CHAPTER 4

The Learning Cycle

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Early approaches to science instruction in the United States consisted mainly of daily recitations from books and lectures. Use of the laboratory was unheard of prior to the mid 1800s. Physical materials and specimens, if used at all, were a means of verifying book or lecture information. But by the late 1800s, laboratory instruction became very popular because it was felt that first-hand observation and manipulation were useful in "disciplining" the mind. The idea of mental discipline stemmed from psychology and the then popular faculty theory. In general, faculty theory claimed that mental behavior was compartmentalized into several "faculties" such as logic, memorization, and observation. In theory, mental behavior could be enhanced by "exercising" these faculties and once the faculties were developed, they would function in all life situations. The theory was used to justify the use of abstract, meaningless, laborious tasks during instruction to exercise and strengthen the mind.

Largely through the research of psychologists such as E. L. Thorndike, faculty theory began to lose favor and emphasis in schools shifted from rote

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† This material is based upon research partially supported by the National Science Foundation under grant No. DUE 9453610. Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author and do not necessarily reflect the views of the National Science Foundation.

A Love of Discovery: Science Education—The Second Career of Robert Karplus,
Edited by Robert G. Fuller, Kluwer Academic / Plenum Publishers, New York, 2002.

tasks to presenting meaningful information and developing positive attitudes and useful reasoning patterns. Indeed by 1898, organizations such as the National Education Association were making rather modern sounding recommendations such as: *"The high school work should confine itself to the elements of the subject . . . full illustration of principles, and methods of thought . . ."* (Hall and Committee, 1898).

The sentiment to teach scientific principles and reasoning patterns was even more apparent in the Central Association of Science and Mathematics Teachers' 1910 report on secondary education. The report identified major goals such as increasing student motivation and the selection of teaching materials that would teach *"the scientific spirit and method"* (Galloway, 1910). The committee suggested: (1) more emphasis on *"reasoning out"*; (2) more emphasis on developing a problem-raising and problem-solving attitude among students; (3) more applications of the subject matter to personal and social issues; and (4) less coverage of territory. Although the report criticized methods that emphasized memorization, no detailed teaching methods were advocated, except to suggest that problems or projects offered promise for better class discussions, more active student participation, and a better opportunity for *"research type"* learning.

John Dewey was an early and vocal advocate of science instruction that emphasized science as a method of inquiry. In an address to the National Education Association, Dewey (1916) argued that:

> science is primarily the method of intelligence at work in observation, in inquiry and experimental testing; that, fundamentally, what science means and stands for is simply the best ways yet found out by which human intelligence can do the work it should do, ways that are continuously improved by the very process of use.

But, according to Hurd (1961), it would take more than 40 years before this view would make its way into a large scale curriculum development movement. The movement Hurd referred to was the National Science Foundation sponsored curriculum development projects initiated in the late 1950s. These inquiry-oriented projects, such as the Biological Sciences Curriculum Study (BSCS), the Chemical Education Materials Study (Chem Study), the Science Curriculum Improvement Study (SCIS), the Elementary Science Study (ESS), the Physical Science Study Committee (PSSC Physics), and the Earth Science Curriculum Project (ESCP), sprang up largely as a reaction to the Soviet Union's perceived superiority in science and mathematics education as evidenced by their successful 1958 launch of Sputnik into outer space.

Although several of these alphabet soup projects, as they came to be called, developed some excellent inquiry-oriented activities, most of them, with the notable exception of the Karplus directed SCIS program and its learning cycle instructional method (see the Karplus, 1974 paper reprinted in this Chapter) failed to generate a systematic method of inquiry instruction. Rather, most projects only alluded to "discovery," "inquiry," or "problem solving" approaches, the steps of which were not always made clear to teachers, thus were sometimes difficult to implement.

