4

Inquiry and the Learning Cycle Approach

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Abstract

Inquiry, as an approach to instruction, is once again making a comeback. It is receiving the attention of teachers at all levels from grade school to college. The National Science Foundation, for example, is encouraging inquiry approaches in the funding of science education initiatives. What inquiry means to different people, however, varies widely. For some, it merely means having hands-on laboratory activities as part of a course. For others, it is a complex learning strategy that pervades all aspects of instruction and curricula. My intention in this chapter is to try and sort out these differences, call upon research and theoretical considerations to identify proven approaches, and provide guidelines for teachers who would like to adopt inquiry into their teaching.

Biography

I am a David Ross Boyd Professor of Chemistry, Adjunct Professor of Science Education, and director of freshman chemistry at the University of Oklahoma. I received a B.A. in Chemistry at Grinnell College, a Masters of Arts in Teaching from Emory University, and a Ph.D. in Science Education from Florida State University. I have taught science at all academic levels from elementary school to college. My research interests are in the field of science/chemical education, specifically instructional strategies, student misconceptions, and the use of computers in helping students visualize atomic and molecular behavior. I have developed curriculum materials using inquiry-oriented instructional strategies at the high school and university levels. At present, I direct the Ph.D. program in Chemical Education at the University of Oklahoma.

Background

In 1902, Alexander Smith, a chemistry professor at the University of Chicago, proposed that the teaching of chemistry should be laboratory based (DeBoer, 1991). His approach was called the Heuristic Method. In this approach, the laboratory played a central role in instruction and was used for two purposes: (1) the verification of chemical principles, and (2) the independent discovery of knowledge. The first use is how laboratory is typically taught in most college chemistry courses today (Abraham et al., 1997). The second represents what most instructors think of when they think of Inquiry as an instructional approach. Smith's approach established the laboratory as a component of instruction in chemistry and the idea that inquiry could be used in chemical education settings.

Inquiry, as an instructional strategy, again became important in the late 1950s with the advent of the National Science Foundation's support of science curriculum reform projects. It was stated that inquiry was a process important to science and as such should be used as a strategy for the instruction of science (DeBoer, 1991, p. 206). It was argued that science instruction should be consistent with the nature of science in order to model scientific processes for students.

Two high school chemistry curriculum projects were originally developed with support from the NSF. They were the Chemical Bond Approach—CBA (Westmeyer, 1961), and the Chemical Education Materials Study—

CHEM Study (Merrill, 1961). The CBA project was more innovative in its instructional approach. The laboratory portion of the course gradually built students toward doing open-ended research-oriented activities by the end of the year. However, the CBA project never caught on. It was felt by many that the approach expected too much from students and the content was too different from the standard chemistry curriculum. As a consequence, although its version of inquiry was a purer example than that of the CHEM Study approach, it didn't have the influence on high school instruction that CHEM Study had. The CHEM Study laboratory program was designed to introduce concepts. Although CHEM Study had a major influence on high school chemistry instruction, the major focus of that influence was not on inquiry-oriented instructional strategies but rather on the revision of the chemistry curriculum toward more modern concepts and principles.

One of the first modern examples of the use of inquiry in college chemistry laboratories was Jay Young's laboratory manual *Practice in Thinking* (Young, 1958). This manual was divided into three parts. Part 1 introduced the student to laboratory procedures and techniques. Part 2 gave the student a group of laboratory actions to perform that illustrated some phenomenon that the student was asked to explain. Part 3 asked the student to design an experiment to demonstrate or prove a chemical idea.

Recently, Inquiry as an instructional strategy, and as an educational outcome of the study of science, has once again become a major emphasis of governmental and professional societies concerned with the improvement of science education at the high school and college levels (Olson and Loucks-Horsley, 2000).

What is Inquiry Teaching?

Inquiry teaching is usually associated with several instructional practices. One of these is the use of the laboratory to introduce concepts rather than verify them. This is sometimes referred to as an inductive use of the laboratory because of its connection to inductive logic—reasoning from specific facts to a generalization. This is in contrast to the more common deductive use of the instructional laboratory—to reason from a known principle to a specific example to verify the principle. A second characteristic of inquiry teaching is the role of the teacher as a guide or facilitator of learning, rather than as source of information. This emphasis manifests itself in the use of questions as the main instructional tactic in the interaction with students. Another characteristic of inquiry teaching is the use of problem-solving activities. Finally, the inquiry teacher will often focus on the processes of science as well as the concepts of science as the goal of instruction.

