spherical, cubical, cylindrical, conical, irregular. |
| | color | red, orange, pink, yellow, blue, white, black. |
| | texture | smooth, rough, soft, hard. |
| | Substances: | |
| | state | solid, liquid, gas. |
| | taste | sweet, salty, sour. |
| | odor | perfume, odorless. |
| | solubility | soluble/insoluble. |
| | Magnets | |
| | kinds | bar, horseshoe. |
| | properties | attract, repel, similar/different poles, magnetic/non-magnetic. |

| Subject Domain | Class Concepts | Attributes |
|---|---|---|
| Energy | Heat: | |
| | sources | sun, electricity, fuel, friction. |
| | effects: | hot/cold, hotter/colder, hottest/coldest. |
| | on ice | melting, heating, boiling, vaporizing. |
| | on paper | burning, smoke, fire, ash. |
| | on wire | long/short, longer/shorter, longest/shortest, equal. |
| | measurement | thermometer, temperature, going up/going down. |
| Earth | Parts | land, water, air. |
| | Weather | rainy, stormy, windy, foggy, smoggy, sunny. |
| | Water cycle | evaporation, condensation, clouds, rain. |
| | Natural surface | mountainous, valley, desert, forest, ocean, lake, river. |
| | Constructions | tunnels, bridges, freeways, houses. |
| Universe | Sun | |
| | appearance | circular, shiny, bright, dull. |
| | distance | far/near, farther/nearer, farthest/nearest. |
| | position | horizon, east, west, north, south, right, left, overhead. |
| | time | day, night, morning, noon, afternoon, evening. |

| Subject Domain | Class Concepts | Attributes |
|---|---|---|
| Universe (cont.) | Moon | |
| | appearance | circular, full-moon, crescent, rugged. |
| | position | in air, in space, beyond. |
| | Stars | |
| | appearance | sparkling, twinkling |
| | number | numerous/few. |

APPENDIX B

ORGANIZATION OF PROPOSED SYSTEMIC
CONTENT IN TERMS OF ANALYTIC CONCEPTS

BIOLOGICAL SCIENCE CONTENT

CLASS VARIABLE AND VALUE CONCEPTS

| Variable name [1,2] | Values | Elements Characterized[3] |
|---|---|---|
| type of living thing | plant | examples of plants and animals |
| | animal | |
| type of body covering | feathers<br>hair<br>scales<br>skin (only)<br>shell | examples of animals |
| type of breathing (opening) | gills<br>nostrils | examples of animals |
| means of locomotion | fins<br>legs<br>wings | examples of animals |
| type of motion | walking<br>swimming<br>flying<br>hopping<br>sliding<br>crawling | examples of animals |
| mode of reproduction | hatching<br>giving "live birth" | examples of animals |
| type of habitat | in water<br>on land<br>in air<br>in ground | examples of plants and animals |

[1]Names in parentheses were not present in the original list and reflect selection of the current writer.

[2]Any class or activity concept can form the basis for a variable with values "is an x," " is not an x," or "does x," or "does not do x." Such dichotomous variables are not included in this list.

[3]If values were used to <u>define</u> a class, this is noted by underlining the class name.

| Variable name | Values | Elements characterized |
|---|---|---|
| type of food eaten | flesh<br>plant<br>plant & flesh | examples of animals |
| stage of growth | larva<br>pupa<br>adult | examples of animals |
| | seed<br>germination<br>seedling | examples of plant plants |

WHOLE-PART CONCEPTS

| Complex element | Part | Function[4] |
|---|---|---|
| animal | body covering<br>skin<br>feathers<br>scales<br>hair<br>fur<br>shell | |
| animal | legs<br>fins<br>wings | moving |
| animal | gills<br>nostrils | breathing |
| plant | roots<br>stems<br>leaves<br>seeds | |
| seed | embryo<br>seedcoat | |

[4] The entries in this column are also activities of the complex elements. This need not be the case. More specialized functions could be specified.

ACTIVITY CONCEPTS

| Activity | Elements or class characterized[5] |
|---|---|
| moving (self propelled)<br>eating<br>growing<br>having babies | animals |
| walking<br>swimming<br>flying<br>hopping<br>sliding<br>crawling<br>giving birth "live"<br>hatching | examples of animals |
| breathing | animals |
| producing own food | plants |
| germinating | examples of plants |

DESCRIPTIVE VARIABLE AND VALUE CONCEPTS

| Variable Name | Values | Elements Characterized |
|---|---|---|
| size | small<br>large | seeds |
| shape | cylindrical<br>flat | roots, stems,<br>leaves |
| (form) | branched | roots, stems |
| texture | smooth | leaves |
| color | green | leaves |
| (whether living or non-living) | living<br>non-living | animals, plants |
| (orientation) | going up<br>going down | stems<br>roots |

[5]Underlined terms are classes defined in terms of the activity.