ORIGINS OF THE LEARNING CYCLE IN THE SCIS PROGRAM

Origins of the learning cycle can be traced to the early work of the SCIS program on the Berkeley campus of the University of California during the early 1960s (*SCIS Newsletter*, No. 1, 1964. Reprinted in SCIS, 1973). To be more precise, its origin can be traced to a day in 1957 when a second grade student invited her father, Professor Robert Karplus, a physicist at Berkeley, to talk to her class about the family Wimshurst machine, a device for generating electrical charges. Professor Karplus found the visit enjoyable and so did the children. During the next few months other talks on electricity and magnetism to both elementary school and junior high school students followed. Soon Professor Karplus turned his thoughts to the possibility of developing a program for elementary school science.

With a grant from the National Science Foundation, Karplus prepared and taught three units entitled "Coordinates," "Force," and "What Am I?" during the 1959–60 school year. Although the experience proved interesting, analysis of the trial teaching revealed serious student misconceptions and other weaknesses. The experience prompted Karplus to raise a key question: "*How can we create a learning experience that achieves a secure connection between the pupil's intuitive attitudes and the concepts of the modern scientific point of view?*"

During the spring of 1960, Karplus continued to familiarize himself with the points of view children take toward natural phenomena as he taught lessons in a first, second and fourth grade twice a week. He also began to develop tentative answers to his question. Following that experience, Karplus was helped by a visit to the research institute of Jean Piaget, the Swiss psychologist and pioneer in the study of children's thinking.

When Karplus returned to the United States in the fall of 1961, he returned to the elementary classroom with a plan to stress learning based upon the pupils' own observations and experiences. However, he also planned to help them interpret their observations in a more analytical way than they would without assistance. During part of that school year, J. Myron Atkin, then a Professor of Education at the University of Illinois, visited Berkeley to share his views on teaching with Professor Karplus. Together Atkin and Karplus formulated a method of "guided discovery," which was implemented in subsequent trial lessons (see Atkin and Karplus, 1962—reprinted in Chapter 5).

The Atkin and Karplus guided discovery method was designed to be analogous to the way in which scientists invent and use new concepts to explain nature. In their 1962 paper, they offered the example of the ancients' observations and interpretation of the motions of the sun and planets. The geocentric theory of the solar system was taken to be a conceptual "invention" following initial observations. The heliocentric theory represents an alternative invention. With the help of these inventions, people attempted to "discover" other phenomena besides the ones that led them to propose the inventions in the first place, that could be understood using the invention. These attempts, if successful, led to a reinforcement and refinement of the invention. If they were unsuccessful, they revealed limits of the invention or, in some cases, led to its replacement.

Atkin and Karplus clearly distinguished between the teacher's initial explication of a new concept or conceptual system (called the invention phase) and its subsequent test or extension (called the discovery phase). They assumed that children are not generally capable of inventing (what some would now call constructing) the modern concepts of science, therefore, it becomes necessary for the teacher to explicate those concepts, but making sure that the students' previous observations can be interpreted (or reinterpreted) using the explicated concepts. Further, the teacher must follow this with opportunities for the children to discover that new observations can be interpreted using the concept. Atkin and Karplus likened the process, in some respects, to the Copernican teacher instructing students that the sun is at the center of the solar system while almost everyone else believes that the earth is at the center. Atkin and Karplus did not introduce the terms "exploration" or "learning cycle" in their 1962 paper, but as mentioned, the terms invention and discovery were clearly evident.

During the summer of 1962, Professor Karplus accepted an invitation to work with the Elementary Science Study. There it became clear to him that children need time to explore an experimental system at their own pace with their own preconceptions. Only after this initial "exploration" is it wise to discuss a more analytical point of view. Armed with this new insight, Karplus tried out the modified approach the following school year in several public school classes near the University of Maryland where the SCIS program was temporarily headquartered. A number of new staff members joined the effort at that time including Dr. Herbert Thier, then Assistant Superintendent of Schools in Falls Church, Virginia. In 1967, Karplus and Thier published a book in which the three phases of the instructional method are first explicitly stated: "*The plan of a unit may be seen, therefore, to consist of this sequence: preliminary exploration, invention, and discovery*" (Karplus and Thier, 1967, p. 40).

