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Module 9

The Learning Cycle

Introduction

It is quite clear in the research related to the work of Piaget that persons need many years of practice in meaningful understanding and manipulating relationships with the aid of concrete-empirical props. Gradually they develop greater facility in performing these operations and they are able to perform the same operations without relying upon props. In other words, "hands-on", "eyes-on" experiences are essential prerequisites for the development of advanced reasoning abilities.

On the basis of this developmental theory, classroom activities may play a central role in the improvement of student reasoning. Given the possible importance of classroom experiences , does it make any difference what kind of classroom exercises we ask students to perform? We have done some research on the cognitive development of college students in response to instructional experiences. We will suggest in this module some of the implications that we deduce from the work of Piaget and Karplus. You can use your classroom as an environment to study the cognitive development of your students.

Objectives

To enable you to describe the "learning cycle" approach to teaching.

To assist you in designing classroom activities that encourage self-regulation.

Procedure

1. Participate in one of the classroom activities as directed.

2. Discuss the Learning Cycle.**

3. Participate in another classroom activity as directed.

** We provide essays on the Learning Cycle in Biology, Chemistry, Economics, English, Mathematics, Philosophy, and Physics. Read the one or ones of your choice.

Essay: The Learning Cycle **Biology**

Suppose you are beginning your biology course's section on evolution. How would you begin? Jot down what you would consider a useful beginning exercise.

Now consider the proposed exercises that follow. Rank from most useful to least useful for your purposes.

_____(a) Showing a film that traces the evolution of several modern organisms by reviewing fossil evidence, procedures of dating rock strata, and reconstructions of ancient forms of these organisms.

(b) Arranging for a trip to a museum where students are free to select exhibits that enable them to observe fossils of ancient organisms, follow the geologic history of the earth, look for relationships between climate changes and changes in populations or organisms, and trace the evolutionary lines of the horse, Darwin's finches, or the skeleton of vertebrates.

(c) Providing groups of students with chalk, meter sticks, and a list of important events in geologic and archeologic time, as a challenge to construct a time line indicating the relative occurrence of these events on a time line.

(d) Presenting an explanation of how biotic potential, limiting factors, variation, heredity, and natural selection interact over enormous spans of time to result in the changes in organisms now called evolution.

(e) Providing a laboratory where students observe, draw, and classify - with the aid of a key - a variety of fossil specimens.

(f) Presenting an explanation concerning the five basic processes recognized by the modern synthetic theory of evolution (gene mutation, changes in chromosome number and structure, genetic recombination, natural selection, and reproductive isolation) and diagramming how these interact to result in progressive change.

Certainly the resources available to you and the preparation of your students will influence your choice. Compare our comments below with yours and if possible, with those of another participant.

(a) Films are popular ways of introducing new topics. In this case the film presents observations the students might make in a museum or laboratory they had access to the necessary materials. However, we would recommend the film be used

after a museum visit. Films raise questions, provoke inquiry, or present contradictions 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 itself.

(b) We believe this approach to be very worthwhile as an introductory activity to the very difficult topic of evolution. The students have a great deal of freedom to examine and compare past life forms according to their own interests and curiosity. Their experience and discussions with one another will lead them to ask themselves how old life forms disappeared from the face of the earth while newer ones took their place. Seeking answers to this question becomes the aim of the remainder of the course's section on evolution. At present, the teacher can evaluate the students' reasoning patterns.

(c) This activity can be very effective for getting students to appreciate the tremendous span of time during which natural selection operated. As described, it is open and allows students initiative, the possibility to make mistakes, and opportunities for self-regulation as they discover contradictions between their preconceived ideas and the lengths of time-line segments. Because of the narrower focus of this activity, it is not so good an introduction to the entire section as alternative (b).

(d) This rather theoretical approach would be highly inappropriate as the introduction of a new topic because it takes for granted that all students have a good grasp of the five rather difficult concepts.

(e) Use of keys for classifying objects can be worthwhile for elementary school pupils in that it involves class inclusion, a reasoning pattern many children of this age find challenging. Very few older students would be challenged by this activity, and most would not re-examine their reasoning patterns.

(f) Even though this approach, often taking the form of a lecture, provides a unified picture and appears very efficient, it is far too abstract for most students and does not provide them with any way by which they can judge the validity of a statement for themselves.

The recommended approach in (b) is an example of exploratory activity upon which later conceptual understandings can be built. It represents the EXPLORATION phase of a three-phase learning cycle based on current theories of learning and designed to encourage self-regulation. The three phases of the entire learning cycle are called EXPLORATION, INVENTION, and APPLICATION.

During EXPLORATION, the students learn through their own actions and reactions in a new situation. In this phase, they explore new materials and new ideas with minimal guidance or expectation of specific accomplishments. The new experience should raise questions that they cannot answer with their accustomed patterns of

reasoning. Having made an effort that was not completely successful, the students will be ready for self-regulation.