One of the criticisms of the Inquiry approach is that science has both inductive and deductive functions. As a consequence, it is claimed that the scientific practice of verifying theories (exposition) was being ignored in inquiry teaching (DeBoer, 1991, p. 208; Lawson, 1995, p. 212). Of course, it might be similarly argued that in traditional instruction, the inquiry nature of science was being ignored. Nevertheless, it is reasonable that both characteristics of science should be included in an instructional strategy used to teach science.

Another criticism of Inquiry is its perceived heavy reliance on laboratory as a source of data for generating concepts. It is said that this is an inefficient use of students' time. Joseph Schwab (1963) showed that the Inquiry approach could be based on data sources other than hands-on laboratory. He used verbal presentations of data, called "Invitations to Inquiry," as a starting point for class discussions (see also Gosser, Strozak, and Cracolice, 2001; Moog and Farrell, 2002).

Some have argued that there is no evidence that Inquiry is an effective way to teach. This is simply not true. There is actually an extensive research literature showing that inquiry-oriented teaching strategies have advantages over traditional instructional approaches in attitudes, motivation, and concept and process learning (Lawson, Abraham, and Renner, 1989; Lawson, 1995; Abraham, 1998; Rudd, Greenbowe, and Hand, 2002; Rudd, Greenbowe, Hand, and Legg, 2003). However, as is true of most things in learning and teaching, breaking down the details of this assertion is important for a true understanding of these advantages. (See issue #1 at the end of this chapter.)

Inquiry as Tactic versus Inquiry as Strategy

In the military, a distinction is made between strategy and tactics. Strategy refers to large-scale planning and development to ensure an overall end. Tactics deal with the use and deployment of procedures for obtaining an advantage. The distinction can be seen as a matter of scale. The same distinction can be made between instructional strategies and instructional tactics. Instructors have used the term Inquiry to describe a variety of quite different instructional activities. Using the strategic/tactic distinction, Inquiry can be seen as instructional activities that range all the way from the simple use of questions to the practice of open-ended research. Inquiry as a tactic (e.g., the use of questions) can be seen in the same light as other instructional tactics like the use of concept maps or the group work characteristic of cooperative or collaborative learning. These tactics can be utilized within an overall instructional strategy. An instructional strategy can be seen as the arrangement, combination, and form of learning activities, materials, and instructional tactics designed to meet educational objectives. An inquiry tactic can be used within a lesson or activity while an inquiry strategy would be the overall plan of action for a unit of instruction. Although tactics are important—after all, the success of a strategy depends on using effective tactics—my purpose here is to discuss what I think are some of the issues associated with adopting Inquiry as an instructional strategy.

Instructional Strategies

A useful way of characterizing an instructional strategy used to teach scientific concepts is to divide instruction into phases that play important roles in the instructional process. These include: (1) identification of the concept; (2) demonstration of the concept; and (3) application of the concept. Many science educators have recommended instructional strategies consisting of these phases, although some have subdivided the phases into more components or have added additional components like evaluation (Karplus and Thier, 1967; Torrance, 1979; Hewson, 1981; Renner, 1982; Bybee and Landes, 1990; Rudd, Greenbowe, Hand, and Legg, 2001). Differences among instructional strategies can be characterized by three characteristics: whether all of the phases are included in the unit of study, how the three phases are arranged (i.e., their sequence), and the formats of the activities in each of the phases: laboratory, discussion, lecture, readings, problem sets, etc. (Abraham 1988–89).

In order to illustrate these ideas, two instructional strategies will be compared with regard to phases of instruction (Renner 1982).

Traditional (Concept → Data)

Phases of Instruction	Goal	Activities	Questions	Data
Inform ↓	Present Concept	Lecture / Discussion, Readings	What is the concept?	
Verify Concept ↓	Confirm the truth of concept	Laboratory, Demos	How do your observations fit the concept?	Confirm Concept with data, Provide Evidence
Practice Concept ↓	Apply, reinforce, review, extend, and understand concepts	Readings, Problem Sets, Application Questions,	Using what you know, answer the following...	
Evaluate		Examinations, Quizzes		

Figure 1. Characteristics of Traditional Instruction.