ORIGINS OF THE LEARNING CYCLE IN BIOLOGY EDUCATION

Origins of the learning cycle can be found in biology education as well. In 1953, the National Academy of Sciences convened a Conference on Biology

Education to examine past teaching practices and suggest alternatives. As a result of that conference, a project funded by the National Science Foundation under the direction of Professor Chester Lawson, a geneticist at Michigan State University, began in the fall of 1956. The result of that project, which involved the work of 30 high school and university biology teachers from throughout the country, was a sourcebook of over 150 laboratory and field activities appropriate for use in high school (Lawson and Paulson, 1958). Although no explicit statement of teaching method resulted from that work, it provoked Professor Lawson and others to begin a search for such a method. The project also served as the precursor to the well known Biological Science Curriculum Study.

Professor Lawson, like Professor Karplus, turned his attention to the history of science for insight into the process of conceptual invention. His 1958 book, *Language, Thought and the Human Mind*, carefully detailed the nature of scientific invention and identified a general pattern of thought he referred to as "Belief—Expectation—Test" (Lawson, 1958). This pattern can now be seen to be similar to Karplus and Atkins' pattern of invention and discovery as conceptual invention constitutes a belief which in turn leads to an expectation to be tested in the real world. If one discovers confirming evidence the invention is retained. If not, it is rejected in favor of another belief.

Following work on the biology sourcebook, Professor Lawson began a careful review of current psychological and neurological research in hopes of developing a comprehensive theory of human learning complete with a model of relevant neurological mechanisms and instructional implications. The theory that resulted from that work stipulated that learning involves: (1) attention directed to some undifferentiated "whole," (2) the differentiation of the whole through the identification of its parts, (3) the invention of a pattern by which the parts are interrelated, (4) testing the invented pattern to see if it applies, and (5) use of the new pattern in other similar contexts. Lawson's theory would not be published until 1967 (Lawson, 1967); however, his literature search uncovered the Atkin and Karplus (1962) paper to which he had this to say:

> *If we substitute the term "initial unity" for system, "differentiation" for the identification of objects within the system, "pattern or relations" for invention, and "reinforcement" for discovery, we can see the relation of this teaching approach to our theory of learning.* (p. 119)

Thus the same pattern of instruction had been independently "invented" by Atkin and Karplus and by Lawson. When Karplus, the physicist, needed a biologist to assist in developing the life science half of the SCIS program, he called Lawson. What began for Lawson as a two-week consultation in the summer of 1965 ended with a ten-year job as director of life sciences within the SCIS program.

The final product of the SCIS program in the mid 1970s was a K-6 life science and physical science curriculum based on learning cycles. In addition to the efforts of Karplus, Thier and Lawson, Jack Fishleder, Rita Peterson, Robert Knott, Carl Berger, and Marshall Montgomery made substantial contributions as staff members during the development years. Mary Budd Rowe, Stanford Davis, John Renner, Albert Carr and Glenn Berkheimer also made substantial contributions to the development effort as coordinators of trial teaching centers in five locations across the country.

CHANGES IN THE NAMES OF THE PHASES OF THE LEARNING CYCLE

Interestingly, the name learning cycle does not appear in any of the early SCIS publications, although the phases of exploration, invention, and discovery are clearly spelled out (cf., Karplus and Thier, 1967; SCIS, 1973; Jacobson and Kondo, 1968). First use of the name learning cycle appears to be in the Teacher's Guides to the SCIS program units beginning in about 1970 (e.g., SCIS, 1970).