The second phase, INVENTION, starts with the invention of a new concept or principle - variation, natural selection, evolution - that leads the students to apply new patterns of reasoning to their experiences. The concept can be invented in class discussion, based on the exploration activity, and re-emphasized by the teacher, the textbook, a film, or another medium. This step, which aids in self-regulation, should always follow EXPLORATION and relate to the exploration activities. The film in alternative (a) above or the lecture in alternative (d) could serve as CONCEPT INVENTION sessions following the laboratory activity (b). Students should be encouraged to develop as much of a new reasoning pattern as possible **before** it is explained to the class, but expecting students to invent the complex ideas of modern science is unrealistic.

In the last phase of the learning cycle, APPLICATION, the students apply the new concept and/or reasoning pattern to additional examples. After the introduction of natural selection, for instance, APPLICATION might be concerned with plant and animal breeding, evolution of an organism in a hypothetical environment, industrial melanism, or the founder principle. The film in alternative (e) could also serve as an APPLICATION activity. The APPLICATION phase is necessary to extend the range of applicability of the new concept. CONCEPT APPLICATION provides additional time and experiences for self-regulation and stabilizing the new reasoning patterns. Without a number and variety of APPLICATIONs, the concept meaning will remain restricted to the examples used during its definition. Many students may fail to abstract it from its concrete examples or generalize it to other situations. In addition, APPLICATION activities aid students whose conceptual reorganization takes place more slowly than average, or who did not adequately relate the teacher's original explanation to their experiences. Individual conferences with these students to help identify and resolve their difficulties are especially helpful.

Note how the learning cycle, though based primarily on developmental principles, takes advantage of other learning theories also. Thus, the EXPLORATION phase permits learning by APPLICATION , the INVENTION phase allows learning from explanation, and the APPLICATION phase provides for learning by repetition and practice. All of these can contribute to self-regulation if students are allowed to benefit from each phase according to their individual abilities and needs. If a phase is eliminated or all students are expected to demonstrate specified uniform accomplishments after each one, then the overall effectiveness of the learning cycle will be compromised.

As another example of the learning cycle, we direct your attention to this essay. We did not begin with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative strategies for teaching evolution according to your own experiences and preferences to be compared with our ideas. That served as EXPLORATION. Next we described the three-phase learning cycle, the INVENTION in this essay, with reference to the evolution example. Your APPLICATION activities in this essay began with a look at the essay itself. Finally, we should like you to examine, after the conclusion of this workshop, our entire workshop plan, which is also formulated according to a learning cycle. That examination will form an "APPLICATION " activity for you, we hope!

Essay: The Learning Cycle **Chemistry**

Suppose you are about to start your chemistry course's section on solubility and solution equilibria. How would you begin? Jot down what you would consider a useful beginning exercise. Would you begin it by:

Now consider the proposed exercises that follow. Rank from most useful to least useful for your purposes.

(a) Presenting a film with scenes of crystals dissolving or being formed (time lapse), along with animated sequences showing the same phenomena at the atomic-molecular level, with the particles represented by small moving circles of various colors.

(b) Arranging for a laboratory period in which your students could use water and alcohol to dissolve colorless and colorful substances, observe schlieren, compare optical densities of solution, and leave liquids to evaporate.

(c) Providing your students with molecular model sets so they could assemble molecules, see their ionic constituents, and compare the models of electrolytes with models of non-electrolytes.

(d) Presenting an explanation with demonstrations on the dynamic equilibrium involving solutions and excess solute, the changes that occur on the addition or evaporation of solvent, and the alterations in freezing and boiling temperatures of solutions compared to pure solvents.

(e) Scheduling a laboratory in which students carefully measure the amounts of solvent and solute they allow to interact so as to determine the solubility of one or two substances at several temperatures.

Certainly the resources available to you and the preparation of your students will influence your choice. Compare our comments below with yours and, if possible, with those of other participants.

(a) Films are popular ways of introducing new topics. In this case, the film combines observations the student might make in the laboratory with theoretical ideas derived from the kinetic theory. We would recommend that the film be used after a laboratory period if laboratory materials are available. Films raise questions, provide inquiry, or present contradictions less effectively than first-hand laboratory experiences. Since paying attention to the film preempts the viewers' initiative, few students watching the film for the first time would think critically bout what they observe. Additionally, seeing a picture of an object or process does not carry the impact of handling the object or influencing the process oneself.

(b) We would highly recommend 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 materials they will study theoretically later. The teacher can evaluate the reasoning patterns the students use and later provide more direction or extend the autonomous investigations as needed.

(c) Even though this approach involves the students in concrete manipulations, they are dealing with ideanlized representations of atoms, not with the atoms themselves. Recognizing the way in which a model is faithful to nature and the ways in which it omits or oversimplifies details requires formal reasoning patterns that a newcomer to the topic is unlikely to possess.

