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ABSTRACT

This paper describes how the learning cycle leads students to become more skilled reasoners. The three phases of the learning cycle are described and examples and goals of each are provided. Information is also offered on the three types of learning cycles: the descriptive; the empirical-inductive; and the hypothetical-deductive. Each is described in terms of: (1) how it addresses the phases of exploration, term introduction, and concept application; (2) the steps used in preparing and using the cycle; (3) its application to a specific topic area, i.e., skull structure/function, air pressure, and transportation. If correctly used, it is contended that the learning cycle will provide the opportunity for students to reveal their prior conceptions and to test them in an open atmosphere. References are included and an appendix contains both teacher and student materials for the activities which were described in the section on the three types of learning cycles. (ML)

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Integrating Research on Misconceptions, Reasoning Patterns and Three Types of Learning Cycles

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Introduction

A recent trend in science education research has emerged which emphasizes the role of prior "misconceptions" in the acquisition of important scientific concepts (e.g. Driver, 1981,1983; Posner, Strike, Hewson, and Gertzog, 1982; Anderson and Smith, in press; Hewson and Hewson, 1984). Misconceptions, defined as knowledge derived from extensive personal experience which is incompatible with established scientific theory (cf., Halloun and Hestenes, 1985a,1985b), are presumed to be deeply-rooted, instruction-resistant impediments to the acquisition of scientifically valid concepts. The overthrow of these misconceptions presumably requires students to move through a phase in which a mismatch between the misconception and the scientific conception exists and provokes a "cognitive conflict" or state of mental "diseqilibrium" (cf. Posner et al., 1982).

Importantly these misconceptions are not viewed as simply minor misunderstandings or trivial gaps in knowledge that students may have forgotten or cognitively "misplaced". Rather they are allegedly embedded in "highly robust" alternative conceptual frameworks for the interpretation of natural events many of which were seriously advocated by leading intellectuals of the past (cf., Halloun and Hestenes, 1985b; Viennot, 1979). Investigators view the cognitive overthrow of these alternative conceptual frameworks as similar to scientific paradigm shifts of the past (in the Kuhnian sense) such as the shift from a geocentric to a helocentric model of the solar system, an Aristotelian view of motion to a Newtonian view, or an Old Testament view of special creation to a Darwinian view of evolution.

Most research into student misconceptions has centered in the physical sciences, primarily physics, in areas such as mechanics (e.g. Aguirre and

Erickson, 1984; Champagne and Klopfer, 1982; Gunstone and White, 1981; Halloun and Hestenes, 1985a,1985b; Minstrell, 1982; Trowbridge and McDermott, 1980; Viennot, 1979), electricity (Idar and Ganiel, 1985; Fredette and Lockhead, 1980) and heat and temperature (Moreira and Santos, 1981; Rosenquist, Popp and McDermott, 1982). The general findings of such studies is typified by results of the Halloun and Hestenes (1985a,1985b) study in which they found that college students' misconceptions about motion significantly influenced achievement and conventional instruction produced very little change in those initial misconceptions.

There is much to be said for such a view of the educational process and the recent research into students' misconceptions of the physical world seems promising. The implied teaching and research agenda is clear. Identify important topics in science instruction, identify students' alternative conceptual frameworks/misconceptions, design models of instruction and specific lessons to overthrow their misconceptions and implant scientifically valid conceptions in their place. Posner et al. (1982) suggest the following four criteria must be met for success:

1. Students must become dissatisfied with their existing conceptions.
2. Students must achieve a minimal understanding of the scientific conception.
3. The scientific conception must appear plausible.
4. Students must see the scientific conception as useful in a variety of situations.

Another major area of research in science education has focused attention on students' reasoning abilities, or more importantly their general lack of reasoning abilities. Lawson (1985) recently reviewed over two decades of research into students' reasoning patterns and concluded that many high school and even college students do not develop skill at using important formal, hypothetico-deductive reasoning patterns (e.g., the control of variables, proportional, probabilistic, and correlational reasoning) beyond very familiar and concrete contexts. Further he concluded that the instruction of materials and methods do exist to significantly increase the percentage of students who successfully utilize these reasoning patterns in a more general sense. Data were reviewed that suggested that improved reasoning skills will raise general academic achievement and should pay off in terms of a better informed, more thoughtful and effective citizenry as well.

In general, the improvement of reasoning skills arises from situations in which students are engaged in exchanges of contradictory viewpoints in which reasons and evidence are actively sought to resolve the contradiction (i.e., arguments). Argumentation thus provides the raw material from which forms of argumentation (i.e., patterns of reasoning) become abstracted from the contexts of the particular arguments in which they are embedded. A person skilled in argumentation is skilled in reasoning. Consider, for example, the classic forms of argumentation shown in Figure 1 and discussed in textbooks of argumentation, critical thinking and debate (cf., Freeley, 1976; Olson, 1969; Shurter and Pierce, 1966; Ziegelmueller and Dause, 1975).