Use of the name learning cycle with its phases of exploration, invention and discovery continued by Karplus and others through 1975 (e.g., Collea, Fuller, Karplus, Paldy and Renner, 1975). However in 1976, it was becoming apparent that many teachers were having difficulty understanding what the terms invention and discovery meant in the context of classroom lessons. So in a series of 1977 publications Karplus decided to refer to the learning cycle phases as exploration, concept introduction and concept application (e.g., Karplus, Lawson, Wollman, Appel, Bernoff, Howe, Rusch and Sullivan, 1977).

Still others have chosen to modify the names further. For example, Lawson (1995) refers to them as exploration, "term" introduction, and concept application. This modification was suggested primarily because of the belief that the names of the phases are intended to convey meanings to teachers (not necessarily to students). Teachers can introduce terms during the second phase of the learning cycle; but they cannot introduce concepts. Concepts must be "invented" by students.

THE LEARNING CYCLE IN THE BIOLOGICAL SCIENCE CURRICULUM STUDY PROGRAM

Tables 4.1 and 4.2 summarize the learning cycle as used in curricular materials, produced by the Biological Science Curriculum Study (BSCS). Notice that the tables divide exploration into engage and explore phases. And the tables refer to term introduction as the explain phase and to concept application as the elaborate phase. In addition to these three phases, BSCS includes another phase called evaluate. Of course students and teachers need to evaluate learning, so the addition of an evaluate phase is not really new. Thus, the

Table 4.1. The BSCS Version of Learning Cycle Instruction: Teacher's Role.

Phase of the instructional model	What the teacher does	
	That is Consistent with This Model	**That is Inconsistent with This Model**
Engage	• Creates interest • Generates curiosity • Raises questions • Elicits responses that uncover what the students know or think about the concept/topic	• Explains concepts • Provides definitions and answers • State conclusions • Provides closure • Lectures
Explore	• Encourages the students to work together without direct instruction from the teacher • Observes and listens to the students as they interact • Asks probing questions to redirect the students' investigations when necessary • Provides time for students to puzzle through problems • Acts as a consultant for students	• Provides answers • Tells or explains how to work through the problem • Provides closure • Tells the students that they are wrong • Gives information or facts that solve the problem • Leads the students step-by-step to a solution
Explain	• Encourages the students to explain concepts and definitions in their own words • Asks for justification (evidence) and clarification from students • Formally provides definitions, explanations, and new labels • Uses students' previous experiences as basis for explaining concepts	• Accepts explanations that have no justification • Neglects to solicit the students' explanations • Introduces unrelated concepts or skills
Elaborate	• Expects the students to use formal labels, definitions, and explanations provided previously • Encourages the students to apply or extend the concepts and skills in new situations • Refers the students to existing data and evidence and asks: What do you already know? Why do you think . . . ? (Strategies from Explore apply here also.)	• Provides definitive answers • Tells the students that they are wrong • Lectures • Leads students step-by-step to a solution • Explain how to work through the problem
Evaluate	• Observes the students as they apply new concepts and skills • Assesses students' knowledge and/or skills • Looks for evidence that the students have changed their thinking or behaviors • Allows students to assess their own learning and group-process skills • Asks open-ended questions, such as Why do you think . . . ? What evidence do you have? What do you know about x? How would you explain x?	• Tests vocabulary words terms, and isolated facts • Introduces new ideas or concepts • Creates ambiguity • Promotes open-ended discussion unrelated to the concept or skill

From Biological Sciences Curriculum Study, 1992, *Science & technology: Investigating human dimensions*, Dubuque, IA: Kendall/Hunt, p. 15 and Trowbridge and Bybee (1990).

Table 4.2. The BSCS Version of Learning Cycle Instruction: Student's Role.

