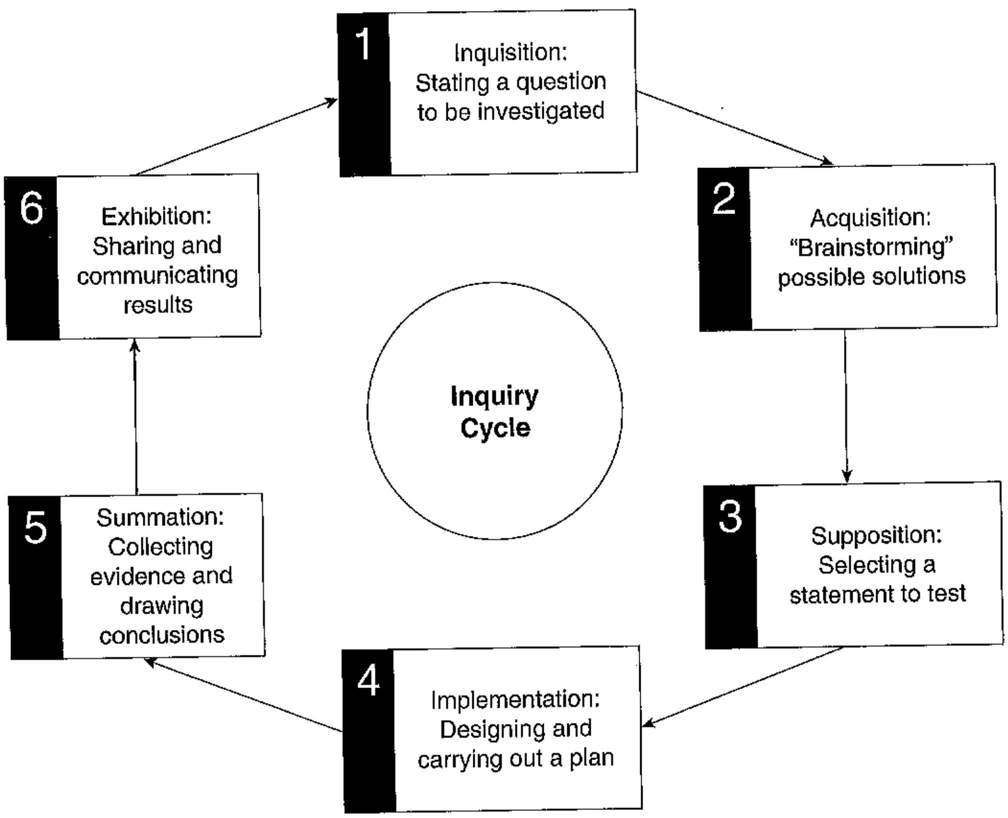
3. What are the benefits of making a concept map?
4. Why did the teacher have students explore their pillbugs before presenting and explaining the Isopod Fact Sheet?
5. How difficult is it for a teacher to monitor 8–12 investigations going on simultaneously?
6. What is the value in having students make presentations to the class? How can presentations support speaking and listening skills? Computer skills?

THE INQUIRY CYCLE

"Inquiring With Isopods" is just one example of an exploration that encourages students to raise questions. In analyzing the group's work, the *Inquiry Cycle* (see Llewellyn, 2002) represents aspects of most inquiry-based investigations (see Figure 2.4):

Figure 2.4 The Inquiry Cycle



1. Inquisition—stating a "what if" or "I wonder" question to be investigated
2. Acquisition—brainstorming possible procedures
3. Supposition—identifying an "I think" or "If . . . then" statement to test
4. Implementation—designing and carrying out a plan
5. Summation—collecting evidence and drawing conclusions
6. Exhibition—sharing and communicating results

During the inquisition phase, students usually initiate their inquiry by exploring and posing a question. The question is often stated as a "What if . . ." question. The question can originate from an open-ended exploration, as with the isopods, or as a discrepant event, or a teacher-directed activity. In the "Inquiring About Isopods" investigation, the inquisition phase was initiated by the initial exploration activity.

During the acquisition phase, students rely on their prior experience to brainstorm possible ideas and solutions to the inquiry. Here students ask, "What do I already know about pillbugs to answer the question?" In the acquisition phase of the isopod exploration, students' prior conceptions about isopod behavior may have affected how they perceived the outcome of their question.

During the supposition phase, students consolidate the information under study to propose a "testable" prediction or an "I think . . ." statement. This phase generally includes stating a hypothesis to test the question being investigated.

During the implementation phase, students design a plan to address or test their prediction and carry out the plan.

During the summation phase, students record and analyze their observations to compare them to the original "What if . . ." statement.

Finally, during the exhibition phase, the students communicate their findings and new information in the form of a written laboratory report, a poster display, an oral report, or a PowerPoint presentation. In the isopod lesson, the groups were eager to share their discoveries and new knowledge about invertebrate behavior.

The inquiry cycle can serve as a general format for teachers planning inquiry-based investigations for their students. We should be reminded that the model serves as a general approach to raising and answering questions. Following the inquiry cycle, students often enter and reenter the phases at different aspects of their inquiry process. Thus, the cycle serves as a model to guide students through their inquiries and investigations.