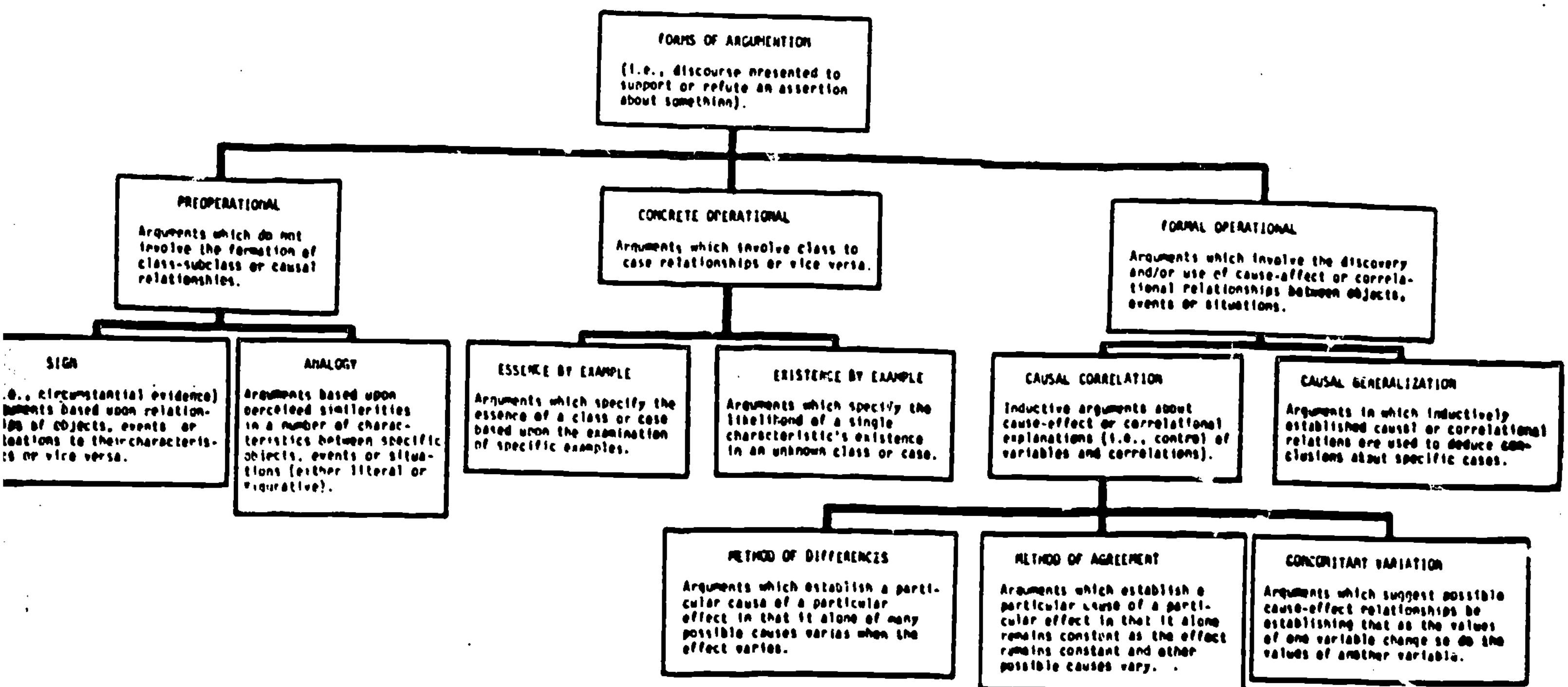

Figure 1
Forms of Argumentation

Figure 1 lists eight well known forms of argumentation classified by Lawson and Kral (1985) as requiring either preoperational, concrete, or formal operational patterns of reasoning. Comprehension or generation of arguments by sign and analogy are not considered to require concrete or formal reasoning because class-subclass or causal relationships are not involved. In contrast, arguments by example (essence and existence) are considered to require concrete operational reasoning in that class-subclass relationships are involved. Arguments of causal correlation and causal generalization are judged to involve formal reasoning, because evidence is sought to test hypothesized causal and/or correlational relationships.

These arguments are basically of two types -- inductive and deductive. Inductive arguments are termed arguments by causal correlation. There are three types of arguments by causal correlation called method of differences, method of agreement and concomitant variation. The methods of differences and agreement require the formal operational pattern of the isolation and control of variables (in fact these are psychologically one and the same), while generating an argument of concomitant variation requires use of the formal pattern known as correlational reasoning. The one form of deductive argument based upon cause-effect or correlational relationships is known as causal generalization in which inductively established causal or correlational relationships are used to deduce conclusions about specific cases.

The Learning Cycle

The central thesis of the present paper is that the research tradition into student misconceptions and that into student reasoning patterns both imply the same method of instruction because examining the adequacy of prior conceptions forces one to argue about and reflect on the reasons for those conceptions which in turn provides the opportunity to abstract the forms of argumentation (patterns of reasoning) from the external and internal arguments that arise when opposing conceptions come face to face. The generally accepted method of instruction to provoke students to reveal and debate prior conceptions and to improve reasoning skills is based in part upon Piaget's notion of equilibration and is called the learning cycle (cf., Atkin and Karplus, 1962; Karplus, Lawson, Wollman, Appel, Bernoff, Howe, Rusch and Sullivan, 1976). The learning cycle consists of three phases called exploration, term introduction, and concept application. The learning cycle phases can be carried out to meet precisely the four criteria listed by Posner et al. (1982) to help students overthrow their misconceptions and become more skilled reasoners. In other words, correct use of the learning cycle provides the opportunity for students to reveal their prior conceptions and the opportunity to debate and test those conceptions which can result not only in the improvement of students' conceptual knowledge but also in an increased awareness of and ability to use the reasoning patterns involved in the generation and test of that conceptual knowledge.

Although there are the three types of learning cycles (not all equally effective at producing disequilibrium, argument, and improved reasoning) they all follow the general three phase sequence of exploration, term introduction, and concept application. To introduce you to that sequence consider the following alternative approaches to beginning a general science course's section on density. Would you begin by:

(a) Presenting a film in which one cubic decimeter blocks of various solid materials are carefully weighed and the volumes of one kilogram blocks of the same materials are calculated from the dimensions, thus allowing two density determinations of each material to be compared.