(d) This rather theoretical approach, often in the form of a lecture, would be completely inappropriate for the introduction of a new topic, because it takes for granted that the students have good grasp of concentration, equilibrium, temperature, and colligative properties. The teacher has no chance to evaluate the students' perceptions since the learners are passive.

(e) This type of laboratory discourages students from asking their own questions and taking responsibility for satisfying their own curiosity. The reason for making the careful observations, waiting for equilibrium to be established, and varying the temperature will not be clear at this time either. Such a laboratory would be more appropriate at a later state of the teaching sequence, but even then it might focus some attention on the transient processes while equilibrium is being established.

The recommended approach in (b) is an example of exploratory activity upon which later conceptual understandings can be built. It represents the EXPLORATION phase of a three-phase learning cycle based on current theories of learning and designed to encourage self-regulation. The three phases of the entire learning cycle are called EXPLORATION, INVENTION, and APPLICATION.

During EXPLORATION, the students learn through their own actions and reactions in a new situation. In this phase they explore new materials and new ideas with minimal guidance or expectation of specific accomplishments. The new experience should raise questions that they cannot answer with their accustomed patterns of reasoning. Having made an effort that was not completely successful, the students will be ready for self-regulation.

The second phase, INVENTION, starts with the invention of a new concept or principle - solubility, equilibrium, concentration - that leads the students to apply new patterns of reasoning to their experiences. The concept can be invented in class discussion, based on the exploration activity and re--emphasized by the teacher, the textbook, a film, or another medium. This step, which aids in self-regulation, should always follow EXPLORATION and relate to the EXPLORATION activities**.** The film in alternative (a) above or the lecture in alternative (d) could serve as INVENTION sessions following the laboratory activity (b). <u>Students should be encouraged to develop as much</u>

of a new reasoning pattern as possible **before** it is explained to the class, but expecting students to invent the complex ideas of modern science is unrealistic.

In the last phase of the learning cycle, APPLICATION, the students apply the new concept and/or reasoning pattern to additional examples. The measurement of solubility of various substances at several temperatures as in alternative (a) would be a good APPLICATION activity following the introduction of the solubility concept. Other APPLICATION activities might concern the effects of different solvents on the same solute and the relation of solubility to properties of the solute. The APPLICATION phase is necessary to extend the range of applicability of the new concept. APPLICATION provides additional time and experiences for self-regulation and stabilizing the new reasoning patterns. Without a number and variety of APPLICATIONs, the concept's meaning will remain restricted to the examples used during its definition. Many students may fail to abstract it from its concrete examples or generalize it to other situations. In addition, APPLICATION activities aid students whose conceptual reorganization takes place more slowly than average, or who did not adequately relate the teacher's original explanation to their experiences. Individual conferences with these students to help identify and resolve their difficulties are especially helpful.

Note how the leaning cycle, though based primarily on developmental principles, takes advantage of other learning theories also. Thus, the EXPLORATION phase permits learning by APPLICATION, the INVENTION phase allows learning from explanation, and the APPLICATION phase provides for learning by repetition and practice. All of these can contribute to self-regulation if students are allowed to benefit from each phase according to their individual abilities and needs. If a phase is eliminated or all students are expected to demonstrate specified uniform accomplishments after each one, then the overall effectiveness of the learning cycle will be compromised.

As another example of the learning cycle, we direct your attention to this essay. We did not begin with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative teaching strategies for solubility and solution equilibria accelerated motion according to your own experiences and preferences, to be compared with our ideas. That served as EXPLORATION. Next we described the three-phase learning cycle, the INVENTION in this essay, with reference o the acceleration example. Your APPLICATION activities in this essay began with a look at the essay itself.

Finally, we should like you to examine, after the conclusion of this workshop, our entire workshop plan, which is also formulated according to a learning cycle. That examination will form an "APPLICATION" activity for you, we hope!

Essay The Learning Cycle English

Suppose you are planning a section dealing with paragraphing for your freshman composition course. How would you begin? Jot down what you would consider a useful beginning exercise.

Now consider the proposed exercises that follow. Rank from most useful to least useful for your purposes.

(a) List the qualities on which good paragraphs are constructed. The qualities would include logical development of a complete idea, appropriate diction, integrity (both of speaker and of matter), coherence, and the like.

(b) Arrange a class period in which groups of students jointly compose paragraphs on assigned subjects and discuss the paragraphs composed by other groups.

(c) Remind your students of their everyday experiences with concrete objects that are constructed with order and coherence (example, a car). Invite them to suggest other such objects from their experience, and ask them to write a paragraph describing such an object and discuss with them the order they used in their paragraphs.

(d) Describe various modes of paragraph structuring, comparison and contrast, chronological; spatial, inductive, deductive; enthememic, etc.

