the targeted concept of the lesson. During discussion, the teacher and students compare how the newly introduced concept affects students' preconceptions. The teacher can further explain the concept by using the textbook, audiovisual aids, and other materials (Beisenherz & Dantonio, 1996).

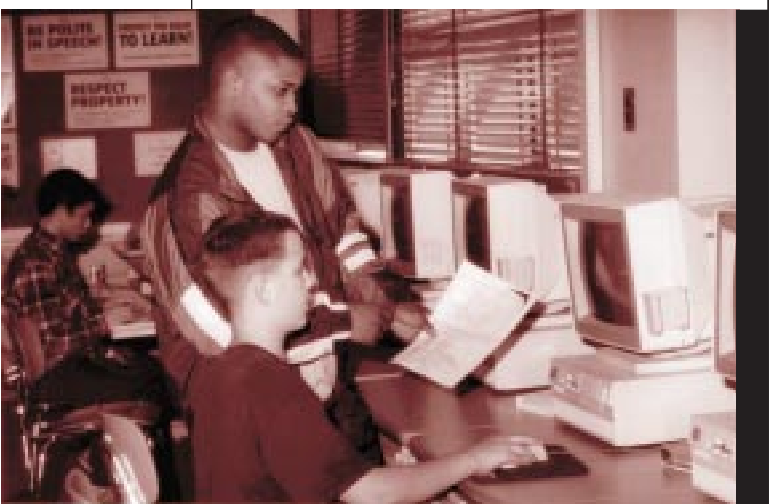
Depth of understanding is facilitated when the concept is reinforced or expanded during the application phase, often through the use of hands-on activities. (Activities in this phase will often do double duty, serving as the initial activity in the exploration phase of a new, closely related concept that will be developed in a separate learning cycle.) The hands-on activities in the exploration and application phases can serve to motivate students as they encounter problems that arouse their curiosity (Beisenherz & Dantonio, 1996).

The problem can be introduced by using "discrepant events"—encounters that students find perplexing. Before being presented with a discrepant event, students should have a familiarity with the concepts, skills, and techniques that allow them to, first, be able to recognize a discrepant event, and, second, be able to suggest hypotheses and procedures for collecting data. Beisenherz and Dantonio provide an example: "The observation that water expands when it freezes is discrepant to students only if they have been led to infer from previous activities that liquids expand when heated and contract when cooled." Using discrepant events to introduce a new topic is particularly effective at piquing students' curiosity, say the authors.

Planning the use of time. Teachers face many time constraints, but they should use available time so that students can experience concepts, not once, but periodically, in different contexts and at increasing levels of sophistication (AAAS, 1990). Structure time so that students can engage in extended investigations. Students need time to discuss and debate with one another, to try out ideas, to make mistakes, to retry experiments, and to reflect. Students also need time to work together in small groups, share their ideas in whole-class discussions, and work together and alone on a variety of tasks, including reading, experimenting, reflecting, writing, and discussing (NRC, 1996).

The *National Science Education Standards* (1996) recommend that teachers plan curriculum goals that are flexible so that they can respond to students' needs and interests: "Teaching for understanding requires responsiveness to students, so activities and strategies are continuously adapted and refined to address topics arising from student inquiries and experiences. An inquiry might be extended or an activity added if it sparks the interest of students or if a concept isn't being understood."

Students need time for exploring and taking wrong turns; testing ideas and doing things over again; time for building things and collecting things; time for constructing physical and mathematical models for testing ideas; time for asking and arguing; and time to revise their previous notions of things (AAAS, 1990).



"It's very rare, in most of my classes, that I make an opening statement, present the lesson, the students go though the lesson, and then I bring it to closure, in one period," says Woolbaugh. "Some of my activities might go four days. Some are ongoing in that I pull ideas from what we did two months ago into a current lesson—that's when I do some real teaching."

Presenting the inquiry topic.

John Graves uses the Learning Cycle Strategy as a way to introduce an inquiry topic to his students.

"You need to introduce it somehow, you don't just put the materials out on the table and turn students loose," says Graves. "The Learning Cycle is a great model for inquiry, especially if you start it with an 'interesting question' so the kids have a reason to move into the exploration. You base your interesting question on a 'discrepant event'—something that is counter-intuitive. A discrepant event is a situation that doesn't go the way you think it should, and it engages you in wondering why. Based on the discrepant event, the teacher asks an interesting question.