(b) Arranging for a laboratory period in which your students could use rulers, calipers, graduated cylinders, and balances to determine the volumes and masses of objects of widely differing shapes and various materials for plotting on a graph of volume vs. mass.

(c) Discussing with your students their experiences with floating and sinking objects, including themselves when they swim or play in the water.

(d) Presenting an explanation with demonstrations in which various specimens of material are weighed, their volumes are found by appropriate means, and you finally calculate the density of each material.

(e) Arranging for a laboratory period during which your pupils will make accurate measurements of density of carefully machined blocks and rods of measurements.

Certainly the resources available to you and the preparation of your students will influence your choice. Compare my comments below with yours.

(a) Films are popular ways of introducing new topics. In this case, the film presents observations the students might make in the laboratory if they had access to the expensive materials. We would recommend the film be used after a laboratory period if a laboratory is available. Films raise questions, provoke inquiry, or present contradictions to prior conceptions less effectively than first hand experiences. Since paying attention to the film preempts their initiative, few students watching a film for the first time would think critically about what they observe. Furthermore, seeing a picture of an object or process does not carry the impact of seeing the object or influencing the process oneself.

(b) An approach of this kind, where the students have a great deal of freedom to use their own judgment, try out their own ideas, and learn from their own mistakes as they gain practical experience with specimen and instruments they will use for the definition of density later, is highly recommended. The teacher can circulate among the students and identify any misconceptions they might have, as well as identify the reasoning patterns they use.

(c) Even though this approach involves students with their own past experience, the relation between density and bouyancy is not so very obvious that it is the focus of a good beginning activity. It would be better at a later time, after density has been defined, to apply the concept to a comparison of solid and liquid materials.

(d) This direct explanation would be very inappropriate for the introduction of a new topic because it takes for granted that the students have a good grasp of volume, mass, and the concept of ratio.

(e) This type of laboratory makes it more difficult for students to ask their own questions and take responsibility for satisfying their own curiosity. The reasons for making careful observations and calculating the density at this time will not be clear to many students. Such a laboratory activity would be more appropriate at a later stage in the learning sequence, but even then it might focus more attention on some of the potential errors in measurement.

The recommended approach in (b) is an example of an exploratory activity upon which later conceptual understandings can be built. It represents the EXPLORATION phase of the learning cycle. During EXPLORATION, the students learn through their own actions and reactions in a new situation. In this phase they explore new materials with minimal guidance. The new experience should raise questions or complexities that they cannot resolve with their present conceptions or accustomed patterns of reasoning. In other words, it provides the opportunity for students to voice potentially conflicting and at least partially inadequate ideas that can spark debate and an analysis of the reasons for their ideas. Exploration also leads to the identification of a pattern of regularity in the phenomena explored such as the straight line which occurs on a graph when volume is plotted against mass of brass objects of varying sizes and shapes.

The second phase, TERM INTRODUCTION, starts with the introduction of a new term or terms, such as density, that is used to label the pattern discovered during EXPLORATION. The term(s) may be introduced by the teacher, the textbook, a film, or another medium. This step should always follow EXPLORATION and relate directly to the pattern discovered during the EXPLORATION activity. The film in alternative (a) above or the lecture in alternative (d) could be part of a TERM INTRODUCTION session following laboratory activities like (b). Students should be encouraged to identify as much of a new pattern as possible before it is revealed to the class, but expecting students to discover all of the complex patterns of modern science is unrealistic.

In the last phase of the learning cycle, CONCEPT APPLICATION, students apply the new term and/or reasoning pattern to additional examples. After the introduction of density, for instance, the accurate measurement of densities in alternative (e) would be appropriate as would activities involving floating and sinking (c), or the densities of liquids and gases.

The CONCEPT APPLICATION phase is necessary for some students to abstract the pattern from its concrete contexts and/or to generalize it to other situations. Without a number and variety of applications, the pattern may not be abstracted from the contexts or its generality may remain restricted to the context used during its definition.

Note that the last phase is referred to as CONCEPT APPLICATION while the previous phase was labeled TERM INTRODUCTION. I am defining a concept as a mental pattern (i.e., a pattern in ones mind) that is accessed by a verbal or written symbol (i.e., a term). Thus a concept is the abstracted pattern plus the term. A person can have the pattern _or_ the term but he does not have the _concept_ until he has both. Teachers can introduce terms to students but students must abstract the pattern themselves. EXPLORATION provides the opportunity for students to discover the pattern. TERM INTRODUCTION provides the teacher with the opportunity to introduce the term and it provides students an initial opportunity to link the pattern with the term thus acquiring the concept. Finally, CONCEPT APPLICATION allows students repeated opportunities to abstract the pattern and to discover applications of the new concept in new contexts.

Three Types of Learning Cycles

Learning cycles can be classified as one of three types --descriptive, empirical-inductive, and hypothetical-deductive. The essential difference among the three types of learning cycles is the degree to which students either gather data in a purely descriptive fashion (not guided by explicit hypotheses they wish to test) or initially set out to test hypotheses in a controlled fashion. The three types of learning cycles, therefore, represent three points along a continuum from descriptive to experimental science. They obviously place differing demands on student initiative, knowledge, and reasoning skill. In terms of student reasoning ability, descriptive learning cycles require only concrete operational skills while hypothetical-deductive learning cycles demand use of formal operational skills. Empirical-inductive learning cycles are intermediate and involve reasoning that can best be termed transitional.

