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Chapter 4: A TEACHER'S GUIDE TO THE LEARNING CYCLE

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CHAPTER FOUR

A TEACHER'S GUIDE TO THE LEARNING CYCLE

A Piagetian-based Approach to College Instruction

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I. EXPLORATION

Suppose you are preparing to teach a new college course this year. Assume that this course is designed to serve students who have career goals other than to become college professors. We would like you to consider what teaching strategies you will use to teach such students. Please write down your responses to the following questions:

How do you select the content to be covered in the course? If you have decided upon the content, how do you decide among the various teaching methods such as lecture-recitation, discussion, group projects, Keller Plan (or PSI), or audio-tutorial schemes?
How do you evaluate the preparation of your students for this course?
If you find that they have the content prerequisites for your course, how do you know that they possess the reasoning skills that you will demand?
What activities can you use to help your students improve their reasoning skills?
What evidence do you have that your course will assist students in improving their reasoning skills?

II. INVENTION

We know that in order to increase one's learning, one must be able to perform a wide variety of mental operations. Examples of some of these operations are excluding irrelevant data, using simple scaling factors (ratios) and formulating the existence of an intermediate step to reach a final answer.

How do you know that your students have developed the ability to perform such mental operations? If they have not, can you select a teaching strategy that will help students develop competence in these mental operations?

Jean Piaget and others (Inhelder and Piaget, 1958) have studied the development of logical thought in children and adolescents, and have proposed a developmental model to explain the growth of logical thinking in humans. Recently Karplus (1974) has suggested a Piagetian-based classroom instructional strategy that may assist students in their development of logical thought. This flexible strategy is called the Learning Cycle and provides some guidance for instructors who wish to combine the development of reasoning with the mastery of content.

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The Learning Cycle is divided into three major phases known as Exploration, Invention, and Application (sometimes called Discovery). The general characteristics of each phase of the Learning Cycle are:

Exploration—Following a brief statement of topic and direction, students are encouraged to learn through their own experience. Activities are supplied or suggested by the instructor which will help the students to recall (and share) past concrete experiences and to assimilate new concrete experiences helpful for later Invention and/or Application activities. During this activity the students receive only minimal guidance from their instructor and explore new ideas in a spontaneous fashion.

Invention—In the invention phase the concrete experiences of the exploration are used as the basis for generalizing a concept or for introducing a principle. Student and instructor roles in this activity may vary depending upon the nature of the content. Generally, students are asked to invent part or all of the relationship for themselves with the instructor supplying encouragement and guidance when needed. This procedure allows the students to gain confidence through familiarity with the concepts introduced.

Application—The application phase allows each student an opportunity to directly apply the concept or skill learned during the invention activity. Application provides the students with additional broadening experiences. They use the invented concepts in different concrete settings. The Learning Cycle allows each student the opportunity to think for himself. The instructor is a present overseer of activity. Yet he must guard against over-playing his role as director and facilitator. He must provide an open classroom atmosphere within a well-defined boundary.

The Learning Cycle offers you a model for designing instructional activities which may encourage your students to develop their reasoning skills and to learn concepts. In the following portions of this paper we offer some details of the Learning Cycle, its applications, and our guidelines for using the Learning Cycle to design classroom activities. The outline below describes the three parts of the Learning Cycle in detail.

A. Exploration

Emphasis—Concrete experience with familiar objects and systems.

Focus—Open-ended student activity.

Function—Student experience is joined with appropriate environmental options not previously considered by the student.

1. This phase of the Learning Cycle provides students with reinforcement of previous concrete experience and/or introduces them to new concrete experiences related to the Invention objectives.
2. Exploration allows for open-ended considerations, encouraging students to use concrete experiences to consider new ideas.
3. During Exploration the instructor supplies encouragement, provides hints, asks questions, and suggests alternatives. The instructor should encourage students to try a variety of experiences.
4. Student behavior during Exploration provides information concerning the student's ability to deal with the concepts and/or skills being introduced. The students will reveal the reasoning skills which they evoke in search for the solution to a problem.