It is best when students are prompted by the discrepant event to produce their own interesting questions, says Graves.

The K-W-L (what you *know*, what you *want* to know, and what you've *learned*) charts are another useful tool for getting students into inquiry, says Graves. The K-W-L charts are traditionally used at the elementary grades, but are equally effective in middle and high school.

"Maybe you're starting something on snow," he says, "so you ask students what do they already know about it, and what do they want to know about it. Out of that discussion, questions are raised. Students are now engaged in the activity, and that leads them into inquiry."

Teachers' knowledge of the content area becomes critical in these strategies. Typically, the elementary teacher has been trained as a generalist because she must teach all subjects to her students. But when a teacher is doing full inquiry at any grade level, she often will find herself dipping deeper into her knowledge reserves. In Graves' example, the teacher will need to know the science behind snow—at least enough to know where to help her students look for answers. Teachers can reinforce their content knowledge by seeking out mentors; talking to professionals in the fields of science and mathematics; using other organizations and the Internet as resources; reading widely; and taking advantage of as many professional development opportunities as they can.

However, knowing it all is not only impossible, it's unnecessary. An important aspect of inquiry teaching is being able to say to students, "I don't know, let's find out." In a community of learners, teachers and students work side by side, collaboratively constructing knowledge.

Classroom discourse and questioning

A key to meaning making, say the authors of *Learning from Exemplary Teachers* (Tobin & Fraser, 1991), is to enable students to interact verbally with their teacher and peers. In inquiry, questioning is one of the basic tools for instruction (Good & Brophy, 1997). To use their higher-order cognitive skills, students need opportunities to describe and clarify; elaborate and justify; speculate and analyze; and reconsider and form a consensus (Tobin & Fraser, 1991).

Valuable classroom discussions can take various forms. Sometimes discourse takes place during guided discussions in which the teacher facilitates learning by asking questions such as "Do you think so?" and "Tell me why" (van Zee, et al., 1996). At other times, student-generated inquiry discussions often "erupt into a cacophony in which students vociferously share their thinking. These may be moments during which students make great progress in developing their understanding" (van Zee, et al., 1996). Lastly, classroom discourse during inquiry often takes place during small-group interactions in which students engage in independent yet collaborative thinking (van Zee, et al., 1996).

PURSUING STUDENTS' DIVERGENT QUESTIONS AND COMMENTS IS ONE OF THE CENTRAL ELEMENTS OF INQUIRY TEACHING.

Classroom discourse. Exemplary teachers use a nonthreatening and encouraging debating style to involve students in whole-class discussions (Tobin & Fraser, 1991). They avoid a tendency to call on the same three to five students. When questioning a student, teachers sometimes use "safety nets," such as giving students hints and prompting a correct answer, but only to help a struggling student who would be otherwise embarrassed in front of her peers. Teachers use positive feedback during activities and social interactions. Occasionally, teachers motivate students by offering rewards, such as giving extra points for quick and accurate work. Teachers' practices are sensitive to the needs and feelings of students and encourage participation in learning tasks (Tobin & Fraser, 1991).

Questioning. In their book, *Methods for Teaching: A Skills Approach* (Jacobsen, et al., 1993), the authors discuss the critical role of questioning in effective teaching. In inquiry, skillful questioning is essential. It allows the teacher to foster high-level discussions, either with the whole class, in small groups, or with individual students.

To spark high-level thinking, the authors say, teachers should ask questions that require intellectual processing on the part of the student, rather than asking questions that require a student only to recall something from memory. Below are some questioning strategies that elicit high-level thinking from students (Jacobsen, et al., 1993):

- Require students to manipulate prior information by asking questions such as, "Why do you suppose?" or "What can you conclude from the evidence?"

- Ask students to state an idea or definition in their own words.

- Ask questions that require the solution to a mathematical problem.

- Involve students in observing and describing an event or object by asking questions such as, "What do you notice here?" "Tell me about this," and "What do you see?"