In descriptive learning cycles students discover and describe an empirical patterns within a specific context (exploration); the teacher gives it a name (term introduction); and the pattern is then identified in additional contexts (concept application). This type of learning cycle is called descriptive because the students and teacher are merely describing what they observe without attempting to generate hypotheses to explain their observations. Descriptive learning cycles answer the question, What?, but do not raise the question, Why?

In empirical-inductive learning cycles students again discover and describe and empirical pattern in a specific context (exploration); but they go further by generating (inducing) possible causes for that pattern. This requires the transfer of terms/concepts learned in other contexts to this new context (term introduction). The terms may be introduced by students, the teacher, or both. With the teacher's guidance, the students then sift through the data gathered during the exploration phase to see if the hypothesized causes are consistent with those data and other known phenomena (concept application). In other words, observations are made in a descriptive fashion, but this type of learning cycle goes further to induce and initially test a cause(s), hence the name empirical-inductive.

The third type of learning cycle, hypothetical-deductive, is initiated with the statement of a causal question to which students are asked to generate possible answers (hypotheses). Student time is then devoted to deducing the logical consequences of these hypotheses and explicitly designing and conducting experiments to test them (exploration). The analysis of experimental results allows for some hypotheses to be rejected, others retained, and terms to be introduced (term introduction). Finally the relevant concepts and reasoning patterns that are involved and discussed may be applied in other situations at a later time (concept application). The explicit generation and test of hypotheses through a comparison of logical deductions with empirical results is required in this type of learning cycle hence the name, hypothetical-deductive.

The following steps are utilized in preparing and using the three types of learning cycles.

1. Descriptive Learning Cycle

    1. the teacher identifies some empirically derived* concept he/she wishes to teach

    2. the teacher identifies some phenomenon that involves the pattern upon which the concept is based

    3. Exploration Phase: the students explore the phenomenon and attempt to discover and describe the pattern

*See Karplus et al., 1976 for a method of classifying concepts as concrete or formal based upon the extent to which their meaning is derived from direct experience (concrete concepts) or through relationships with othe concepts within hypothetical conceptual systems (formal concepts).

4. Term Introduction Phase: the students report the data they have gathered; and they and/or the teacher describe the pattern; the teacher then introduces a term to refer to the pattern
5. Concept Application Phase: additional phenomena are discussed and/or explored that involve the same concept

2. Empirical-Inductive Learning Cycles
    1. the teacher identifies some concept he/she wishes to teach
    2. the teacher identifies some phenomenon that involves the pattern upon which the concept is based
    3. Exploration Phase: the teacher raises a descriptive and causal question
    4. students gather data to answer the descriptive question
    5. data to answer the descriptive question are put on the board
    6. the descriptive question is answered and the causal question is raised
    7. hypotheses are advanced to answer the causal question and the already gathered data are examined to initially test it
    8. Term Introduction Phase: terms are introduced that relate to the explored phenomenon and hypothesized explanation
    9. Concept Application Phase: additional phenomena are discussed or explored that involve the same concept(s)

3. Hypothetical-Deductive Learning Cycles
    1. the teacher identifies some concept or reasoning pattern he/she wishes to teach
    2. The teacher identifies some phenomenon that involves the pattern upon which the concept is based

3. Exploration Phase: the students explore a phenomenon that raises the causal question or teacher raises the causal question
4. in a class discussion hypotheses are advanced and either students are told to work in groups to deduce implications and design experiments or this step is done in a class discussion
5. the students conduct the experiments
6. Term Introduction Phase: data are compared, analyzed, terms are introduced and conclusions are drawn
7. Concept Application Phase: additional phenomena are discussed or explored that involve the same concepts

Descriptive Learning Cycles

Recall it was stated earlier that the three types of learning cycles are not equally effective at generating disequilibrium, argumentation and the use of reasoning patterns to examine alternative conceptions/misconceptions. Descriptive learning cycles are essentially designed to have students observe a small part of the world, discover a pattern of regularity, name it and look for the pattern elsewhere. Little or no disequilibrium may result as students will most likely have few if any erroneous preconceptions. Graphing a frequency distribution of the length of a sample of a species of sea shells will allow you to introduce the term normal distribution but will not provide much argumentation among your students. A descriptive learning cycle into skull structure/function (see appendix) allows the teacher to introduce the terms herbivore, omnivore, and carnivore and also allows for some student argumentation as they put forth and compare ideas about skull structure and possible diets. Yet seldom are ideas hotly debated and hard evidence is not sought in descriptive learning cycles.

Empirical-Inductive Learning Cycles

On the other hand, consider the following empirical-inductive (EI) learning cycle which involves the concept of air pressure. It, like other EI learning cycles, requires students to do more than describe a phenomenon. An explanation is required. Explanation opens the door to a multitude of misconceptions, suction in this case, and the resulting arguments and analysis of evidence and reasoning patterns represent a near perfect example of how EI learning cycles can be used to promote disequilibrium and the development of conceptual knowledge <u>and</u> reasoning patterns.

To start, students invert a cylinder over a candle burning in a pan of water. They observe that the flame soon goes out and water rises into the cylinder. Two questions are posed. Why did the flame go out? Why did the water rise? The typical explanation students generate to answer these questions is that the flame used up the oxygen in the cylinder and left a partial vacuum which sucked the water in from below. This explanation reveals two misconceptions: (1) flames destroy matter thus produce a vacuum and (2) water rises due to a nonexistant force called suction. Testing of these ideas requires use of a formal hypothetico-deductive pattern of reasoning utilizing the isolation and control of variables. Example teacher and student materials prepared for this learning cycle are also found in the appendix.