B. Invention

Emphasis—Generalization of concrete experiences and abstract possibilities.

Focus—Student's active involvement with instructor for generalization.

Function—Students become familiar with generalized concepts and/or skills.

1. During Invention students are encouraged to formulate relationships which generalize their new ideas and concrete experiences.

2. The instructor acts as a mediator in assisting students in formulating these relationships to be consistent with results of their exploration activities.

C. Application

Emphasis—Relevant use of generalized concepts and/or skills.

Focus—Directed student activity.

Function—Further use of generalized concepts in other systems.

1. To begin the Application, the students and the instructor may interact in planning an activity for applying the invented concept and/or skill. The activity should provide a new or unique concrete solution.

2. Students are asked to complete the designed activity to the satisfaction of the instructor. The activities should provide further experience which will act as broadening and stabilizing experiences related to the new skills or concepts.

III. APPLICATION

The ADAPT program at UNL is an experimental, multi-disciplinary program for freshmen. The intervention strategy utilized by this program is founded on Piagetian principles. The instructors involved in the project utilize the Learning Cycle model in planning their class activities. The examples which follow are taken from ADAPT experiences. They are representative of classroom activities which have proven to be successful in terms of improved student reasoning. (Campbell, 1976).

Physics Learning Cycle Example

A. Instructional Objectives

The objectives of this intervention are to:

1. introduce students to the general properties of periodic motion and to a subset of systems which illustrate simple harmonic motion.

2. provide appropriate symbols and names for the variables used in discussing simple harmonic motion.

3. invent a mathematical relationship between mass, period, and amplitude for a system which vibrates in simple harmonic motion.

B. Exploration Activity

Name_____

Lab Partner_____

PERIODIC MOTION

Exploration Activity

On various tables in the lab you will find systems which oscillate periodically when displaced from their rest (equilibrium) positions. The type of systems include the following:

A. Rolling motion (weighted cylinders)

B. Bobbing motion (long flexible rods)

C. Vibrating motion (mass vibrated by fixed hacksaw blades)

D. Swinging motion (cylinder hung on fixed support)

Please investigate the properties of as many of these types of periodic motion systems as time allows. As you observe them, look for and identify the following characteristics:

1. Physical variables which are present in each of the systems.

2. Physical variables which can be controlled (held constant) while other variables are allowed to change.

What experiments could you design to investigate the properties of the systems above? What data would you collect and what methods might you see for analysis?

Rationale: Many students involved in this activity have had experience with oscillating objects: Fish bobbers, swings, pendulum clocks. Most, however, have not considered the properties of systems which illustrate simple harmonic motion. Concrete experience is expanded by providing familiar and unfamiliar systems for exploration. Students are encouraged to explore by changing variables within a single system. The exploration is designed to provide needed concrete experience for the Invention sheet below and encouraged to invent many of the concepts on their own.

C. Invention Activity

NAME_____

PERIODIC MOTION

Invention Activity

1. List the characteristics of the various systems which were different.

2. List the characteristics of the various systems which were similar.

3. What experimental tools could be used to investigate the nature of the similar characteristics of the systems lised in 2 above? What does the experimenter do about the other variables of the system?

4. What mathematical and/or graphical tools could be utilized in investigating the relationships between period, restoring force, amplitude, mass and/or length for each of the systems that vibrate. How would you set up an experiment for collecting the data needed?

Rationale: In beginning the invention, the instructor requires that students discuss the results of their exploration. This interaction provides a check on student progress and indicates a readiness to begin the invention phase.

The invention activity allows for instructor leadership in assigning common symbols and names to variables the students explored. Then depending on students ability, the relationships between force, displacement, mass and period can be introduced. Before completing the Invention, the instructor should provide an example showing how each of these variables influence one of the systems investigated during the exploration activity.

D. Application Activity

NAME _____

LAB PARTNER _____

PERIODIC MOTION

Application Activity

Your lab instructor will provide you with apparatus for another oscillating system, the rubber band-mass system.

Equipment: 1 rubber band
1 meter stick
1 set of metric masses
1 support rod
1 timer

Carefully design and perform an experiment which will provide the following information about this system:

A. Force (measured in grams) needed to stretch the rubber band through some given distance. (Are there any limitations to this measurement?)