Phase of the instructional model	What the student does	
	That is Consistent with This Model	**That is Inconsistent with This Model**
Engage	• Asks questions, such as Why did this happen? What do I already know about this? What can I find out about this? • Shows interest in the topic	• Asks for the "right" answer • Offers the "right" answer • Insists on answers or explanations • Seeks one solution
Explore	• Thinks freely, but within the limits of the activity • Tests predictions and hypotheses • Forms new predictions and hypotheses • Tries alternatives and discusses them with others • Records observations and ideas • Suspends judgment	• Lets others do the thinking and exploring (passive involvement) • Works quietly with little or no interaction with others (only appropriate when exploring ideas or feelings) • "Plays around" indiscriminately with no goal in mind • Stops with one solution
Explain	• Explains possible solutions or answers to others • Listens critically to others' explanations • Questions others' explanations • Listens to and tries to comprehend explanations the teacher offers • Refers to previous activities • Uses recorded observations in explanations	• Proposes explanations from "thin air" with no relationship to previous experiences • Brings up irrelevant experiences and examples • Accepts explanations without justification • Does not attend to other plausible explanations
Elaborate	• Applies new labels, definitions, explanations, and skills in new, but similar situations • Uses previous information to ask questions, propose solutions, make decisions, design experiments • Draws reasonable conclusions from evidence • Records observations and explanations • Checks for understanding among peers	• "Plays around" with no goal in mind • Ignores previous information or evidence • Draws conclusions from "thin air" • Uses in discussion only those labels that the teacher provided
Evaluate	• Answers open-ended questions by using observations, evidence, and previously accepted explanations • Demonstrates an understanding or knowledge of the concept or skill • Evaluates his or her own progress and knowledge • Asks related questions that would encourage future investigations	• Draws conclusions, not using evidence or previously accepted explanations • Offers only yes-or-no answers and memorized definitions or explanations as answers • Fails to express satisfactory explanations in his or her own words • Introduces new, irrelevant topics

From Biological Sciences Curriculum Study, 1992, *Science & technology: Investigating human dimensions*. Dubuque, IA: Kendall/Hunt, p. 15 and Trowbridge and Bybee (1990).

only substantive difference exists in use of and/or need for a separate phase of engagement. Clearly students need to be engaged for learning to take place. Good explorations do this as they provoke the raising of questions and the elicitation of connections with past experience. However, some teacher comments to "set the stage" for exploration are usually a good idea. In short, Tables 4.1 and 4.2 do an excellent job of identifying just what teachers and students should be doing, and not doing, during the phases of learning cycle instruction.

The learning cycle is a very flexible method for instruction. Certainly for young children and for anyone who lacks direct physical experiences with a particular set of phenomena, the exploration phase should involve that direct physical experience. This, however, does not imply that all explorations have to be conducted this way. Indeed, I had the pleasure of taking a history of science course in graduate school taught using learning cycles where the explorations consisted of slide presentations, lectures and discussions. The class explored various scientists' ideas and activities in this way and only later "invented" the concept of science. The key point is that one can change the learning format of the three phases of the learning cycle, but one cannot change the sequence of the phases or delete one of the phases. If the sequence is changed, or if a phase is deleted, one no longer has a learning cycle.

Thus, the main thesis is that a situation that allows students to examine the adequacy of prior beliefs (conceptions) forces them to argue about and attempt to test those beliefs. This in turn provokes disequilibrium when those beliefs are contradicted and provides an opportunity for self-regulation and the construction of more appropriate concepts. Along the way students become increasingly conscious of and skilled in using the reasoning patterns (forms of argumentation) required for concept construction. In other words, they learn how to learn. The central instructional principle is that correct use of the learning cycle accomplishes this end (see Karplus, 1977 reprinted in this Chapter).

CURRENT STATUS OF THE LEARNING CYCLE

Most educational policy makers and theorists agree that the educational system should help students: (1) construct sets of meaningful and useful concepts and conceptual systems, (2) develop skill in using the reasoning patterns essential for independent, creative and critical thought, and (3) gain confidence in the ability to apply knowledge to learn, solve problems, and make carefully reasoned decisions. Modern learning cycle theory (the primary postulates of which are listed in Table 4.3) argues that the most appropriate way, perhaps the only way, to accomplish these ends, is to teach in a way that allows students to reveal prior conceptions and test them in an atmosphere in which

Table 4.3. Postulates of Modern Learning Cycle Theory (after Lawson, 1995).