Hypothetical-Deductive Learning Cycles

Like EI learning cycles, hypothetical-deductive (HD) learning cycles require explanation of some phenomenon, thus open up the possibility for the generation of alternative conceptions/misconceptions, disequilibrium and the resulting argumentation and analysis of data to resolve conflict. Unlike EI cycles, however, HD cycles, call for the immediate and explicit statement of alternative hypotheses to explain a phenomenon. In brief, a causal question is raised and students must explicitly generate alternative hypotheses, which in turn must be tested through the deduction of predicted consequences and experimentation. This places a heavy burden on student initiative and formal reasoning skills.

Consider, for example, the question of water rise in plants. Objects are attracted toward the center of the earth by a force called gravity, yet water rises in tall trees to the upper most leaves to allow photosynthesis to take place. What causes the water to rise in spite of the downward gravitational force? The following alternative hypotheses (alternative conceptions/misconceptions) were generated in a recent biology lab at Arizona State University: a) water evaporates from the leaves to create a vacuum which sucks water up, b) roots squeeze to push water up through one-way valves in the stem tubes, c) capillary action of water pulls it up like water soaking up a paper towel, and d) osmosis pulls water up.

Of course equipment limitations keep some ideas from being tested but the "leaf evaporation" hypothesis can be tested by comparing water rise in plants with and without leaves requiring the reasoning patterns of the isolation and control of variables. The "root squeeze" hypothesis can be tested by comparing water rise in plants with and without roots; and the "one-way valve" hypothesis can be tested by comparing water rise in right-side-up and up-side-down stems. Results allow rejection of some of the hypotheses and not others. The survivors are considered "correct", for the time being, at least, just as is the case in doing "real" science, which of course is precisely what the students are doing. Following the experimentation, terms such as transpiration can be introduced and applied elsewhere as is the case for all types of learning cycles. Example student materials for this learning cycle are included in the appendix.

The water rise in plants question may involve misconceptions but few students would feel strongly committed to any one point of view as these points of view are not likely to be tied to others which do have strong intellectual and/or emotional committments. But consider the case of evolution and special creation. Here committments often run very deep, thus a hypothetical-deductive learning cycle into the question -- Where did present-day life forms come from? -- can stir up considerable controversy, argumentation and reflective thought.

To introduce the concept of evolution using a hypothetical-deductive learning cycle once again we start with alternative hypotheses. At least three can be offered: a) Present day organisms were all created during a brief period of time by an act of special creation (i.e., God). Further, organisms were created by God in virtually the same forms as we see today. b) Present day organisms have spontaneously arisen from dead material throughout time including the present. For example, dead, rotting meat will produce fly larvae. Old rags in damp places will produce baby rats. c) Present day organisms have evolved from very few simple organisms gradually over vast periods of time. Students may generate other hypotheses but at least these three should be mentioned.

Notice that an interesting thing has been done. What represents the revealed truth for some people, namely special creation, is treated not as truth but rather simply as one of three alternative hypotheses. The recognition that alternative hypotheses can in fact exist, as opposed to revealed truths, represents a crucial step.

Once the hypotheses have been generated, they must be tested. The hypothesis of spontaneous generation leads to replication or discussion of the classic experiments of Spallanzani, Needham, and Pasteur and to its ultimate rejection. The hypotheses of special creation and evolution lead to consideration of the process of geologic sedimentation, fossil formation, and to the fossil record. Clearly the predicted fossil records for the two hypotheses are quite different, even contradictory, in some respects. Special creation predicts a pattern of fossil remains with no fossils in the deepest, oldest sedimentary layers (before special creation), all forms of simple and complex life in the layer immediately following creation, with the remaining layers up to the surface showing fewer and fewer life forms as some become extinct. Evolution also predicts no life in the deepest, oldest layers (before evolution began) but the next layers should contain very few and only the simplest life forms (e.g., single-cell bacteria, blue-green algae), with the progressively higher, younger layers showing gradually more complex, larger and more varied life forms.

Students thus have opposing hypotheses and dramatically different predictions. Which is correct? To find out the students simulate a hike in the Grand Canyon and observe fossils found in six sedimentary layers from the Canyon walls. The fossils reveal a pattern like that predicted by the evolution hypothesis and clearly unlike that predicted by the special creation hypothesis. Therefore support for the evolution hypothesis has been obtained. Subsequent activities allow the concept of evolution to be applied in other contexts. Most certainly one such activity would be a learning cycle into the concept of natural selection.

Concluding Remarks

In summary the major thesis of this paper is that science instruction has two major goals: (1) to help students develop skill in using the reasoning patterns involved in generating and testing hypotheses and (2) to help them acquire a set of scientifically valid conceptions. It is argued that the most appropriate way, perhaps the only way, to accomplish both these objectives is to teach in a way that allows students to reveal their prior conceptions and test them in an atmosphere in which ideas are openly generated, debated, and tested with the means of testing becoming an explicit focus of classroom attention. The learning cycle method of instruction can allow this to happen.

References

Aguirre, J., & Erickson, G. (1984). Students' conceptions about the vector characteristics of three physics concepts. Journal of Research in Science Teaching, 21(5), 439-457.

Anderson, C.W., & Smith, E.L. Teaching science. In V. Koehler (Ed.), The Educator's Handbook: A Research Perspective. New York: Longman, Inc. (in press).

Atkin, J.M., & Karplus, R. (1962). Discovery or invention? Science Teacher 29(5), 45.

Champagne, A., Klopfer, L., & Gunstone, R. (1982). Cognitive research and the design of science instruction. Educational Psychologist, 17(1), 31-53.

Driver, R. (1981). Pupils' alternative frameworks in science. European Journal of Science Education, 3(1), 93-101.

Driver, R. (1983). The Pupil as Scientist. Milton Keynes, England: The Open University Press.