B. Force constant of the rubber band in grams/cm. Is this constant always constant? (Hint: Plot a graph showing displacement (x) vs. grams of load (y) and take the slope of the graph.) Is the graph linear?

C. Period of oscillation as a function of the mass of the oscillating object.

Rationale: The application activity requires the students to directly apply the invented relationships between amplitude, mass, displacement, and period. The activity may center upon one of the examples used for Exploration but is more effective if it is a new apparatus such as the rubber band oscillation shown above. This activity serves to broaden students learning by providing a system where they can directly apply the invented concepts.

Mathematics Learning Cycle Example

A. Instructional Objectives
1.to review addition, subtraction, multiplication, and division of signed numbers, fractions, and decimals.
2.to review the commutative and associative laws of arithmetic.
3.to practice making and testing conjectures.
4.to discover and apply a formula for the sum of an arithmetic series.

B. Exploration Activity

1.Presentation to class: Here is an example of what can be called a 3 x 3 box puzzle. A square is divided into nine regions, two odd and two even numbers are placed in the four upper left regions as shown.

2	3	
5	−6	

The first two rows can be completed by addition. The first two columns can also be completed by addition. Now the lower right corner could be reasonably completed as the sum of the third row. In this case either method gives the same answer, 4. So we say that this 3 x 3 box puzzle "works".

2	3	5
5	−6	−1
7	−3	4

2. Exploration in class.

a) Try a couple more 3 x 3 addition box puzzles starting with two even and two odd integers. Do they also work?

b) How could such box puzzles be changed? Suggestions by students included: use different m=numbers, drop even-odd requirement, use a different operation (e.g. subtraction, multiplication), use different sizes (e.g. 4 x 4, 5 x 5), and use a different shape (e.g. 3 x 8).
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3. Exploration as homework.
The exploration of box puzzles was continued as homework using the assignment shown.

Math Homework - Exploration Activity

Math Homework - Exploration Activity

1. Work these addition box puzzles:

a)

.102	1.02	
-10.2	12	

b)

1/3	3/5	
$2\frac{1}{8}$	$\frac{-5}{12}$	

c)

1	2	3	4	5	
5	4	3	2	1	

d)

a	b	
c	d	

Here a,b,c,d are all numbers

2. Will 3 x 3 box puzzles work using mult?, subtraction?, divition? Support each answer with two examples one using fractions and one using decimals.

3. Work these two box puzzles using addition on the rows and mult. on the columns:

Example

1	2	3	=1+2
3	-6	-3	=3+(-6)
3	-12	-9	=3-12
1x3	2x-6	3x-3	

3	-2	
-6	-4	

10	5	
-6	8	

4. What do you conjecture about row-addition, column-mult box puzzles? How can you test your conjecture? Try it.

C. Invention Activity

The homework exercises were discussed the following day. In problems three and four most students guessed that such puzzles always work and then discovered an example which did not work. These examples bothered three students enough so that they hunted for and found necessary and sufficient conditions for such puzzles to work.

When directed to choose c=0 in problem 1d) and use parentheses carefully, the class recognized the associative law for addition. Choosing a=d=0 produces the commutative law.

Several other 3xn addition box puzzles similar to 1c) were worked until the class noted that an arithmetic series in the first row and the same numbers backwards in the second row gives the same sum in each column. Thus the final answer is the column sum times the number of columns. But this answer is also the sum of the first row and of the second row, that is twice the sum of the series. So the formula for the series sum was derived and related to the "average value times the number of values" formula many of the students had seen before.

D. Application Activity

Assigned homework problems asked the students to:

a) obtain the associative and commutative laws of multiplication from a 3 x 3 multiplication box puzzle.

b) obtain the distributive law from a special hybrid box puzzle.

c) apply the formula for the sum of an arithmetic series to various other problems.

Two months later on the final exam the students were asked to find the sum of all odd numbers between zero and one million. Without further class time on this topic 49% found the sum, 39% used the box puzzle approach but missed some of the details, and only 12% had no idea how to begin.