(1) Children and adolescents construct personal beliefs about natural phenomena, some of which differ from currently accepted scientific theory.
(2) These alternative beliefs (misconceptions) may be instruction resistant impediments to the construction of scientifically accepted beliefs (conceptions).
(3) The replacement of alternative beliefs requires students to move through a phase in which a mismatch exists between the implications of the alternative belief and the scientific conception and provokes a "cognitive conflict" or state of mental "disequilibrium."
(4) The improvement of reasoning patterns (procedural knowledge) arises from situations in which students state alternative beliefs and engage in verbal exchanges where arguments are advanced and evidence is sought to resolve the contradiction.
(5) Argumentation provides experiences from which particular forms of argumentation (i.e., patterns of reasoning) may be internalized.
(6) The learning cycle, a method of instruction consistent with the way people spontaneously construct knowledge, provides the opportunity for students to reveal alternative beliefs and the opportunity to argue and test them, thus become "disequilibrated" and acquire more adequate conceptions as well as more powerful and effective reasoning patterns.

ideas are openly generated, debated and tested, with the means of testing becoming an explicit focus of classroom attention.

A considerable amount of research has been conducted, much of it reviewed by Lawson, Abraham and Renner (1989), supporting the claim that correct use of the learning cycle in the science classroom at all levels of instruction is effective in helping students move toward the stated objectives. This is good news, as is the fact that a recent electronic literature search turned up nearly 400 reports of research and development efforts using the learning cycle since 1989. Clearly use of the learning cycle method is growing as more and more educators learn of its effectiveness. Indeed, research has shown that the learning cycle is effective in other fields as well. For example, Kral (1997) used learning cycles to teach 12th grade English and found significant improvements on the English portion of the American College Test (ACT). This comes as no surprise to those of us who teach science using learning cycles. Nor is it a surprise to find that research in the neurosciences is confirming the belief-expectation-test model of brain activity and human learning upon which the learning cycle is based (e.g., Kosslyn and Koenig, 1995).

Another piece of very good news are the position statements on teaching methods recently taken by organizations such as the National Science Foundation (1996), the American Association for the Advancement of Science (1989, 1990), and the National Research Council (1995), and by many state and local boards of education. These position statements clearly spell out that science teaching should be consistent with the nature of scientific inquiry—that science should be taught as science is practiced. These declarations lead teachers directly to learning cycle instruction.

Unfortunately, not all the news is good. Some educators still have not heard of the learning cycle or if they have, they have yet to see its importance and appreciate the successful curricular reforms that have resulted from its implementation. In the words of Sir Isaac Newton (Holten and Roller, 1958, p. 185), "*If I have seen farther than others, it is by standing upon the shoulders of Giants.*" One could argue that as a country we could see farther if we found the shoulders of giants such as Robert Karplus to stand on. The ones who suffer as a consequence of our often uncoordinated efforts to improve instruction are our children. The relatively poor performance of secondary school students in the United States is well documented (United States Department of Education, 1998). As a country we need to develop a more coordinated effort, one which builds on past successes, so that our curriculum development and implementation efforts produce the kind of science instruction our children and nation so desperately need and deserve.

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The Learning Cycle

Suppose you are working with a class that is going to examine rocks and minerals, but has had no experience using magnifiers. You are planning activities that will give your pupils the necessary skill with magnifiers. Would you introduce magnifiers by

a. showing them to the class and demonstrating their use to look closely at a rock?
b. showing them to the class and then explaining their use by means of chalkboard diagrams of lenses and light rays before they are distributed?
c. distributing them to the children with the invitation to use them to look at objects on their desks, their hands, or at other things they would like to examine?