The Traditional Approach to General Chemistry

At the present time, general chemistry is taught in colleges and universities in a fairly uniform way. As represented in Figure 1, this teacher-centered instructional strategy can be seen as being divided into phases that are taken in order. First, students are assigned readings in a textbook, are expected to attend lecture where often the same material is presented, and listen passively while taking notes. This might be called the "Inform Phase" and is used to identify the concept. This phase is followed by a laboratory activity that either verifies the concept that students were already informed about in lecture (called the "Verification Phase," which demonstrates the concept), or is completely unrelated to what is being covered in lecture. Then, students are assigned problems from the end of the chapter in the textbook (called the "Practice Phase," which applies the concept). After a period of time, they are given an examination to test what they have learned. The "Inform—Verify—Practice" (I—V—P) sequence corresponds to the three phases previously discussed. For many reasons, not the least of which is the negative attitude of students, many chemistry instructors have become dissatisfied with this approach.

The Learning Cycle Approach

An alternative instructional strategy is a student-centered inquiry-oriented approach called the Learning Cycle (Lawson, Abraham, and Renner, 1989; Lawson, 1995; Marek and Cavallo, 1997). The Learning Cycle approach, as represented in Figure 2, can also be seen as being divided into phases that are taken in order. First, students are exposed to data (called the "Exploration Phase," which demonstrates the concept) from which concepts can be derived (called the "Invention Phase," which identifies the concept). Students can then apply the concept to other phenomena (the "Application Phase," which applies the concept). In contrast to the traditional approach, this inquiry-oriented approach is based upon data. This difference has several consequences for the role played by various instructional activities. Laboratory and other data generating activities play a more central role in instruction by introducing concepts rather than verifying concepts. The curriculum can be said to be data driven. Classroom discussions are focused on using data to generate concepts rather than informing students of the concepts. Textual materials are used to apply, reinforce, review, and extend concepts rather than introduce concepts. This approach encourages more active learning by students.

Inquiry (Data → Concept)

Phases of Instruction	Goal	Activities	Questions	Data
Explore ↓	Explore relations and patterns in data	Laboratory, Demos, MoLES, Lab Simulations, Video	What did you do? What did you observe?	Gathering Data
Invent Concept ↓	Develop and understand concepts with teacher/peers	Lecture / Discussion	What does it mean?	Explaining Data
Apply Concept ↓	Apply, reinforce, review, extend, and understand concepts	Readings, Problem Sets, Application Questions, Verification Laboratory	Using what you know, answer the following...	Using Data, Provide Evidence
Evaluate		Examinations, Quizzes		

Figure 2. Characteristics of the Learning Cycle Approach.

The Learning Cycle approach is an inquiry-based instructional strategy derived from constructivist ideas of the nature of science (Bodner, 1986), and the developmental theory of Jean Piaget (Piaget, 1970). Although Piaget's theories are too complex to discuss in detail here, a brief consideration of one aspect of his ideas is provided to clarify how the Learning Cycle approach is consistent with these ideas. According to Piaget, human beings have mental structures that interact with the environment. We assimilate or transform information from our environment into our existing mental structures. Our mental structures operate on the assimilated information and transform it in a process of accommodating to it. Thus, information from the environment transforms our mental structures, while at the same time, our mental structures transform the information. This change is driven and controlled by the process of disequilibration. If there is an incompatibility between the assimilated information and existing mental structures, disequilibration takes place. This requires a change or accommodation of the mental structure or a change in the perception of the assimilated information. When our mental structures have accommodated to the assimilated information, we are in a state of equilibrium and have reached an "accord of thought with things" (Piaget, 1963, p. 8). In accommodating the new information, however, the altered mental structure can become disequilibrated with related existing mental structures. The new structure must be organized with respect to the old structures to develop a new equilibrated organization. In other words, we must bring the "accord of thought with itself" (Piaget, 1963, p. 8). This overall process, called Piaget's functioning model, has implications for instruction. (For an overview of Piaget's theories, refer to Dudley Herron's *Journal of Chemical Education* article, "Piaget for Chemists" (Herron, 1975), and Good, Mellon, and Kromhout's article "The Work of Jean Piaget" in the same journal (Good, Mellon, and Kromhout, 1978).)

If learning spontaneously occurs through a process of assimilation accommodation and organization, then instruction could take advantage by sequencing instructional activities to be compatible with the nature of learning. In order to facilitate assimilation, instructional activities should expose the learner to a segment of the environment that demonstrates the information to be accommodated. This should be followed by activities that help the learner to accommodate to the information. Finally, in order to organize the accommodated information, activities should be developed to help the learner to see the relation between the new information and other previously learned information. The parallels between Piaget's functioning model, the Learning Cycle approach, and learning activities are illustrated in Figure 3.