(e) Divide the class into groups as in 'b', but this time have them compose sentences as models, in miniature, of a "complete thought" such as the paragraph represents in greater magnitude. Topic sentences might receive special attention, as might introductory transitional or concluding sentences.

(f) Provide a class in which each student is assigned to examine paragraphs for topic sentences, tgransitions, structural clues, and other such items.

Certainly many factors would influence your choice, factors too numerous and diverse to be fully accounted for here. But you might nevertheless compare your reactions to the foregoing materials with ours.

(a) This procedure seems a favorite of some popular textbooks; and their suggested grading procedures encourage teachers to adopt it. Its great appeal seems to lie in its being apparently so concise. In fact it is likely to be difficult for your students, especially the concrete thinkers, to respond to because they cannot readily conceive such formal concepts aside from particular examples. If you consider the variations in length, complexity, subordination, coordination, etc., which in different contexts constitute a "complete thought" (whether of sentence or of paragraph duration), you will note how formal that concept really is. Concrete thinkers cannot readily keep in mind a concept with so many variables. Besides, procedure 'a' leads more to thinking about compositions than to composing. Furthermore, it leads to correctional feedback, which is surely not the response writers expect to evoke in ordinary writing situations.

(b) Of these procedures, this is the one we would recommend. Here students exercise considerable freedom of judgment and at the same time must consider the judgment of their peers. In most of the situations for which we are preparing students, writing is a social activity, so it is good for a student to have access to the thought processes of others. Approach 'b' has the further advantage of providing the social context Piaget maintains is so vital to all learning. Learners are much more likely to experience disequilibrium when they face the disparate notions of their peers than when such notions are laid out by authority. Finally this approach has the advantage of promoting the free and spontaneous generation of materials -which is a fundamental component of composition.

(c) This approach has the advantage of relating paragraphing to the students' previous experience. But it should be noted that it loses the spontaneity of 'b' and is more directive.

(d) This approach would be less appropriate at the beginning of paragraph teaching because it is rather theoretical and because it highlights segments of paragraphing theory (i.e. how to construct one or another kind of paragraph) before the students consider actual paragraphs.

(e) Since sentences in one sense compose paragraphs, we would consider a task such as this useful, at least potentially. It has many of the social qualities of 'b' but it also has some drawbacks. Unless more carefully modulated, such assignments are too theoretical to be useful. (This problem will be more fully explored in Module 9.) It is also too prescriptive to be useful at this sate.

(f) This exercise prevents students from asking their own questions and satisfying their own curiosity. It is, like 'e', too restrictive and is more analytical than generative. All the concepts of paragraphing must have been properly assimilated before the students could cope with it.

The preferred approach in (b) or (c) is an example of the "EXPLORATION" phase in the learning cycle which we recommend for the planning of teaching activities. The entire learning cycle consists of three phases that we call EXPLORATION, INVENTION, and APPLICATION. During EXPLORATION the students learn through their own more or less spontaneous reactions to a new situation. In this phase, they

explore new materials or ideas with minimal guidance or expectation of specific achievements. Their patterns of reasoning may be inadequate to cope with the new data, and they may begin self-regulation.

During the "INVENTION" phase, the student's are looking for concepts, principles, and tactical tricks that will help him to solve the problems that have arisen during "EXPLORATION." At this stage they should receive hints and suggestions from the teacher; such hints and suggestions, however, must be carefully designed to help them with the problems that they see and not the problems that the teacher sees. The "INVENTION" step should always follow EXPLORATION and relate to the EXPLORATION activities. In the example of the paragraphing exercise above, for instance, alternative (a) represents a possible "INVENTION" phase, perhaps introduced via (e) as an intermediate step to relate EXPLORATION and INVENTION. Since students have been reading and writing paragraphs all their lives, it is better if the concepts are "invented" by the students, after which the teacher may introduce the conventional terms for them.

The last phase of the learning cycle is "APPLICATION", during which a student finds new APPLICATIONs for the concepts or skills he has "INVENTED." Surely in a unit on paragraphing this means writing additional paragraphs but just as surely it does not mean writing done as a mechanical exercise. That is, the student must be set on a new task which he recognizes as calling for a new EXPLORATION phase leading to the APPLICATION of his new concepts or skills. Other APPLICATION activities could involve writing descriptions of paragraphs written by other students in the class, or by published authors.

The "APPLICATION" phase provides additional time and experiences for self-regulation to take place. It also gives you the opportunity to introduce the new concept repeatedly to help students whose conceptual reorganization proceeds more slowly than average, or who did not adequately relate your original explanation to their experiences. Individual conferences with these students to identify their difficulties are especially helpful.