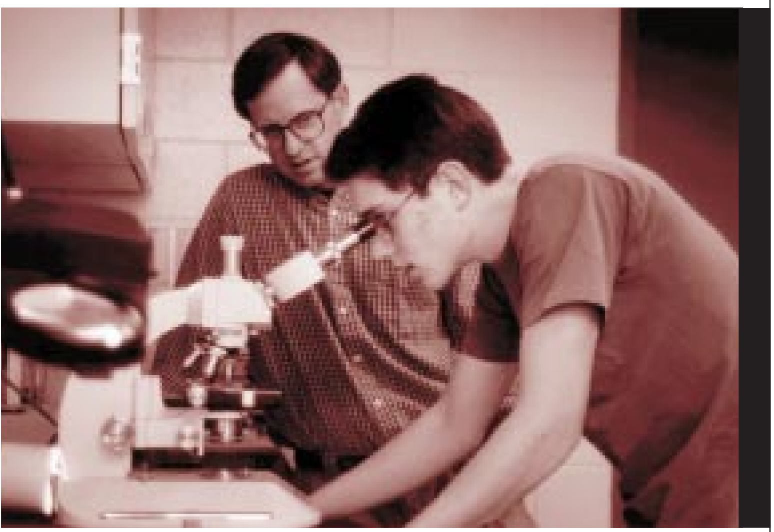
- Ask students to compare two or more objects, statements, illustrations, or demonstrations, and to identify similarities or differences between them. While identifying similarities, students will begin to establish patterns that can lead to understanding of a concept or generalization.

The authors also recommend that teachers wait three seconds or longer after asking a student a question before prompting or calling on another student. When teachers increase their wait time during questioning, the quality and frequency of student responses improves.

Asking probing questions. Students need opportunities to process information by justifying or explaining their responses—dealing with the "why," "how," and the "based upon what" aspects of a concept. Probing promotes reflective and critical thinking. Because it requires teachers to think quickly in the moment, it can also be one of the most difficult questioning techniques (Jacobsen, et al., 1993).

For a student who is having trouble answering a question, probing can be effective (Ornstein, 1995). When a student's response to a question is accurate but incomplete, a teacher needs to ask probing questions to get the student to think deeper about an hypothesis or problem. Asking for clarification, rephrasing the question, asking related questions, and restating the student's ideas are all aspects of probing (Ornstein, 1995).

Divergent questions and comments. Pursuing students' divergent questions and comments is one of the central elements of inquiry teaching. It not only engages students in classroom discussions, it allows them to think independently, creatively, and more critically. It teaches them to take ownership of their own learning—while also feeling a shared responsibility for the learning of the entire class—and to respect others' opinions and ways of thinking.



A teacher can ask divergent questions to elicit many different answers. For example, there could be many appropriate answers to questions like, "How are the beans alike?" or "Give me an example of a first-class lever" (Jacobsen, et al., 1993). Divergent questions allow a number of students to respond to the same question, encouraging student participation. Redirecting questions will also help to increase the number of students participating in a discussion, but teachers need to make a strong effort to call on all students equally. When students are called on with the same frequency and in the same manner, student achievement increases, while behavior problems and absenteeism decreases (Jacobsen, et al., 1993). Redirecting questions—especially description and comparison questions—to numerous students during a discussion fosters positive teacher/student interaction.

Knowing when to follow up on a student's divergent question or comment takes skill and experience. Teachers must decide whether to set aside a student's question, to answer directly, or to try to follow up on a student's ideas through an extended discussion (van Zee, et al, 1996). The authors of *Teachers as Researchers: Case Studies of Student and Teacher Questioning During Inquiry-based Instruction* (van Zee, et al., 1996), a paper presented at the meeting of the American Association for the Advancement of Science in Seattle, Washington, identify a number of dilemmas teachers face regarding students' questions:

- Gauging the interest of the rest of the class in the question
- Assessing the risk of confusing others while examining the issue raised
- Assessing the risk of exceeding one's own knowledge and being able to proceed appropriately even if one doesn't know the answer
- Pondering the best way to address issues on the spot or perhaps at a later time