Piaget's Functioning Model	Learning Cycle Teaching Model	Learning Activities and Materials
Assimilation	Exploration	Data Collection and Analysis
Accommodation	Concept Invention	Conclusions and/or Interpretation
Organization	Application	Application Activities

Figure 3. Piaget Functioning Model and the Learning Cycle Approach.

There are several characteristics which, when used in combination, establish the Learning Cycle approach as a distinct instructional strategy. The most important of these is the presence of the three phases of instruction in a specific sequence: "exploration—concept invention—concept application" (E—I—A). This sequence has a number of logical consequences. The "Exploration Phase" coming first implies that learners will use the information gained during the learning activity to propose or invent an explanation. This is an inductive use of data (proceeding from the specific to the general). The key to this instructional approach is that the learner derives the concept from their observations of the behavior of a chemical system. In this sense, data plays a central role in instruction. In the "Application Phase," learners use the invented concept to verify and modify their ideas. This is a deductive use of data (proceeding from the general to the specific). The learning cycle approach has advantages over other instructional strategies because it takes into account both inquiry and exposition. That is, it requires the learner to use both inductive and deductive logical processes.

There has been a large amount of research concerning the Learning Cycle approach since its origins in the 1960s. Most of the research supporting the Learning Cycle approach is discussed in detail in Lawson, Abraham, and Renner (1989). A summary of this research supports the conclusion that the Learning Cycle approach can result in greater achievement in science, better retention of concepts, improved attitudes toward science and science learning, improved reasoning ability, and superior process skills than would be the case with traditional instructional approaches (see Raghubir, 1979; Renner, Abraham, and Birnie, 1985; Abraham and Renner, 1986; Ivins, 1986; McComas III, 1992). This is especially true with intermediate level students where instructional activities have a high level of intellectual demand (Lott, 1983).

Issues in the use of Inquiry as an instructional strategy

Issue #1— What are you trying to teach? "There is no one best way to teach" is an educational cliché that, although having elements of truth, is so general that it offers no guidance to practicing teachers. This cliché might be incorrectly interpreted to mean that it makes no difference how one teaches. A better interpretation is that different learning outcomes are best approached by different instructional means (Gagné and Briggs, 1979; Gagné, 1985). A useful way to address this dilemma is to divide the learning outcomes of a chemistry course into categories. Figure 4 lists these outcomes as concepts, processes, skills, facts, and attitudes. It is useful to do this because different specific instructional tactics have been shown by research to be educationally effective for different categories of learning.

Category of Learning	Definition	Example	Instructional Tactic
Concepts	Generalization, Principle, or Theory	Conservation of Mass	Inquiry—Questioning
Processes	Method	Separation and Control of Variables	Practice
Skills—Laboratory —Mathematical	Ability	Using a Balance Curve Fitting	Informing or Demonstrating
Facts	—Observation —Definition	Cu^{2+}(aq) is blue Ag is silver	Observing Informed in Context
Attitudes	Beliefs or Feelings	Chemistry is Fun	Example

Figure 4. Effective Instructional Tactics.

Concepts are theories or principles that are used to explain phenomena. Research has shown that inquiry tactics (e.g., the use of questioning) are the best instructional tactics for concept learning. In traditional instructional strategies, concepts are often treated as facts. As a consequence, less effective instructional tactics (e.g., lectures) are commonly used.

Processes are methods. The science education literature has developed a long list of these processes. A representative list can be found in Table 1 (Livermore, 1964). Research has shown that scientific processes are best learned by practicing them in multiple settings.

There are two kinds of skills of interest: laboratory skills and mathematical skills. Unlike processes, skills are more specific to particular situations. However, there is some overlap between processes and skills. Skills are best learned by being shown how to use the skill by an expert.

Facts are truths. They are true either by definition or by observation. Although teachers often require their students to memorize facts, a more effective approach is to teach facts in context by using them to develop concepts. Students find it easier to remember factual information if related facts are associated with a concept or principle.

Finally, attitudes are learned through example.

The Learning Cycle approach gives an instructor the opportunity to expose students to all of these categories of learning. Learning cycles are generally built around concepts. These concepts are usually introduced in a laboratory setting or some other source of data from which the concept can be developed through discussion. The collection, manipulation, and interpretation of data give students ample opportunity to practice scientific processes. In the laboratory, students learn how to use equipment and procedures. In processing data, they learn various mathematical skills. During their observations and discussions, they are exposed to factual information connected with the topic they are studying. In using the ideas that they gain from their activities, they can again use processes to expand their understandings.