Economics Learning Cycle Example

The following is an example of implementation of a learning cycle approach to economic studies.

Development of a College Student Price Index (analogous to the Consumer Price Index) is one "real world" activity which economics students have accomplished and which exemplifies several of the pedagogical components implicit in Piaget's work. Particularly during an inflationary period, a device which can help them see the shape and size of inflation as it affects them, is of interest to students.

The ***exploration*** phase of this learning cycle involved two components. One was collection of data from the students themselves to determine what they bought and what they spent for it. This data emerged from a record the students were asked to keep for a period of two weeks listing all purchases and amounts expended. The second ***exploration*** component was gathering price data from the shelves of Lincoln merchants.

Many "***invention***" or kinds of concept formation were necessary to complete construction of a respectable price index. One "***invention***" centered on the concept of a representative market basket of students utilized commodities. It was, of course, apparent to students that we could not manage an index which contained every conceivable purchase during the school year. Thus their own records of purchases made were used to generate a list of 65 commodities, selected by the class to represent their buying activity.

The students were soon confronted by the fact that simply adding up the prices of the selected commodities during two time periods and comparing the results was not sufficient as a representation of changes in their purchasing power. The importance of each item, or class of item, in their budget needed to be considered; thus the idea of grouping the commodities into classifications and appropriately weighting each class was interjected. Six classifications were used (food, toiletries, school supplies, recreation, clothing and miscellaneous) and weights were assigned again based on their recorded expenditures over the two week period. (Housing was omitted because of the anticipated stability of dorm rates during the academic year.)

The necessity for developing standards and specificity in the product selection quickly became apparent. Simply going to the store and pricing "soap", or "gasoline" was not good enough; and our list soon specified "Dial, 5 oz.", and "DX plus" gasoline. Thus the ideas of care and rigor in data collection, and the necessity of subsequent replication, were made tangible for the student (were invented).

Not to be forgotten among all the other ***inventions*** which were occurring is the concept of an index number itself. The students found indexation a useful concept to make some sense out of the mass of information gathered over a period of time, and it was regarded as a helpful aid rather than a teacher-imposed burden by the time it was used in class.

Finally, the ***application*** phase of this unit is nicely built in, as the students were given the job of price gathering and index calculating at the first of each month. Thus we watched the index grow month by month, each calculation reinforcing work done earlier. Each month the movement of the components of the index is somewhat different; the effects of seasonal changes are apparent, and the students become more comfortable with this tool.

Disequilibration and self-regulation are a natural and unavoidable part of the process. Having student A price soap one month at $.89 and having student B report it at $.35 the following month led to the self-regulation of product specification and standardization. The idea of grouping and weighting grew from the disequilibration caused by having the 10% change in the price of a pair of shoes completely overwhelm price decreases in small ticket items (such as toothpaste) when the entire list was aggregated in an undifferentiated way.

Anthropology Learning Cycle Example

Assignment:

What are the rules for saying "Hello" or "Hi" to a stranger?

(To answer this question, the student must observe, count, describe, and then test in operation a whole series of non-verbal behavior, that allow him/her to get the attention of a stranger--another student usually--and say "Hello" or "Hi" without seeming odd or peculiar. Especially important: the student has to be able to do this without stress.)

Exploration Phase:

The students go out in pairs, one greeting people, the other watching. At this time, most people trip up by observing too large of units of behavior: "I said Hello and he said Hello".

Invention Phase:

The students start to break down the "say Hello" package to a series of smaller, connected wants. One student observed that the following sequence is necessary:

1) Look at stranger.

2) Establish eye contact (How?)

3) Look down at ground briefly.

4) Look back at stranger.

5) If stranger makes eye contact, continue eye contact.

6) When between 6 feet apart, say "Hello".

7) With "Hello" or "Hi", nod your head.

8) Break eye contact.

Application Phase:

With this pattern established, the students then go out and try this pattern of behavior with persons of same and opposite sex, with different age persons, with different status persons and with various other non-verbal behavior, as, for example, smiles.