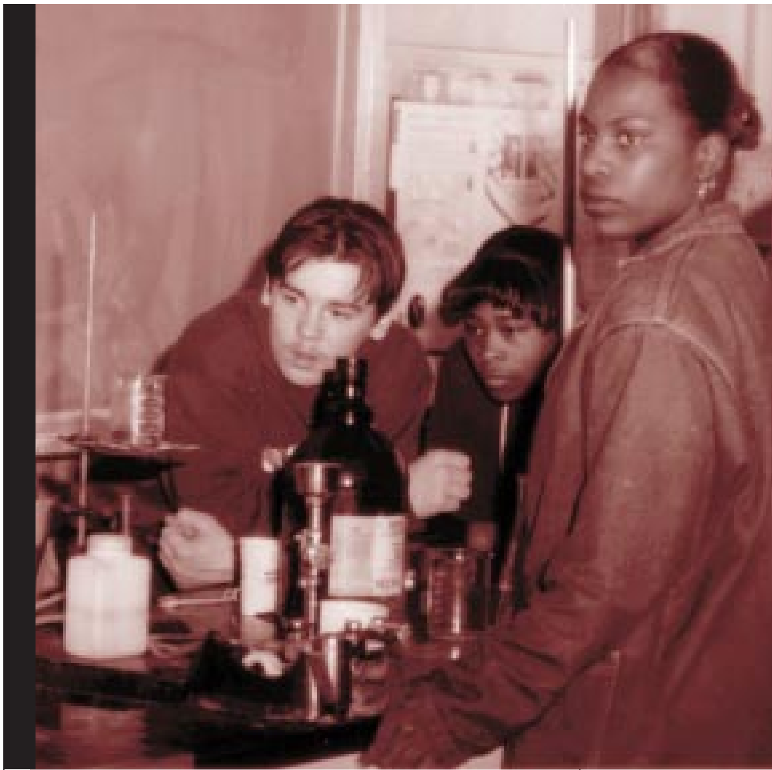
■ Considering the time available to the end of the lesson and the end of the term

How a teacher handles divergent questions depends on the circumstances, says Graves. “A lot of times, if the kids are able to generate questions that are worthy of the exploration, you go with them,” he says. “The other aspect of this is the instructor’s skill in taking a student’s question and refocusing it so that it becomes the question needed (to get to the core of the content). A skilled teacher can elicit these kinds of questions. You can go back into the teacher’s lesson plan and find the exact question that the teacher wanted—it’s fun when that happens.”

Responding effectively to divergent questions can be difficult, especially for a new teacher, says Graves. “It takes time to develop good questioning skills,” he says, “Even for a seasoned teacher, you can’t expect to do it with every lesson. I don’t think that’s realistic.”

Challenges of inquiry-based teaching

Demands on teacher content knowledge. Inquiry can make significant demands on teachers’ content knowledge (Magnusson & Palincsar, 1995). By including students in decision-making, and encouraging them to ask questions, debate, and negotiate, a teacher must rely even more heavily on his expertise in the subject, knowledge of resources, and ability to think quickly. With sufficient content knowledge, a



teacher can prepare multiple learning experiences for his students, providing them with ample opportunity to develop deeper understandings of concepts (Tobin & Fraser, 1991).

“In some situations you don’t just do inquiry on one thing, only one time,” says Graves. “For example, doing the air pressure experiment with Cartesian divers, you need more than two little pop bottles and the medicine dropper. You need to have another air pressure demonstration that the kids can do, and another one, and another one—as many of those as you can get.”

Teachers will want to pursue every opportunity to deepen their knowledge of the subjects they teach. In addition to attending workshops and conferences related to their fields of expertise, teachers can pursue advanced studies or fel-

lowship opportunities at a local university or college; attend summer institutes; seek opportunities to work with scientists and mathematicians in authentic research; and read widely. Teachers can also develop out-of-school contacts with professionals who can offer expert advice and resources. Not only will a teacher develop expertise in his subject areas by undertaking some of these endeavors, he will model valuable lifelong learning practices to his students.

Demands on pedagogical skill.

Teacher skill is crucial to inquiry. It is even more critical if the teacher lacks sufficient classroom equipment and materials (Flick, 1995). Even with sufficient support, a teacher will face many dilemmas when engaged in inquiry.

How can the teacher facilitate discovery and provide guidance? When does the teacher intervene, and when does he stand back and allow students to make "mistakes"? How can a teacher determine when a problem centers on an important principle or a trivial one? What does a teacher do when he doesn't know the answer? Many of these dilemmas can be met with questioning and management strategies.

Conclusion

Today's view of teaching suggests that students and teachers must share responsibility for learning. No longer are teachers thought to be sole dispensers of knowledge. Rather, they must balance the need to ensure that students have ample opportunity to learn core concepts, with students' need to explore—alone and with one another—and to construct their own understandings. Inquiry is central to mathematics and science learning (NRC, 1996). It is an important tool teachers can use in helping students boost their performance in academics, critical thinking, and problem solving (Haury, 1993; Flick, 1995). On the following pages, teachers will find further resources to help them implement strategies from the inquiry continuum.