Table 1—Scientific Processes

Basic Processes	Integrated Processes
Observing	Hypothesizing
Using Time/Space Relationships	Controlling Variables
Orienting	Interpreting Data
Measuring	Reasoning (Inductive and Deductive)
Classifying	Drawing Conclusions
Identifying and Differentiating	Evaluating
Discriminating	Defining Operationally
Communicating	Experimenting
Describing	Modeling
Comparing	
Predicting	
Inferring	

Issue #2—How do you design inquiry-oriented activities? Following is a set of guidelines for constructing inquiry activities using the Learning Cycle approach.

1) Identify the concept/principle/law that you are trying to teach as the target of the activity. This is the tricky part. This should be a big idea, not a skill or fact. The activity should concentrate on a single concept, certainly not more than two. If more than two concepts are involved, you should subsume them under a larger and more central concept, put them in separate activities, or address them in follow-up application activities related to the main concept.
2) Write a concept statement. This should be a brief description of the concept to be taught.
3) Write a problem statement/question. This should be a descriptive statement or question whose answer leads to the concept. Be careful to not give the concept away in the statement. These statements can be used to introduce the activity to students.
4) Identify the data/observations that can be used to explore the concept. Write procedures that will cause students to collect that data and/or make the observations.
5) If necessary, write procedures that will cause students to organize the data into a form that will facilitate interpretation (e.g., in tabular or graphical form).
6) Write questions or procedures that will lead the student to interpret the data or to draw a conclusion that will develop the target concept.
7) Write questions or activities that will lead the student to use or apply the concept in a new setting.
8) Optional: Ask students to represent, model, or visualize the invented concept at the molecular level by drawing a diagram(s) that explains/represents/models their observations.
9) Optional: Write questions that ask students to design experiments that will answer these questions. These can be used to cause students to explore related concepts, reinforce the concept, or apply the concept. Use anticipated or observed student misconceptions to generate open-ended challenges (e.g., "prove or disprove the following statement...").

Pre-laboratory activities should be limited to safety in the laboratory and procedures and skills necessary to do the activity. It should not tell the students what the concept to be learned is, how to do the laboratory, what they will observe, or what they will conclude.

As an example of a simple learning cycle lesson, consider the following instructional activity designed to teach the concept of acids and bases (Abraham and Pavelich, 1999a, p. 99). The concept statement might be "Acids are any species that produces H^+ ions in water solution. Bases are species that produce OH^- ions in water solution." The problem statement might be "What are the characteristics of acid and base solutions?" Students are provided with a number of unknown solutions and asked to perform tests that might include the use of several acid/base indicators, the interaction of the solutions with active metals (which react with acids), and interaction of the solutions with soluble metal ion solutions (which precipitate in bases). They might also be asked to measure the conductivity of each solution. During this "Exploration Phase" of instruction, students are asked to identify patterns that enable the unknown solutions to be grouped. During a subsequent class discussion, the students would compare data and notice that the solutions could be classified into three groups. The instructor then might define these groups operationally and label them as acids, bases, and neutral substances ("Concept Invention Phase"). Depending on the age and scientific sophistication of the students, the instructor might continue the discussion by introducing the chemical formulas of the solutions and ask what the formulas in each category have in common. This information could be used to invent a theoretical definition of acids and bases. Using these ideas, students might then be given "Application Phase" activities involving additional solutions to fit into the classification scheme. They also might be asked to rationalize the acid/base characteristics of substances that don't seem to be consistent with the previously invented acid/base theory.

Issue #3—What kind of questions should be used? One of the most important tactics of inquiry instruction is the use of questions (Dillon, 1983; Saunders and Shepardson, 1987; Bateman, 1990; Mazur, 1997). A way to analyze this tactic is to classify questions according to type in order to guide their use. A useful classification scheme is discussed by Pavelich (1982) and is based on the level of thinking processes necessary for students to respond.

Another way of addressing questioning is to look at what kinds of questions can be used with data driven activities like those of a learning cycle (see Table 2). Questions used by an instructor during or right after an exploration activity might be *What did you do?* and *What did you observe?* These questions serve a useful role in a class discussion. The *What did you do?* question serves to orient the students to the focus of the discussion. The *What did you observe?* question establishes consensus concerning what happened, allows students to resolve differences, and encourages a focus on the data that will be used to invent the target concept. During the "Concept Invention Phase," the question type used by the instructor is *What does it mean?* This question allows students to invent a concept or have a concept invented for them by the instructor. Finally, during the "Application Phase," students can be asked to answer questions that require the concept as prerequisite knowledge.