Comment:

The two most important aspects of this learning cycle are the detailed observations of the student and the possibility of applying the behavior sequence.

Logic Learning Cycle Example

Organizing instruction according to the learning cycle may be particularly effective in a course in which students must gain skills in application of a system of symbolic representation of ordinary language, such as a symbolic logic course. Where students are to learn to read and use propositional logic in a symbolic logic course and where the majority of those students are frightened of things that remind them of mathematics, it is extremely helpful to begin with what they are comfortable with--namely, presenting their reasons for their conclusions in their everyday English. From there they may extend one step at a time into the symbol language with much less frustration than if they are given the symbol system separately and forced to make their own connections between it and their own language.

Once students were introduced to the term "proposition," and were comfortable with the task of "picking out the propositions" from various examples of writing and speaking, my logic students had to become adept at recognizing the different sorts of expressions that indicate the five different logical operators which our symbol-system used. They were engaged in the following series of activities in order to facilitate their learning.

1) I asked them to suggest expressions they knew which are used to connect propositions in their ordinary acquaintance. The generated a list of 38 English expressions including the standard logic-teacher's ones such as "or," "and," but," if," and "therefore." This took about 15 minutes of class time. The words were listed on the board as they were suggested--later they were copied onto a ditto master so that each student could have a copy at the beginning of the next class hour.

2) Students divided into groups of about 5 persons each--Instructions: Sort through the list of expressions and decide how to group them so that those expressions that seem to work alike are put in the same group (In deciding try to make up examples of propositions related by each of those expressions.) About 2 1/2 class-hours were given to their working in this stage.

3) Each group of students presented their way of grouping the list-telling why and giving their examples when their peers questioned them. Since there were 5 groups of students in the class, there were 5 schemes of classification. Each was put on the blackboard so all 5 could be referred to by the whole class. Sorting through the 5 schemes it was obvious that there were four main groups in each scheme and that a nucleus of expressions in some group of each scheme were similar--e.g., in each scheme, there was one group that contained at least "if," "because," "since," "therefore," and "so," and in each scheme was one group that contained at lease "and," "also," "too," "but," "in addition," and "however." These similarities were found by the students who were encouraged. The four main groupings contained some expressions which the students tended to make into a subgrouping—they were expressions that combined the same sort of connection as the others of the group but also included a negative sense—e.g. "neither__nor__," and not both." Noting this, attention was drawn to the ways "negation" worked in the examples given and how that made a difference in the sense of the regular (non-negative) connection.

4) Within each of the four main groupings, students selected and expression that they thought would be useful as a model with which to compare new-connectors they might come across. In this step the category of implication indicators became troublesome for them--they found a solution in making two subgroups: one containing the conclusion-statement or that for which the "reason" was offered. Thus, "Because," "Since," and "For" were put in one subgroup separated from "Therefore," "Hence," and "So."

5) Having generated the categories for the operations we would need to use in the propositional logic system they were to learn, names of and "official definitions" for the logical relationships between propositions used in the course were simply pronounced in terms of: "We will take these expressions as indicators of disjunction which is the relationship of alternatives between propositions--e.g., "this is so or else that is so." "The operators we used were conjunction, disjunction, implication, double implication, and negation.

A total of about 4 class hours were given to this series of activities. That investment of time seemed later on to be well worth it because students gained a considerable security in recognizing the logical connectors, differentiating them from one another, and of finding ways of handling the classifying of new examples that they encountered during the semester. This was a significant difference from what happens when students are presented the operators, their definitions, and expressions in ready made groups coincident with the operators to be used in the symbol-system and are expected, by doing exercises, to learn to differentiate them one from another. Using this last, traditional, method it commonly takes undergraduate non-math and non-philosophy majors at least four weeks (12 class hours) to achieve sufficient stability in their skills at operation recognition and usually even then there will be some slow students who never get them settled for themselves. However in using the new method, in a class of 35 students, after the four class-hours in generating the categories and sorting things themselves, there were no cases brought up by students or by instructor which any student had trouble or was hesitant in deciding whether, e.g., if it worked like "and" which category it belonged in, etc. That's success!