PROCESS-STAGE-EVENT-CONCEPTS

| Process | Stages | Events |
|---|---|---|
| animal growth | larva<br>pupa<br>adult | |
| plant growth | seed<br>seedling | germination |

CLASS CONCEPTS

| Class Name | Relevant variable | Class definition: Defining values |
|---|---|---|
| animals | | moves by itself<br>has babies<br>breaths<br>eats<br>grows |
| plants | | does not move by itself<br>produces own food |
| legs<br>fins<br>wings<br>nostrils<br>gills<br>feathers<br>hair<br>scales<br>skin<br>shell<br>fur<br>body covering | | |
| food | | |

Class Definition

| Class name | Relevant variable | Defining values |
|---|---|---|
| flesh-eater | | |
| plant-eater | | |
| flesh and plant eater | | |
| larva | | |
| pupa | | |
| adult | | |
| stems | (orientation) | going up |
| | shape | cylindrical |
| | (form) | branched |
| roots | (orientation) | going down |
| | shape | cylindrical |
| | (form) | branched |
| leaves | shape | flat |
| | color | green |
| | texture | smooth |
| seeds | size | small |
| embyro | | |
| seedcoat | | |
| seedling | | |
| babies | | |
| habitat | | |
| water | | |
| air | | |
| land | | |
| ground | | |

## PHYSICAL SCIENCE CONTENT

### DESCRIPTIVE VARIABLES AND VALUES

| Variable Name | Values | Elements Described |
|---|---|---|
| (living or nonliving) | living<br>nonliving | examples of objects |
| weight | light,-er,-est<br>heavy, -er, -est<br>equal | examples of objects |
| shape | spherical<br>cubical<br>cylindrical<br>conical<br>irregular<br>circular<br>cresent | examples of objects seen |
| color | red<br>orange<br>pink<br>yellow<br>blue<br>white<br>black | examples of objects |
| texture | smooth<br>rough<br>rugged | examples of objects<br>moon |
| (hardness) | hard<br>soft | examples of objects |
| state | solid<br>liquid<br>gas | examples of substances (samples) |
| taste | sweet<br>salty<br>sour | examples of substances (samples) |
| odor | perfume<br>odorless | examples of substances (samples) |
| solubility | soluble<br>insoluble | examples of substances (samples) |

| Variable Name | Values | Elements described |
|---|---|---|
| (magnetic characteristic) | magnetic<br>non-magnetic | |
| (magnetic interaction) | attract<br>repel | |
| (temperature) | hot,-er,-est<br>cold,-er,-est | |
| (length) | long,-er,-est<br>short,-er,-est | wire |
| (motion) | going up<br>going down | liquid column of thermometer |
| (illumination) | bright<br>dull | sun |
| distance | far,-ther,-thest<br>near, -er,-est<br>beyond | sun<br>moon |
| location | in space<br>in air? | moon |
| number | few<br>numerous | stars |
| (constancy of light) | sparkling<br>twinkling | stars |
| time (of day) | day<br>night<br>morning<br>noon<br>afternoon<br>evening | |
| position | east<br>west<br>north<br>south<br>right<br>left<br>overhead | |

CLASS VARIABLE AND VALUE CONCEPTS

| Variable name | Values | Elements described |
|---|---|---|
| (kind of magnet) | horseshoe | examples of magnets |
| sources of heat | sun<br>electricity<br>fuel<br>friction | |
| kind of natural feature of earth's surface | mountain [ous]<br>valley<br>desert<br>forest<br>ocean<br>lake<br>river | |
| kind of construction (man-made feature) | tunnels<br>bridges<br>freeways<br>houses | |

PART-WHOLE CONCEPTS

| Complex Element | Part | Characteristics or function[7] |
|---|---|---|
| Earth | land<br>water<br>air | |
| magnet | pole | |
| fire(?)[6] | smoke<br>ash<br>(fuel) | |

[6]The phenonenon of burning could be treated as a part-whole concept or process-stage concepts. However, the systemic concepts listed do not seem to completely fit either.

[7]It seems doubtful that the "function" of a part plays the same rule in physical science as in biological science. It seems appropriate only when dealing with mechanical devices, etc. In other cases, the term characteristics seems more applicable.

PROCESS-STAGE-EVENT CONCEPTS

| Process | Stages | Events |
|---|---|---|
| heating | social | |
| | | melting |
| | liquid | |
| | | vaporizing (evaporating) |
| water cycle | | |
| | | evaporation |
| | cloud | condensation |
| | rain/snow | |
| burning(?)[8] | paper | |
| | | (add)heat |
| | fire | |
| | ash | |

CLASS CONCEPTS

| Class name | Class description | |
|---|---|---|
| | Relevant variables | Defining values |
| non-living things | | cannot move<br>cannot grow<br>cannot breathe<br>cannot eat<br>cannot have babies |
| object | | |
| magnet | | |
| fuel | | |

[8]The phenomenon of burning could be treated as part-whole concepts or process-stage concepts. However, the systemic concepts listed do not seem to completely fit either.

| Class name | Class description | |
|---|---|---|
| | Relevant variables | Defining values |
| mountain | | |
| valley | | |
| desert | | |
| forest | | |
| ocean | | |
| lake | | |
| river | | |
| tunnel | | |
| bridge | | |
| freeway | | |
| house | | |
| smoke | | |
| fire | | |
| ash | | |
| cloud | | |
| rain | | |
| fog | | |
| smog | | |
| water | | |
| watercycle | | |
| ice | | |
| liquid | | |
| solid | | |
| gas | | |
| paper | | |
| wire | | |
| thermometer | | |
| earth | | |
| sun | brightness | shiny, bright |
| | distance | far (?)[9] |
| | position | |

[9] It is not clear how the listed values are to be used.

| Class name | Class description | |
|---|---|---|
| | Relevant variables | Defining values |
| moon | shape | circular (?)<br>full moon<br>crescent |
| | texture | rugged |
| | position | in space, beyond |
| stars | constancy of light<br>number | twinkling, sparkling<br>numerous |

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