Issue #4—How do instructional tactics fit into the Learning Cycle Strategy? Other instructional tactics besides questioning can be utilized in a learning cycle. Student generated concept maps are a research-proven method for helping students to organize their knowledge of a concept with other related concepts (Novak and Gowin, 1984; Novak and Wandersee, 1990). As such, the construction of a concept map is an excellent "Application Phase" activity. (See Chapter 11.)

Cooperative learning and other small group tactics are also an excellent research-proven replacement for more formal teacher-led discussions and lectures (Johnson, 1991; Johnson, Johnson, and Holubec, 1993). Cooperative procedures can also be used in laboratory (Cooper, 2003: Abraham and Pavelich, 1999b, p. 13). Cooperative learning activities can be used in many of the phases of the learning cycle approach. As "Exploration Phase" activities, they can be used by students to explore the *What did you observe?* question (for a non-laboratory example, see Moog and Farrell, 2002); as "Concept Invention Phase" activities to organize their data and begin to address the *What does it mean?* question, and as "Application Phase" activities to address extensions of their concept (e.g., Gosser, Strozak, and Cracolice, 2001).

The science writing heuristic (Rudd, Greenbowe, and Hand, 2002; Rudd, Greenbowe, Hand, and Legg, 2003) can also be used as a format for the laboratory portion of a course. This approach encourages students to formalize their inquiry into chemical systems by giving students an inquiry-based procedure for planning and reporting their chemical investigations.

Issue #5—Guided versus Open Inquiry. Inquiry-oriented instructional strategies are usually placed in one of two categories, guided or open. A useful way to look at this distinction was first proposed by Pella (1961) and was used to distinguish types of laboratory activities. Figure 5 is based on Pella's vision. This figure identifies components of instructional laboratory work and asks the question, *Who is in charge of the decision making for that component, the teacher (T) or the student (S)?* In the traditional or verification laboratory, the teacher is in charge of making all of the decisions. In open inquiry, the student is in charge of all of the decisions. In guided inquiry, the teacher and student share the responsibility for decision-making.

	Verification	Guided Inquiry	Open Inquiry
Choose Problem	T	T	S
Design Experiment	T	T	S
Collect Data	T	S	S
Interpret Results	T	S	S

Figure 5. Degree of Freedom in Instructional Strategies.

In a research study (Abraham, 1982), students were exposed to the three laboratory types in Figure 5 and asked to describe the main characteristics of their laboratory experience by choosing from a list of 25 descriptive statements. According to these students, the major goal of the verification laboratory was to develop skills in the techniques and procedures of chemistry. Students said they followed step-by-step instructions, recorded information required by the instructions, and discussed their data and conclusions with each other. Laboratory was characterized as requiring interpretation of data and answering specific questions. Instructors were said to be mostly concerned with the correctness of the data collected by students. Students in guided inquiry laboratory said they followed step-by-step instructions, answered specific questions, and discussed and explained laboratory phenomena. These students said that laboratory reports required them to provide evidence to back up their conclusions. Students said that open inquiry laboratory required them to back up their conclusions with evidence. Students also said they designed their own experiments.

Using these ideas, the distinction between guided and open inquiry can be characterized as the degrees of freedom in decision-making allowed to students. Open inquiry activities can play a useful part in a learning cycle. For example, an "Application Phase" laboratory activity could ask the student to design and carry out an experiment to investigate an application of the concept they developed earlier (Abraham and Pavelich, 1999a, p. 275). If a student developed a misconception associated with an investigation, he/she might be challenged to design an experiment to prove or disprove their conception.

Summary

The Learning Cycle Approach is an inquiry-oriented instructional strategy that has great promise for chemistry instruction. It has a solid research base testifying to its effectiveness. It has been shown to be superior to traditional instructional approaches developing achievement in science, retention of concepts, improved attitudes toward science and science learning, improved reasoning ability, and process skills. This has been shown to be especially true with intermediate level students where instructional activities have a high level of intellectual demand. The Learning Cycle Approach gives guidance to instructors as to how to interact with students during instruction, how to design activities for classroom use, and what to emphasize as the goal of instruction. A wide variety of proven instructional tactics can be utilized within its format.

Suggestions for Further Reading

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