English Learning Cycle Example

This learning activity is designed for a freshman English course stressing writing by students. The cycle described for the study of Pride and Prejudice requires at least three weeks of class time.

A. Instructional Objectives:

To appreciate the interaction of plot, character, and theme in causing us as readers to respond strongly as we read good fiction. We are not read P and P to learn about plot, character and theme. Rather, in order to enhance awareness of what Jane Austen has put into the novel to engage our interest, we talk about specific actions, characters, and ideas found in this novel.

B. Exploration Activity

1. Two students take the roles of Mr. and Mrs. Bennet and read aloud the conversation in Chapter 1. Students react to Jane Austen's language. Ask students to state what the novel will be about, judging by this chapter.

2. Ask for three volunteers to write papers to be duplicated and discussed in group sessions the following Monday. (Regular paper-writing is required and students readily volunteer, since by now they have learned the value of lots of criticism of their papers, before they hand in the final version for teacher evaluation.) Topic of papers: Late in Volume One, Bingley, who had seemed to be falling in love with Jane, leaves Netherfield along with his party, apparently not to return. We do not at this point in the novel know what Bingley's motives are for leaving, so we can only speculate. How do you as a reader react to this development: when you look back through the chapters of the novel leading up to it, what do you find that might influence your reaction?

3. Have students read aloud the letter from Mr. Collins to Mr. Bennet, and the reactions of members of the Bennet family that follow. Lead a discussion exploring what students think of the various characters and the way these characters are talked about. As students mention various traits of character, list them on the blackboard.

4. Since it was established in discussing the first chapter that the novel will be about courtship and marriage, students may now be asked to discuss what they think the characterizations and the comments characters make about each other have to do with marriage. To stimulate the discussion, ask students to help make a list of the couples in the book and to try to give a reason why a list of the couples in the book and to try to give a reason why Jane Austen has included each couple. Ask what the different characters think is important in a marriage. (On blackboard, write the list of couples and suggested reason for inclusion.)

C. Invention Activity

Monday, divide into three groups. Each group discusses one of the papers with the writer, the students making written comments on their copies, suggesting to the writer what the strong and weak points of the paper are and how it can be improved. End session by asking students to mention something they learned during the session. It will typically emerge that 1) the writers claimed to have been caught by surprise when Bingley left, and 2) on reviewing the chapters leading up to his departure they found all sorts of hints, that they had missed, that should have prepared them for this possibility. They will have found these hints in the conversations that show the importance in a marriage of property, family and personal compatibility; in the occasions that permit the Bennet family members to display their silliness and "lack of breeding"; and in the traits of Bingley and Jane that could lead Bingley to take the action he takes. They will thus have become aware of the complex interaction of plot, character, and theme in shaping the response of an attentive reader, for they will either have been attentive readers themselves or have seen how much an attentive reader among them has observed.

D. Application Activity

1. Ask for three volunteers to write papers for class discussion on the following Monday. Topic: After Elizabeth has though over Carcy's letter (following her refusal of his marriage proposal) she exclaims, "Till this moment, I never knew myself." How do you react to this declaration, and what do you find in the book to this point that has conditioned you to react as you do?

2. Proceed as with first papers.

3. Repeat with a discussion of papers on a similar topic based on an incident in Volume Three.

It is, of course, understood that because reading a novel is a very complex activity, from which different readers carry away different impressions, the direction by the teacher toward a specific learning objective must be tactful and flexible. While students are learning to distinguish elements that contribute to creating novelistic effects, they are also learning to complicate their observations and their consequent judgments by identifying the variety of features of the novel, the variety within each feature, and the impingement of Austen's fictional world upon what they know of the historical period and place as well as upon their own time and place.

IV. ANOTHER EXPLORATION

We have attempted to present this article in a Learning Cycle. We asked you to explore how you plan to teach a college course (Exploration, Sec. I.). We invented the learning cycle concept for you (Invention, Sec. II). We applied the Learning Cycle to several examples of classroom work. (Application, Sec. III). We encourage you to try the Learning Cycle in your college teaching. Now it's your turn. Please pick a topic. Perhaps one you currently are teaching or one that gives students difficulty. Take a few minutes and consider how you will introduce students to the concept using the Learning Cycle.