Fredette, N.H., & Lockhead, J. (1980). Student conceptions of simple circuits. The Physics Teacher, 18(3), 194-198.

Freeley, A.J. (1976). Argumentation and Debate. Belmont, California: Wadsworth.

Gunstone, R.F., & White, R.T. (1981). Understanding of gravity. Science Education, 65(3), 291-299.

Halloun, I.A., & Hestenes, D. (1985a). The initial knowledge state of college physics students. The American Journal of Physics, 53(11), 1043-1055.

Halloun, I.A., & Hestenes, D. (1985b). Common sense concepts about motion. The American Journal of Physics, 53(11), 1056-1065.

Hewson, P.W., & Hewson, M.G.A. (1984). The role of conceptual conflict in conceptual change and the design of science instruction. Instructional Science, 13, 1-13.

Idar, J., & Ganiel, U. (1985). Learning difficulties in high school physics: Development of a remedial teaching method and assessment of its impact on achievement. Journal of Research in Science Teaching, 22(2), 127-140.

Karplus, R., Lawson, A.E., Wollman, W., Appel, M., Bernoff, R., Howe, A., Rusch, J.J., & Sullivan, F. (1976). Science Teaching and the Development of Reasoning: A Workshop. Berkeley: Regents of the University of California.

Lawson, A.E. (1985). A review of research on formal reasoning and science teaching. Journal of Research in Science Teaching, 22(7), 569-618.

Lawson, A.E., & Kral, E.A. (1985). Developing formal reasoning through the study of English. The Educational Forum 49(2), 212-226.

Moreira, M.A., & Santos, C.A. (1981). The influence of content organization on students' cognitive structure in thermodynamics. Journal of Research in Science Teaching, 18(6), 525-531.

Olson, R.G. (1969). Meaning and Argument: Elements of Logic. New York: Harcourt, Brace and World.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. Science Education, 66(2), 211-227.

Rosenquist, M., Poop, B.D., & McDermott, L.C. (1982). Some elementary conceptual difficulties with heat and temperature. Paper presented at the National Meeting of the American Association of Physics Teachers, San Francisco, CA.

Shurter, R.L., & Pierce, J.R. (1966). Critical Thinking: Its Expression in Argument. New York: McGraw Hill.

Trowbridge, D.E., & McDermott, L.C. (1980). Investigation of student understanding of the concept of velocity in one dimension. American Journal of Physics, 48(12), 1020-1028.

Viennot, L. (1979). Spontaneous reasoning in elementary dynamics. European Journal of Science Education, 1(2), 205-221.

Ziegelmueller, G.W., & Dause, C.A. (1975). Argumentation: Inquiry and Advocacy. Englewood Cliffs, N.J.: Prentice-Hall.

APPENDIX

TEACHER MATERIAL
SKULL STRUCTURE/FUNCTION

WHAT CAN BE LEARNED FROM SKULLS?

Synopsis

Students observe a variety of vertebrate skulls and attempt to identify the animal and what it eats. Through class discussion the relationships between skull characteristics and implied functions are explored and the terms herbivore, omnivore, carnivore, nocturnal, diurnal, and niche are introduced. This is a descriptive learning cycle.

Suggested Time

Two class periods

Background Information

Vertebrate skulls reveal adaptations for specific functions. Large eye sockets, for example, accommodate large eyes needed for nocturnal activity. Eye sockets located on the sides of the head imply a similar positioning of the eyes for the good peripheral vision needed by prey animals, whereas a more frontal location implies good depth perception needed by predatory animals. Teeth also reveal adaptations. The teeth of herbivore are relatively flat for the grinding of plant material while the teeth of carnivores are more pointed and sharp for the grasping and tearing of flesh.

The purpose of this learning cycle is to provide students with an opportunity to observe skull characteristics and attempt to infer facts about the animal's food source and habitat (i.e., place where it lives) and to improve their ability to support or refute ideas through use of evidence and logical argumentation. It also provides you an opportunity to introduce the concepts of herbivore, omnivore, carnivore, and niche where niche is defined as an organism's role or function within a biological community.

Teaching Tips

Advance Preparation

1. A variety of skulls can be obtained from the Arizona Game and Fish Department.

2. Place a different skull at each of the 10 numbered stations.

Exploration

3. To introduce the lesson you may want to remind students of the work of paleontologists who are able to infer many things about the life style and habitat of ancient animals from only a very few fossil bones. Ask them for any examples of this sort of work that they may know of and what might be some of the clues paleontologists use to draw their inferences. Tell students that the lesson today will challenge them to draw inferences about the life style and habitat of a variety of vertebrate skulls located

throughout the room. Specific questions they should consider are: What type of food does this animal eat (e.g. plants, animals, or both) and what evidence exists for that inference (e.g. number, shape, size, location of teeth)? Is this animal active during the day, night, both? What is the evidence (e.g. size, location of eye sockets)? Is the animal a predator or prey? Why (e.g. eyes front for depth perception - predator, eyes to the side for peripheral vision - prey)? Make sure only to raise the questions during the introduction. Do not mention specific characteristics and inferences such as sharp teeth mean meat eater or eyes front means predator. Let the students discover these on their own. If they are not discovered you may mention them later during the concept introduction discussion.

Term Introduction

4. After students have gathered data on each skull, have them describe differences they observed. Start the discussion by holding up skull 1. Ask for ideas and evidence. Go on to skull 2, etc.

5. As the discussion begins to center on teeth, put the words the students use to describe them (tearing, crushing, grinding) on the board.