Compare your reactions with our comments on the alternatives:

a. This procedure is used very frequently to introduce unfamiliar pieces of apparatus; it provides the students with a model they can imitate in subsequent activities. This approach has the disadvantages—especially with young children—that your pupils may not be able to see the demonstration well because of the magnifier's small size, that they may not pay attention, and that they may not be able to relate what they see you do to their own actions later.
b. Since this approach is not directly relevant to the learner's needs, which relate to using the magnifier and not to the theory of how magnifiers are designed and used, we consider this plan to be unsuitable for learners of any age. We believe that they should be familiar with the operation of an instrument before becoming concerned with the theory on which it is based.
c. We usually take this approach in the SCIS program because it involves the children most directly. It also gives them an opportunity to explore various ways of using the magnifier so that they will later be able to adapt it to their needs in

different situations. Furthermore, it enables you to identify children who have difficulty so you can help them individually, while giving others the satisfaction of having figured it out for themselves or of having shared their findings with their classmates. This approach requires more time than the one described in (a), but we consider the time well spent. Only when there is danger of damage to an instrument (e.g., breaking a thermometer) would we describe certain procedures to be followed and others to be avoided.

The stages in the learning cycle. The preferred approach in (c) is an example of the exploration stage in the learning cycle that is used to organize activities in the SCIS program. The learning cycle consists of three stages that we call exploration, invention, and discovery. During exploration children learn through their spontaneous reactions to a new situation. In this stage children explore new materials and/or ideas with minimal guidance or expectations of a specific achievement. (Note: For simplicity in explanation, we have based our example of exploration on the introduction of the magnifier; in the SCIS teacher's guides, the learning cycle is usually applied to the introduction of a concept, as it is in the discussion on the next page dealing with the teaching of the interaction concept.)

During the invention stage you define a new concept or explain a new procedure in order to expand your pupils' knowledge, skills, or reasoning. This step should always follow exploration. Since the magnifier is relatively simple to use, many children may "invent" how to use it themselves; for others you can provide the necessary instruction individually. The invention lessons in the SCIS program serve to introduce concepts, such as interaction or life cycle, that few children can phrase for themselves. You will "invent" these concepts in an activity involving the entire class or with small groups.

The last stage of the learning cycle is discovery, during which a child discerns new applications for the concept or skill he has learned recently. The children's investigations of rocks and minerals after they have partially mastered use of the magnifiers are discovery activities that enable them to practice and refine their skill. Discovery is most effective when there is wide variety in the examples and materials investigated, so that each child can test what he has just learned under many differing conditions. Note that the investigation of the rocks, which serves as a discovery activity in relation to the use of magnifiers, can also function as exploration to introduce a new learning cycle concerning the classification of rocks and minerals. In this way, a longer teaching unit can be built up from a sequence of learning cycles.

To summarize, the basic intent of the invention lessons is to introduce definitions of new terms and concepts that relate these immediately to objects and actions, not merely to other words. The exploration lessons provide a background for the new idea, and the discovery lessons permit its further application and extension.

The following example deals with activities related to the interaction concept. Identify the stage of the learning cycle that is represented by each of the following four scenes, or point out why it does not fit any of the stages; then see our comments below.

a. The children experiment with tumblers of water and vials of copper chloride after the teacher asks them to look for evidence of interaction in their investigations.
b. After student assistants have distributed trays with magnets, water-filled tumblers, colored candy balls, light bulbs, scissors, paper, crayons, batteries, wires, and paper clips, the teacher invites the pupils to find out what these objects can do.
c. While the teacher is demonstrating with a large rubber band that is stretched tightly between his thumbs, he asks "Are my thumbs and the rubber band interacting now?"

d. While the teacher is demonstrating with a large magnet attracting a pair of scissors, he says "When two objects, like this magnet and the scissors, are doing something to each other, we say that the objects interact."