V. ANOTHER INVENTION

Planning Learning Cycle Activities

As the facilitator of classroom interaction you have the responsibility for planning the Learning Cycle activities: Exploration, Invention, and Application. When planning, you use your past experience to anticipate problems and difficulties that your students will have with each activity. Remember that while some difficulties are necessary if students are to learn, their reasoning capabilities must soon match the reasoning required to complete the tasks you ask them to perform.

Your first responsibility will be to isolate a concept that you wish to introduce to your students. Next, you should list all the concrete experiences which are associated with this concept; both those you expect your students to have had, and those which you think are directly related to the concept to be introduced.

Next, you can plan the invention activity.

The flow chart shown in Figure 1 summarizes the main features of your responsibilities in planning your learning cycle activities.

You should consider how the explorat activity will help your students to begin the In on their own. In discussion with your student begin the Invention on their own. In discussi your students you may suggest variables and relationships suitable to the explored system. with your help and assistance (either in group class) your students can solidify the generaliz you have planned. Again, your past experien assist you in being prepared to deal with the t your students will have about the relationship found during the Exploration.

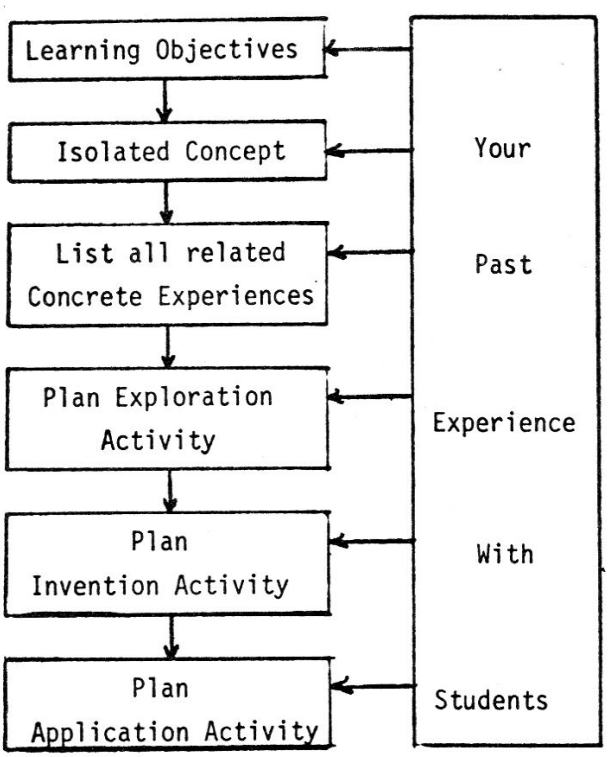

Figure 1.

Finally, the application activity will provide a direct use of the concepts invented. Students conduct further investigations with specific variables that have been isolated and seek to establish definite relationships among the variables. You may introduce new materials that permit investigation of the phenomenon in other contexts. For example, the characteristics of periodic motion can be invented after exploration of rolling, bobbing, twisting, and vibrating objects. Then experimental investigations of the properties of a pendulum will allow for concept reinforcement, refinement, and enlargement.

A positive benefit of the initiation of course content with the investigation of some concrete experience is that, in most cases, unexpected events will occur and questions will be raised that cannot be answered by looking in textbooks or lab manuals. Textbooks contain general answers. These experiences pose specific questions—questions that must be answered through specific inquiries.

Interactions During the Learning Cycle

Following your planning, you are ready to begin the exploration activity with your students. You should begin by giving minimal direction. This will get things started. Be careful that you do not give too many specific directions; allow the students to investigate on their own.

During the exploration you should observe what the students are saying and doing. Listen to their conversations. Watch their attempts. Consider the explanations they provide one another. They will arrive at unanticipated results. Do not reject these results, but encourage them to try other tests. Give encouragement to students who require your assistance but don't be willing to provide answers to all their questions. Let things develop on their own, within limits of your tolerance. As the exploration draws to a close, visit each student and look at his data, his results, and ask him a few questions about what he has concluded. During this time your students will tell you more about their reasoning skills than at any other time during the Learning Cycle.