As another example of the learning cycle, we direct your attention to this essay. We did not begin it with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative teaching strategies according to your own experiences and preferences, to be compared with our thoughts. That served as "EXPLORATION." the best we could think of in the context of this module. Next we described the three-phase learning cycle, the "INVENTION" in this essay, with references to your exploratory experience with paragraphing. Finally, we should like you to examine, after the conclusion of this workshop, our entire workshop plan, which is also formulated according to a learning cycle. That examination will form an "APPLICATION" activity for you, we hope!

What additional "APPLICATION:" activities can you suggest?

Logic and Language Learning Cycle **PHILOSOPHY**

Suppose you are responsible for teaching a course in Elementary Logic in which you want students to be able to translate ordinary language argument into the symbolic language used in your text materials. You already have the students able to determine what strings of words to consider as "propositions" and what strings not to count as "propositions." Now they need to learn to distinguish between the kinds of expressions used to show logical relationships between propositions so that they will be able to determine what "operator" to use in their symbolic formulae for various forms of argument.

What would you consider to be a useful exercise for introducton to the logical opeatons? Rank the following form the most useful to the least useful.

Now consider the proposed exercises that follow. Rank from most useful to least useful for your purposes.

_____(a) Present the students a list of the operations you are going to work with (e.g., implication, disjunction, conjunction, negation, etc.) along with a definition of each operation in terms of the possible truth-values of the component propositions in each operation. Have them memorize the definitions and do exercises in applying them to a variety of passages containing argument.

(b) Present the list, as in a above, along with examples of ordinary expressions that fit the definitions of each operation. Then have students expand those examples to include most of the ordinary language expressions that they are likely to encounter.

(c) Have the students produce a list of English expressions that they think are used to show relationships between whole propositions. Have them work in small groups to classify those expressions according to the kind of relationship they indicate. Then have them characterize those "kinds" in the form of some sort of definition and provide a class-heading for each kind. After they have completed this, have them compare their groupings and their "definitions" with each other's and with that presented in their text materials.

(d) Present the students a list of about a dozen most common expressions which sort readily into two or three operational 'kinds' and have them sort and 'define' as in c above, but as a <u>whole classroom</u>, while you write the groupings they suggest on the board. Then compare these with that presented in the text material.

(e) Present students with examples of sentences showing the prepositional relations and tell the students which ones are alike and how you can characterize the relationships in terms of truth-values. (Make sure your groupings and definitions are similar to those presented in the text material.)

Certainly many factors would influence your choices in ranking these ways of proceeding. Compare our comments below with yours and, if possible, with those of other participatns.

(a) This procedure is probably used in most textbooks and thus is probably most used by teachers. However, it prevents the students from asking their own questions and, thus, from feeling the real usefulness of the definitional categories other than that they are what's "given in the book". Commonly the students are not encouraged to ask "why it's given that way?" Hence they have little opportunity to judge different methods of classification presented in different texts, etc. Against such a background, applying the definitions to specific passages is likely to become an algorithmic exercise with success resting primarily on the students' ability to memorize a list of expressions for each operator. It relays on rote memory, rather than on understanding. Encountering relational expressions which were not included in the lists will present a difficult problem to students.

(b) Although this has most of the same limitations as (a) above, the addition of the procedure of having students expand the lists of expressions that exemplify the defined operations is a significant advantage. By way of this exercise, students will be actively engaged in building at least portions of the categories themselves and, in a format in which they must explain their additions, it would afford the teacher helpful access to the students' reasoning. How much of an advantage over a this would be would depend a great deal on how much in-class time was devoted to this part of the exercise - too little time to afford the students peer and teacher feedback about their reasoning in classifying could make it a relatively useless and very frustrating exercise. Enough time must be afforded to allow all students - but especially concrete operational students - to explore expressions of their ordinary language for nuances of various relationships to find sense in classifying them.

(c) We prefer this way of proceeded, providing there is adequate time to allow the students to do the initial sorting and to get some sort of characterization that is acceptable in their groups and to gain the feedback from comparing with other groups. The fact that students generate their own list of expressions to sort has the advantage of providing a greater variety of expressions for them to consider. Although the sorting will take more time, they will be more likely to formulate useful definitions having contrastive, as well as comparative, features. The operation of sorting and defining can be extremely helpful for students if they are required to formulate rationale for each sort they do. (c), therefore, has the advantage over (d), because working in small groups, rather than as a whole classroom, several students can be gaining experience at the same time. Also, the tendency to submit to the teacher's characterizations and valuations of suggestions is not liable to get in the way of the students' own reasoning activities, when their major confrontations are with their peers in the small groups. Teachers, of course, can eavesdrop on the groups to get access to the students' reasonings.)

(d) In the face of serious limitations on in-class time, making (c) impractical, this is the procedure we recommend next. By limiting the variety with which students must deal in their in-class sorting, they can complete the groupings in a relatively short time. But their characterizations of the 'kinds' are liable to be in more general terms, since there will be fewer kinds with which they have had to contrast each group. As a means of promoting flexibility in handling a greater variety of expressions, one might assign "Revise your system" tasks to be done out of class time, but it will be less helpful to those who have no access to classmates outside the class, because they will lack important opportunities for self-regulation provided by working with others.