Comments:

a. This is an example of discovery because the children carry out experiments with their attention focused on evidence of interaction and not completely undirected. Note, however, that the teacher's instruction is still divergent in that the evidence of interaction may take many different forms. Presumably, the concepts of interaction and evidence of interaction were "invented" during an earlier science session.
b. Since the children are investigating materials with no specific focus from the teacher, this is exploration.
c. Here, the teacher is gathering feedback in a quick group activity. He is trying to determine whether most pupils respond knowledgeably to the term "interacting." In spite of the teacher's leadership, this is not an invention because the teacher is not explaining or defining.
d. Along with the demonstration, the teacher is defining the term "interact"; this is an example of invention, therefore.

Many experimental and longitudinal studies suggest that the amount of new information children can incorporate into their understanding is dependent both on the knowledge they have already and on the way that knowledge is organized. This finding highlights the importance of the exploration lessons, where the children are left largely on their own to explore and discover. These lessons enrich their experience, enable them to reorganize their knowledge, and provide opportunities for you to appraise to what extent they are accommodating their ideas to those presented in past invention lessons.

The SCIS program aims to nurture the children's ability to discover new relationships and to think imaginatively, at the same time as it facilitates the transition from preoperational to concrete or formal operational thought (see Chapter 3). Accordingly, it also includes invention and discovery lessons. The invention lesson provides guided practice in using new labels and categories. It is clearly teacher-directed and should provide an opportunity for each child to stretch his already acquired association of meanings for the objects in his world to include new meanings. The child accommodates his thought to that of the teacher as he imitates the teacher's classification or designations. Such momentary accommodation may have little effect on the child's ability to use the new concept, however, unless he can also try it out independently in new situations.

The discovery lessons leave the children somewhat on their own in order to test and eventually assimilate the new information. This kind of lesson also provides opportunities for children to make observations, perhaps paying attention to aspects of their world that have been highlighted for them in previous activities or perhaps focusing their attention on aspects uniquely and personally of interest to them.

To assist young children in making the transition from preoperational to operational thinking as expeditiously as possible, keep the different functions of the three stages of the learning cycle clearly in mind.

Learning theories. You are probably familiar with several psychological theories of learning that have been used in the development of educational materials. Best known is the theory of "learning-by-association," which views the student's behavior as a response to well-planned stimuli. With repetition, practice, correction of errors, and suitable rewards or punishment, the learner is expected to master the desired behavior. This is the theory behind rote learning of much of past education and has led to programmed instruction in more recent times. As usually applied, this theory leaves no room for spontaneous or creative expressions by the student.

A sharp contrast is provided by the theory of "learning-by-discovery," which claims that everything of which an individual is capable is latent within him. Given a sufficiently rich environment, the learner is expected to discover the properties of objects, the conditions under which interaction takes place, the principles governing energy exchange, and the concepts necessary for understanding life. In its extreme forms this theory allows no direct input that might limit or focus the student's natural interests.

Still another theory, based on the work of Jean Piaget, may be called "learning-by-reasoning." According to this theory, the student is brought to understand relationships through logical reasons provided by himself, the teacher, or classmates. Drill and practice, according to this view, are less important in learning than analysis and interpretation of a few problem situations.

We believe that all three of these learning theories have merit and that no one of them presents a complete picture that applies in all situations and to all individuals. The learning cycle of the SCIS program, therefore, reflects the three theories in a complementary way, using each of them for its strongest points but giving greatest weight to "learning-by-reasoning." The process of self-regulation to which Piaget ascribes intellectual development (see Chapter 3) is facilitated especially well by all three stages of the learning cycle taken in sequence. (The relationship of learning theories and the learning cycle is described in the *SCIS Omnibus*, page 126.)

For further investigation of the learning cycle, we suggest that you look for examples of exploration, invention, and discovery in an SCIS teacher's guide, some of the SCIS films, and your colleagues' teaching approaches. Discuss your conclusions with your friends and/or science consultant.