Now you are ready to begin the Invention phase of the Learning Cycle. During the Exploration activity you have gained insight into how your students think about this concept. Now you must help them generalize the concept by meeting them where they are and by leading them to more advanced thinking. Encourage them to interact with one another. Try to let them have the feeling that they are inventing a new concept.

At the close of the Invention activity you may introduce the Application activity. The directions given for this activity should be more specific than those given during the beginning of the Exploration. While your students are applying the new concept you should interact freely with them answering questions that they have about the activity. Slower students will need additional assistance because they may not have completely understood the Invention. Again you should be interacting with the students. The feedback which you get through the interactions with students during the application activity provides you with additional information about their ability to apply the new concept. A model illustrating student-instructor interactions during the Learning Cycle is shown in Figure 2.

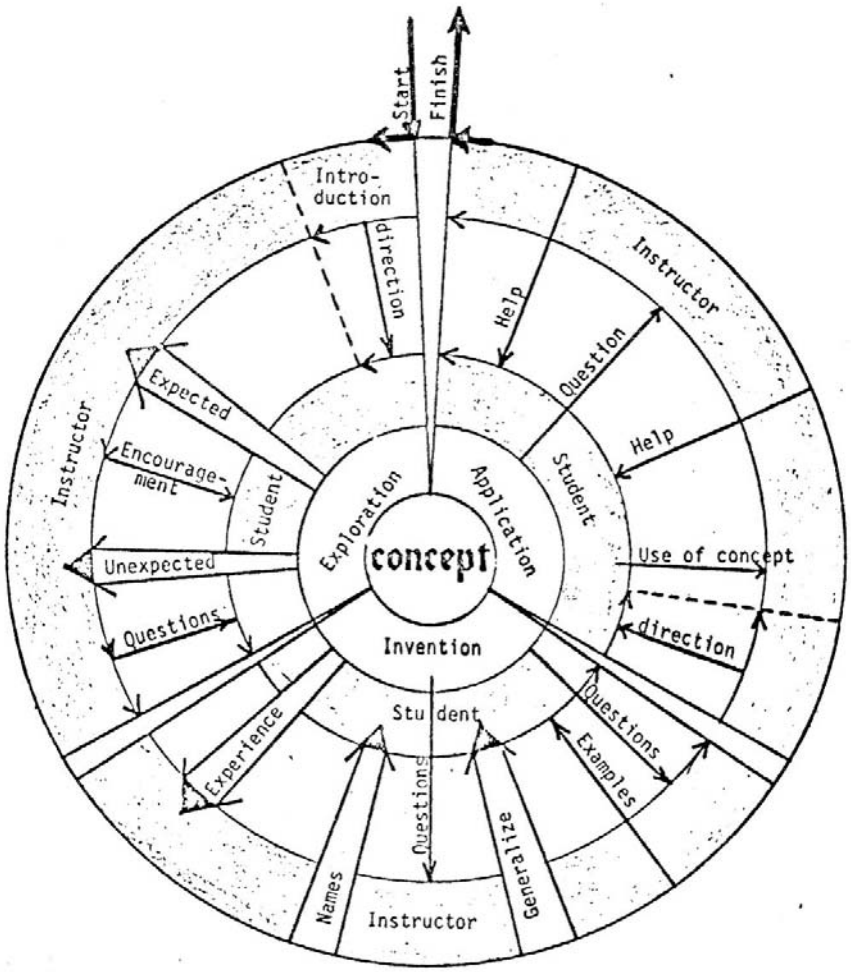

Figure 2. Learning Cycle model illustrating student and instructor interactions during each of the activities of the Learning Cycle.

VI. ANOTHER APPLICATION

Please apply the concept of the Learning Cycle developed during this article to the teaching of a concept to your class. If you would like further examples of learning cycles that we have tried with college students please contact us. Let us know about the learning cycles you use in your college classes.

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