(e) This approach relates the operations which the student must learn to example-sentences. The students may relate these sentences to their own experiences with their language. Its disadvantage is that the students are left to find their own rationale for the groupings and for the definitions. The teacher has no way of getting access to the students' reasoning. It offers no adequate way for the teacher to be sure that the students understand the principles is sufficient for them to handle a variety of problems for themselves.

In our preferred approach (c) you can allow for the experiences necessary to learn new concepts while you gain data on the students' reasoning processes along the way.

The exercise of sorting out expressions of relationships between propositions focuses the student attention on a part of their language behavior that has become automatic to them. Since it engages them in <u>exploring</u> purposefully parts of their language that they use with confidence, they are liable to share their expertise in small group work with their peers. There they can gain the feedback they need for self-regulation when they propound something that doesn't work well for others.

As each word is compared to others, similarity and differences in their uses are considered and their importance is weighed. Then the <u>INVENTION</u> of classes of uses which are defineable by the student requires at least advanced concrete operational thought. And the ability to invent criteria by which to sort consistently and systematically an indefinite number of expressions requires formal operations.

Once the initial list of words has been classified and the criteria for those groups formulated, the APPLICATION phase of the learning cycle is undertaken with the presentation of more expressions, including some which do not readily fit into the established groups.

As another example of the learning cycle, we direct your attention to this essay. We did not begin it with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative teaching strategies according to your own experience and preferences, to be compared with our thoughts. That served as 'EXPLORATION,' the best we could think of in the context of this module. Next we described the three-phase learning cycle, the 'INVENTION' in this essay, with references to your exploratory experience with logic and language. Finally, we should like you to examine, after the conclusion of this workshop, our entire workshop plan, which is also formulated according to a learning cycle. That examination will form an 'APPLICATION' activity for you, we hope!

Essay **The Learning Cycle** **MATHEMATICS**

What teaching strategy do you detect in following procedure used to discuss an algorithm for listing all subsets of a finite set?

How would you begin? Jot down what you would consider a useful beginning exercise.

Now consider the proposed exercises that follow. Rank from most useful to least useful for your purposes.

1._____(A) Give the class several easy combinatorial problems which use all subsets of, say, three elements. Examples: 1) how many ice cream sundaes can one make with apple, banana, and cherry topping? 2) Given a dime, penny, and dollar, what different donations could you make to the Salvation Army kettle at Christmas? Ask each student to solve these problems by listing the different possibilities on his paper.

_____(B) Have each student write the numbers zero to seven in a column using the binary number system: 0, 1, 10, 11, etc.

_____(C) Have students exchange papers or confer in small groups. Have them note any particular order of the answers in the combinatorial problems 1) and 2). Have them share with each other, if they don;t remember, how to count in base two.

II_____(A) Bring the class back together and list in a column the base two numbers zero to seven. Comment that in order to keep things straight and in the right columns you will write each as a three digit number, e.g. 010 for 10 and 000 for 0.

(B) Pick a paper at random and record the answers to 1). For the apple-cherry sundae list that as "a) c" in the same row as 101 in the list of base two numbers. Again comment the 0 is to keep the rows straight. Continue to list all 8 possibilities. For ease of notation, write apples above the first column and change each a to a 1. Point out you consider 1 to mean present or yes and 0 to mean absent or no. By this time some the class will have noticed the one to one correspondence you wish them to understand.,

(C) List the possible donations to the kettle in numerical order. Change from dollars to cents, and add zeros to have all three digit numbers.

(D) State as clearly as you can the correspondence between n-digit binary numbers and subsets of sets of n elements. If appropriate interpret as characteristic functions. Make certain all students understand the

III. A. Suggest some problems to see if they really understand the algorithm. Have them list all subsets of two or of our elements in the order given by the binary numbers.

B. Propose some new problems: 1) By just having your fingers up or down, how far can you count on one hand? 2) Can you write all six digit binary numbers in a column by giving all theleft most digits first, then second to left, etc?

One could consider pat I of this proposed scheme as an "EXPLORATION" phase. The students are working with some fairly concrete ideas and they gather some information when they share their answers with their classmates. They will have in their minds several problems but may not be aware that they are mathematically the same. They maybe a bit puzzled by the apparent lack of order or by the indefinite order of some of the answers.

The purpose of part II was in invite them to notice the one to one correspondence which is the basis for the algorithm. Many students will notice this correspondence in these cases, but it should be explicitly stated for all to apply in other cases. This stating of the correspondence we will call the "INVENTION:" stage. Here the instructor is suggesting a new way of viewing the experiences in the EXPLORATION phase. In essence the instructor is proposing anew structure which will account for the experiences of EXPLORATION.