BRAINSTORMING

As you can see, during the acquisition phase, brainstorming is an essential element of scientific inquiry. Brainstorming is not a tool for determining the best solution to a problem or issue but rather a means for generating as many ideas or solutions as possible to a question, a problem, or an issue. As high school science teachers, we often underutilize the value of brainstorming in the inquiry process. This may be due to the added amount of time the discussion process takes. Often, we are in a rush to move the inquiry process along as quickly as possible. In any event, for students to be effective problem solvers, we must teach them how to engage in a thoughtful dialogue and brainstorm ideas to become effective group members. When we take time for students to be involved in brainstorming, we foster higher-level thinking skills such as analyzing, synthesizing, and making judgments and evaluations, as well as habits of mind such as creativity, openness, and reflection. Teachers who plan for brainstorming sessions during scientific inquiry communicate to students that discourse and dialogue are integral aspects of the classroom culture.

Before beginning any effective brainstorming session, ground rules must be set. This does not mean that rules or boundaries are set so tightly that students cannot be creative. It does mean, however, that a code of conduct for person-to-person interactions has been set. It is when this code of conduct is breached that people stop being creative and the brainstorming and sharing process degenerates.

The best way to set meaningful ground rules is to have the students or teams create their own. In the beginning of the school year, and before small group discussions, allow students to create their own brainstorming ground rules. This should provide an opportunity to practice the skills necessary for an effective brainstorming session. It also allows the students or teams to take ownership of acceptable and unacceptable behaviors. Once the list of ground rules is generated, be sure to gain consensus that brainstorming sessions will be conducted according to them, then post them in a highly visible location in the room.

With procedures for setting ground rules in mind, the following are key rules that high school students often identify as useful when conducting a brainstorming session.

- There are no dumb ideas. It is okay to give a wild or wacky idea. This is a brainstorming session, not a serious discussion that requires only serious solutions.
- Don't criticize other people's ideas. This is not a debate, discussion, or forum for one person to display superiority over another.
- Build on other students' ideas. Often, an idea suggested by one student can trigger a bigger or better idea by another student.
- Strive for quantity over quality; the more creative ideas, the better. As the teacher/facilitator, make a challenge to the teams to come up with as many ideas as possible.
- There are no "put-downs" or judgments made of individual ideas or suggestions.
- All ideas are recorded. One team member may be selected as the recorder.
- Everyone in the group is encouraged to contribute.
- There are no lengthy discussions. Contributions made should be to the point. Set a time limit on the discussion/brainstorming session.

To clarify the roles and responsibilities of the individual group members, consider the following preparation questions:

- What is the desired outcome of the brainstorming session?
- Who will lead or facilitate the brainstorming session to meet the outcome?
- Who can write quickly enough to record the ideas contributed without slowing down the group process?
- Who will keep time for the discussion session?
- Who will report the findings of the brainstorming session to the entire class?

During the inquiry process, a brainstorming session usually starts with an idea or a question. The question, in turn, often leads to a divergent level of thinking toward a solution to the question. Everyone in the group is given a chance to talk or give input without comments or a debate. This is followed by a convergent level of thinking designed to build consensus in reducing all the possible solutions to a manageable few, discussion of the few that remain, and selection of an acceptable procedure to investigate.

During this process, the teacher makes periodic process checks with each of the groups and clarifies questions that are unclear or confusing. Students may need assistance from the teacher in eliminating or combining procedures to form a better investigation. Students may also need assistance in ordering individual steps of the investigation into a logical pattern or sequence. In the end, students should determine if the procedure or solution is appropriate and meets the purpose of the question. In other words, does this procedure lead us to answering the question being investigated?

Why Brainstorming Fails

Science teachers may find that during the inquiry process, brainstorming sessions sometimes fail because of the role played by the facilitator, a pivotal part of the discussion process. Thus, the teacher's selection of the student facilitator is extremely important. A good facilitator creates a trusting climate, stays neutral throughout the discussion, treats all members as equals, listens intently, remains flexible, and provides closure to the discussion. A poor facilitator, on the other hand, becomes the center of the group's activity, puts down other students' ideas, does not manage group conflict, is passive, allows a few people to dominate the process, or lets discussion ramble.

A DEFINITION OF INQUIRY

As you can see from the isopod investigation, inquiry is the scientific process of active exploration by which we use critical, logical, and creative thinking skills to raise and engage in questions of personal interest. Driven by students' curiosity and wonder about observed phenomena, inquiry investigations usually involve

- generating a question or problem to be solved,
- brainstorming possible solutions to the problem,
- stating a hypothesis to test,
- choosing a course of action and carrying out the procedures of the investigation,
- gathering and recording the data through observation and instrumentation to draw appropriate conclusions, and
- communicating their findings.

As high school students communicate and share their explanations, inquiry helps them connect their prior understandings to new experiences, modify and accommodate their previously held beliefs and conceptual models, and construct new knowledge. In constructing newly formed knowledge, students generally are cycled back into the processes and pathways of inquiry with new questions and discrepancies to investigate.

In the isopod investigation, we saw students exhibiting five essential features of classroom inquiry:

- Learners are engaged by scientifically oriented questions.
- Learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically oriented questions.
- Learners formulate explanations from evidence to address scientifically oriented questions.
- Learners evaluate their experiences in the light of alternative explanations, particularly those reflecting scientific understanding.
- Learners communicate and justify their proposed explanations. (NRC, 2000a, p. 35)

Finally, learning through inquiry empowers high school students with the knowledge, skills, and dispositions to become independent thinkers and lifelong learners. Teachers can encourage students to use communication, manipulation, and problem-solving skills to increase their awareness of and interest in science and guide them on their way to becoming scientifically literate citizens.

The inquiry approach requires a different "mind-set" and different expectations on the part of the teacher. In subsequent chapters, we will describe in more detail this mind-set and the role teachers and students play in inquiry-based classrooms.