6. These teeth types will suggest function. Discuss this relationship. At the appropriate time introduce the terms herbivore, carnivore, omnivore and niche. Introduce the terms by stating the definitions first. Then state the term. For example say, "This animal has sharp teeth for tearing and no flat teeth for grinding. This implys that it eats only animals. An animal which eats other animals is called a carnivore." An animal that eats only plants is called a herbivore," etc.

7. Student attention to eye sockets will allow you to introduce the terms nocturnal and diurnal (e.g. "This animal has large eye sockets which implies that it has large eyes for night vision. An animal that is active during the night is called nocturnal.").

Concept Application

8. For concept application, provide opportunities for students to examine a variety of bones in addition to skulls and make inferences from their structure about their functions. For example, bird bones, fish bones, etc.

Biological Concepts

nocturnal
herbivore
carnivore
omnivore
niche
diurnal

Thinking Skills

observation
isolation of variables
inference
seeking and stating evidence

STUDENT MATERIAL
SKULL STRUCTURE/FUNCTION

WHAT CAN BE LEARNED FROM SKULLS?

Introduction

Do we need to see an entire animal to determine where it lives or what it eats? Sometimes we can use bones as clues to provide insight into possible answers to these questions. Observation is a key to understanding. What can be inferred by looking at skulls?

Objectives

1. To infer function and animal behavior from observation of skull characteristics.

2. To improve your ability to support or refute hypotheses through use of evidence and logical argumentation.

Materials

10 skulls of 10 different species of vertebrates.

Procedure

1. In your group go to a station and take about 5 minutes to carefully examine the skull.

2. Observe the size and shape of the overall skull as well as other characteristics of the teeth, eyesockets, brain case, etc. Record interesting observations on the data sheet. Make a sketch if you want.

3. Try to decide what kind of animal the skull came from and what type of food it eats and where it might have lived. What characteristics of this skull allow organisms of this type to be successful? What evidence do you have for your guesses?

4. Move to the next station when you are ready. (No more than two groups may work at one station simultaneously.)

TEACHER MATERIAL
AIR PRESSURE

WHAT CAUSED THE WATER TO RISE?

Synopsis

Students invert a cylinder over a candle burning in a pan of water. They observe that the flame soon goes out and water rises into the cylinder. They then attempt to explain their observations. Testing of these explanations leads to new explanations and increased understanding of combustion, air pressure and the nature of scientific inquiry. This is an empirical-inductive learning cycle.

Suggested Time

Two class periods

Background Information

The primary purpose of this learning cycle is to personally involve students in the use of science in an attempt to answer two questions which arise from first-hand observation.

A burning candle is held upright in an pan of water using a small piece of clay. Shortly after a cylinder is inverted over the candle and placed in the water, the candle flame goes out and water rises in the cylinder. These observations raise two major questions. Why did the flame go out? And why did the water rise? The generally accepted answer to the first question is that the flame "consumed" oxygen in the cylinder to a level at which too little remained to sustain combustion, thus causing the flame to die. The generally accepted answer to the second question is that the flame heated the air in the cylinder causing it to expand and causing some to escape out the bottom. When the flame went out, the remaining air then cooled and contracted creating a partial vacuum. This partial vacuum is then replaced by water rising into the cylinder until the air pressure pushing on the surface of water inside is equal to the air pressure pushing on the water surface outside.

This investigation is a particularly good way to introduce students to science as a hypothesis generating and testing enterprise as the hypotheses they invariably generate to answer the questions can be experimentally shown to be inadequate, therefore, must be modified through the use of both creative and rational thought processes and data gathering and analysis.

Students' initial misconceptions generally center around a theory which states that oxygen is "used up", therefore, creating a partial vacuum which "sucks" water into the cylinder. They fail to realize that when oxygen is "burned" it combines with carbon producing CO_2 rather than being destroyed (hence no partial vacuum can be created in this way). They also fail to understand that a vacuum cannot "suck" anything. Rather the force which causes the water to rise is a push from the relatively greater number of air molecules hitting the water surface outside the cylinder.

The experiments and discussions provide you with an opportunity to not only attempt to modify these misconceptions by introducing more satisfactory models of combustion and air pressure but, and more importantly, to introduce science as an intellectually stimulating and challenging way of trying to describe and explain nature.

Teaching Tips

Exploration

1. You may wish to initiate this lesson with a demonstration or simply let the students obtain the materials and get started on their own.

2. If you decide to demonstrate the phenomena procedure steps 4-5 can be done during the class discussion. If you let the students start on their own you will probably have to stop them after about 15-30 minutes for a discussion of their observations and ideas.

3. During the discussion, observations and ideas should be listed on the board. The most obvious questions are: Why did the flame go out? And Why did the water rise? The most likely explanation to the second question is that since the oxygen was "burned up? the water rose to replace the oxygen which was lost.

   Lead the students to realize that this explanation (hypothesis) predicts that varying the number of burning candles will not affect the level of water rise. Four candles, for instance, would burn up the available oxygen faster and go out sooner than one candle but they would not burn up more oxygen.

4. Have the students do this experiment and report results. The results, of course, will show that the water level is affected by the number of candles (the more candles the higher the water level). Their hypothesis, therefore, has been contradicted. At this point you should emphasize the need for an alternative explanation and ask students to propose one. This may be an excellent time for the bell to ring as no one may have a good alternative so you can challenge them to think up a new explanation as their homework assignment.