Part III can be called APPLICATIONs or "APPLICATION" of new ways of using the INVENTION. These APPLICATION experiences should serve to reinforce, refine, and enlarge the content of the INVENTION. It's a good chance to check that everyone understand the INVENTION.

The sequence of EXPLORATION-INVENTION-APPLICATION is what we will call the learning cycle. As another example of this learning cycle, we direct your attention to this essay. We did not begin it with a definition of the learning cycle, but rather tried to place you in a situation of considering teaching strategies to be compared with our thoughts. That served as "EXPLORATION", the best we could think of in the context of this module. Next we described the three phase learning cycle and gave it a specific name. This was the "INVENTION" in this essay and it referred to your exploratory experience. At the conclusion of this workshop, we should like you to examine the entire workshop plan, which was formulated on the explore-invent-apply cycle. Hopefully that will be an APPLICATION activity for you.

Essay **The Learning Cycle** **ECONOMICS**

Suppose you are planning to begin your course's section on diminishing returns and marginal product. How would you begin? Jot down what you would consider a useful beginning exercise.

Now consider the proposed exercises that follow. Rank from most useful to least useful for your purposes.

(a) Drawing a production possibilities curve and explaining the significance of its curvature.

(b) Assigning some arithmetical computation problems requiring the student to compute total product and marginal product as a production process expands.

(c) Putting your students to work collating and stapling mimeographed materials into packets, requiring them to work in groups ranging from 1 to 10 students per given table space and asking them to record how quickly they completed 50 packets.

(d) Discussing the labor market, the demand for labor, and income distribution.

(e) Asking the students to imagine a typical agricultural example of a farmer applying more and more variable inputs (labor, fertilizer, water) to a given amount of a fixed resource (land).

(f) Explaining a mathematical approach to this concept in which the marginal product of a resource is shown to be the first derivative of total product with respect to that resource.

Certainly, the time available to you as well as the level of students will influence your choice. Compare your reactions with our comments on the alternatives:

(a) This procedure is often used because of its "universality" and because of its reminder to the students of opportunity cost and trade-off. However, it seems to us to require rather sophisticated formal thought processes to comprehend this abstraction and to relate the real idea of output to the mathematical properties of the diagram.

(b) This is a more concrete approach, and could be very useful in "cementing" (excuse us) the concept after the foundation for the idea has been established. Its major drawback is that it is a purely computational approach with no experiential base.

(c) We would recommend an approach of this kind, where the student is asked to undertake an activity with no prior conception of what will happen, which generates its own data (which the student identifies and can trust), and which allows the concept to emerge from the student's world.

(d) This approach would be inappropriate at the beginning of the topic. Discussion of the topics mentioned seems to require as a prerequisite the concepts you are trying to teach in this unit.

(e) In the absence of an experiential project such as described in (c), we would recommend this approach to connect the new ideas with the students' previous experience.

(f) Comment needed" This approach is obviously highly formal and would present an impossible learning situation for a student using concrete reasoning.

The preferred approach in (c) or possibly (e) is an example of the "EXPLORATION" phase in the learning cycle which we recommend for the planning of teaching activities. The entire learning cycle consists of three phases what we call EXPLORATION, INVENTION, and APPLICATION. During EXPLORATION the students learn through their own more or less spontaneous reactions to a new situation. In this phase, they explore new materials or ideas with minimal guidance or expectation of specific achievements. Their patterns of reasoning maybe inadequate to cope with the new data, and they may begin self-regulation.

During the "INVENTION" phase, you define a new concept, invent a new principle, or explain a new kind of APPLICATION to expand the students' knowledge, skills, or reasoning. This step should always follow EXPLORATION and relate to the EXPLORATION activities. It will thereby assist in your student' self-regulation. In the example of diminishing returns above, for instance, alternative (b) represents a possible "INVENTION" phase, particularly if the computations are based on the results of the classroom activity in (c). Do encourage students to "invent" part or all of a new idea for themselves, before you present it to the class.

The last phase of the learning cycle is "APPLICATION" during which a student finds new uses for the concepts or skills he has learned recently. Diminishing returns, for example, can be applied to other situations, or might even lead to a better understanding of concepts such as the production possibilities curve, diminishing marginal utility, etc. The APPLICATION phase provides additional time and experiences for self-regulation to take place. It also gives you the opportunity to introduce the new concept repeatedly to help students whose conceptual reorganization proceeds more slowly than average or who did not adequately relate your original explanation to their experiences. Individual conferences with these students to identify their difficulties are especially helpful.