5. If someone does propose the "correct" explanation (i.e., the heated air escaped out the bottom, etc.) do not immediately tell the class it is correct. Rather treat it as just another hypothesis to be tested. Ask students to try to think of a way to test the hypothesis. They should realize that the hypothesis leads to the prediction that bubbles should be seen escaping out the bottom of the cylinder. (Note that it also leads to the prediction that the number of candles will affect the level of water rise because more candles will heat more air, therefore, more will escape which in turn will be replaced by more water.) Have the students repeat the experiment to see if bubbles can be seen. If no one proposes the correct explanation you will have to propose it yourself but again make sure that you do not give the students the impression that this is the correct explanation. Rather it is simply an idea you had that should be tested along with any other ideas that are generated. The conclusion that it is correct should come only after data have been gathered which are consistent with its predictions (e.g., bubbles, more candles - higher water rise, water rise after flame goes out while air cools).

Term Introduction

6. After such data have been gathered, you should carefully repeat your explanation of the phenomena introducing the term air pressure and a molecular model of gases which assumes air to be composed of moving particles that have weight and can bounce into objects (such as water) and push them out of the way. You may wish to discuss the common conception of "suction" in this context. The molecular model implies that suction (as a force that can suck up water) does not exist (i.e., the water is being pushed into the cylinder by moving particles of air rather than being sucked by some nonexistent force).

Concept Application

7. To allow students to apply the molecular model of gases and concept of air pressure to new situations provide each group a piece of rubber tubing, a syringe, a beaker and a pan of water. Instruct them to invert the beaker in the pan of water and fill it with water in that position with the mouth of the beaker submerged. Hint. Students will probably make futile efforts to force water through the tube into the beaker before discovering that they must extract the air through the tube.

8. As a homework assignment, challenge the students to find a way to insert a pealed, hard boiled egg into a bottle with an opening which is smaller in diameter than the egg. They must not touch the egg after it has been placed on the opening. Hint. After a small amount of water in the bottle has been heated, it is only necessary to place the smaller end of the egg over the opening of the bottle to form a seal. The egg will be forced into the bottle by the greater air pressure outside as the air inside cools.

9. Unobserved by the students place water in a ditto fluid can to a depth of about one centimeter and boil the water vigorously. Then screw the cap on tightly to form a seal. Place the can on your desk in full view of the students and allow them to witness the can being crushed. Challenge the students to explain their observations using the molecular model of gases and the concept of air pressure.

10. Applications of the thinking skills of observation, hypothesis generation and testing will come in subsequent learning cycles.

Scientific Concepts	Thinking Skills
air pressure	observation
molecular model of gases	hypothesis generation and testing
combustion	control of variables

STUDENT MATERIAL
AIR PRESSURE

WHAT CAUSED THE WATER TO RISE?

Introduction

Often things seem simpler at first glance than they really are. Upon closer examination the complexity and mystery become more apparent. Discovering and solving these mysteries can be enjoyable and more satisfying than looking for answers in books or asking people who claim to know better than you. There is a way to search for your own answers. It is called science and it can be fun. We are going to do some now.

Objectives

1. To stimulate curiosity about natural phenomena.
2. To become aware that science is activity that involves generating hypotheses and predictions to arrive at explanations.

Materials

aluminum pie tins
birthday candles
matches
modeling clay
cylinders (open at one end)
jars (of various shapes, sizes)
beakers and/or test tubes
syringes
rubber tubing

Procedure

1. Select a parner and obtain the materials.
2. Pour some water into the pan. Stand a candle in the pan using the clay for support.
3. Light the candle and put a cylinder, jar or beaker over the candle so that it covers the candle and sits in the water.
4. What happended? ____

____

____

5. What questions are raised? ____

____

____

6. What possible reasons can you suggest for what happened? ____________

7. Repeat your experiment in a variety of ways to see if you obtain similar or different results. Do your results support or contradict your ideas in #6? Explain. ______

STUDENT MATERIAL
TRANSPIRATION

WHAT CAUSES WATER TO RISE IN PLANTS?

Introduction

If you place a plant such as a stalk of celery (with leaves) in a beaker with colored water, you will soon notice that the colored water somehow moves up through the celery stalk into the leaves. Observations such as this suggest that the general pattern of water movement in plants is from the roots, through the stem, to the leaves. But what causes the water to move upward? Clearly this movement is against the force of gravity which pulls things down. Do you have any ideas?

Objectives

1. To determine the cause or causes of water rise in plants.
2. To identify some of the structures through which water travels in plant stems.

Materials

food coloring
toluidine blue stain
slides and coverslips
compound microscope
colored pencils or markers
petroleum jelly
test tubes
test tube rack
single edge razor blade
a variety of plants and stems (e.g., celery, coleus, bean, onion, sunflower, pyrocantha, palo verde, orange, corn, _Impatiens_)

Procedure

1. List any hypotheses you and others in the lab may have concerning the cause of the upward movement of water through plants.

____

____

____

2. Select one partner to work with. Use the materials provided to design experiments to test these hypotheses. In general you will have to place plants or plant parts into containers partially filled with colored water and wait several minutes to observe the movement or lack of movement of the colored water through the plant. Your plan of attack should be to try to disprove (or support) each of the hypotheses advanced by comparing predicted results with actual results. Use Table 1 to summarize your work for each experiment. Should you include some sort of control? If so, what and why?

3. Were you able to tell precisely where in the plant stem the water was moving?__________ If not you may want to make some cross sections of

stems that have had colored water and/or stain passing through them. Perhaps the colored water will have stained the water conducting portion of the stem that will be visible under the microscope in cross section.

4. Be prepared to report your observations, experimental results, and tentative conclusions to the class near the end of the lab period.

TABLE 1

Hypothesis	Experimental Manipulation	Predicted Result	Actual Result	Conclusion
Experiment 1				
Experiment 2				
Experiment 3				
Experiment 4				