As another example of the learning cycle, we direct your attention to this essay. We did not begin it with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative teaching strategies according to your own experience and preferences, to be compared with our thoughts. That served as "EXPLORATION," the best we could think of in the context of this module. Next we described the three-phase learning cycle, the "INVENTION" in this essay, with references to your exploratory experience with diminishing returns. Finally, we should like you to examine, after the conclusion of this workshop, our entire workshop plan, which is also formulated according to a learning cycle. That examination will form an "APPLICATION:" activity for you, we hope!

Essay The Learning Cycle PHYSICS

Suppose you are planning to begin your course's section on geometrical optics. How would you begin? Jot down what you would consider a useful beginning exercise.

Now consider the proposed exercises that follows. Rank from most useful to least useful for your purposes.

(a) List the assumptions of the ray model for light, from which the results of geometrical optics can be derived.

(b) Arrange for a laboratory period in which your students could assemble light sources, lenses, mirrors, plastic blocks, and glasses of water into optical system to observe image formation under various conditions.

(c) Remind your students of their everyday experiences with light and invite them to describe some of the properties of light that are revealed by their observations.

(d) Describe the transfer of energy by means of electromagnetic radiation of various frequencies, and then specializing to the visible part of the spectrum.

(e) Provide a laboratory as in (b), but making certain that your students could work with "pencils" of light, as emitted by a laser or a source with a good collimator

(f) Provide a laboratory where your students are assigned to measure accurately the focal lengths of convergent and divergent mirrors and their lenses on a carefully aligned optical bench.

Certainly, the resources available to you and the level of students will influence your choice. Compare your reactions with our comments on the alternatives:

(a) This procedure is frequently used because of its conciseness but it is likely to be difficult for your students, especially those using concrete reasoning patterns, to assimilate. They do not know the basis of the assumptions and therefore cannot evaluate them when and how these are to be used.

(b) We would recommend an approach of this kind, where the students have a great deal of freedom to use their own judgment and try out their own ideas as they gain practical experience with the objects they will study theoretically later. See also (e).

(c) In the absence of laboratory materials, we would recommend this approach to connect the new ideas about light propagation with the student's previous experience; demonstrations with student participation would help.

(d) This rather theoretical approach would be inappropriate at the beginning of the topic, because it highlights the wave nature of light which is disregarded in geometrical optics except insofar as it limits the applications.

(e) Since light "rays" play an important part in geometrical optics, we would consider this a very helpful addition to the lab. An ordinary comb with coarse teeth can

be used very effectively to make a bundle of light "rays" whose behavior can be followed.

(f) This type of laboratory prevents the students from asking their own questions and satisfying their own curiosity. The concept of focal length needs to be defined and understood before this lab can be worthwhile. At a later time in the course it might be quite appropriate, though we favor a more open approach.

The preferred approach in (b) or (e) is an example of the "EXPLORATION" phase in the learning cycle which we recommend for the planning of teaching activities. The entire learning cycle consists of three phases that we call EXPLORATION, INVENTION, and APPLICATION. During EXPLORATION the students learn through their own more or less spontaneous reactions to a new situation. In this phase, they explore new materials or ideas with minimal guidance or expectation of specific achievements. Their pattern of reasoning may be inadequate to cope with the new data, and they may begin self-regulation. The workshop exercise opening this module gave you an "EXPLORATION" experience.

During the "INVENTION" phase, a new concept is defined or a new principle invented or to expand the students' knowledge, skills, or reasoning. This step should always follow EXPLORATION and relate to the EXPLORATION activities. It will thereby assist in your students' self-regulation. In the example of geometrical optics above, for instance, alternative (a) represents a possible "INVENTION" phase, perhaps introduced via (c) as an intermediate step to relate EXPLORATION and INVENTION. Do encourage individual students to "invent" part or all of a new idea for themselves, before you present it to the class.

During the last phase of the learning cycle, "APPLICATION," a student finds new uses for the concepts or skills he has invented earlier. The measurement of focal lengths of a variety of optical systems (single and multiple lenses, glasses of water) would be an appropriate APPLICATION activity to follow the introduction of geometrical optics. Other APPLICATION activities could involve the theoretical analysis of various optical elements and systems for object-image relationships. The APPLICATION phase provides additional time and experiences for self-regulation to take place. It also gives you the opportunity to introduce the new concept repeatedly to help students whose conceptual re-organization proceeds more slowly than average, or who did not adequately relate your original explanation to their experiences. Individual conferences with these students to identify their difficulties are especially helpful.

As another example of the learning cycle, we direct your attention to this essay. We did not begin it with a definition of the learning cycle, but rather tried to place you in a situation of considering alternative teaching strategies according got your own experience and preferences, to be compared with our thoughts. That served as "EXPLORATION," the best we could think of in the context of this module. Next we described the three-phase learning cycle, the "INVENTION" in this essay, with references to your exploratory experience with the optics example. Finally, we should like you to examine, after the conclusion of this workshop, our entire workshop plan, which is also formulated according to a learning cycle. That examination will form an "APPLICATION" activity for you, we hope!