Inquiry Strategies for Science and Mathematics Learning

It's Just Good Teaching

by Denise Jarrett
Science and Mathematics Education

May 1997

Northwest Regional Educational Laboratory

Table of Contents

Preface

Inquiry-based teaching is a perfect complement to a child's natural curiosity about the world and how it works. Whether it is the elementary student's wonder that is prompted by a story about hibernating animals, the middle school student's predictions about the relationship between circumference and diameter that arise from an exploration of different-sized spheres, or the high school student's questions that are provoked by a local environmental issue, students become actively engaged in the learning process when given the opportunity to hypothesize and investigate.

The Science and Mathematics Education unit at the Northwest Regional Educational Laboratory offers *Inquiry Strategies for Science and Mathematics Learning* as the second publication in our It's Just Good Teaching series. Intended to furnish K-12 teachers with both research-based rationale and recommendations for effective techniques that can be applied in today's complex and changing classrooms, future topics in the series will explore standards-based teaching and using assessment to inform instruction.

All publications follow a similar format. An initial summary of the key themes in the current research and literature sets the stage for the subsequent discussion of research-recommended practices. Included throughout the publications are insights from Northwest educators who are implementing these strategies and represent examples of "real-life research in practice." The listing of print materials, organizations, and online resources enables teachers to access and explore additional tools to support their efforts to provide all students with the mathematics and science knowledge, skills, and abilities necessary for success.

The Northwest Regional Educational Laboratory is committed to improve educational results for children, youth, and adults by providing research and development assistance in delivering equitable, high-quality educational programs. We are proud to be partners with the dedicated practitioners who work on behalf of students throughout the Northwest. We invite your analysis and feedback of *Inquiry Strategies for Science and Mathematics Learning: It's Just Good Teaching* as a resource to strengthen science and mathematics education in the region.

Kit Peixotto
Unit Manager
Science and Mathematics Education
May 1997

Introduction

In the past 20 years, our understanding of how people learn has changed dramatically. Not long ago, educators and psychologists believed that students' brains were like empty vessels waiting to be filled with knowledge imparted by a teacher. But advances in cognitive research and developmental psychology, combined with today's urgency to educate all students in an increasingly diverse and technological society, have transformed the way we think about teaching mathematics and science (Brown & Campione, 1994; Rosenshine, 1995; Roth, 1993; Nowell, 1992; Ornstein, 1995).

Today, educators and researchers understand that most people learn best through personal experience and by connecting new information to what they already believe or know (National Research Council [NRC], 1996; American Association for the Advancement of Science [AAAS], 1993). Excellent teaching and quality textbooks aren't enough. Students need to personally construct their own knowledge by posing questions, planning investigations, conducting their own experiments, and analyzing and communicating their findings. Also, students need to have opportunities to progress from concrete to abstract ideas, rethink their hypotheses, and retry experiments and problems (NRC, 1996; AAAS, 1990, 1993; National Council of Teachers of Mathematics [NCTM], 1991; Rosenshine, 1995; Flick, 1995). In short, students construct their own knowledge by actively taking charge of their learning—one of the primary tenets of inquiry.

Science and mathematics reform standards call for inquiry teaching methods that enable students to contribute their own ideas and to pursue their own investigations (NRC, 1996; NCTM, 1991; AAAS, 1990, 1993). However, no single teaching method is appropriate in all situations, for all students. Teachers need to know how and when to use a variety of strategies (Good & Brophy, 1997). Embedding teaching strategies within an overall inquiry-based pedagogy can be an effective way to boost student performance in academics, critical thinking, and problem solving.

An inquiry-based classroom is more than a "gathering of individual learners brought together for reasons of economy." Rather, it is a "community of inquiry" (Schifter, 1996). In this community, students and teachers share responsibility for learning, and collaborate on constructing new knowledge. Students have significant input into just about every aspect of their learning—how their classroom is set up, how time is structured, which resources are used, which topics are explored, how investigations will proceed, and how findings are reported. No longer are teachers the sole purveyors of knowledge and students passive receptacles.

> "INQUIRY IS THE [SET] OF BEHAVIORS INVOLVED IN THE STRUGGLE OF HUMAN BEINGS FOR REASONABLE EXPLANATIONS OF PHENOMENA ABOUT WHICH THEY ARE CURIOUS."

What is inquiry?

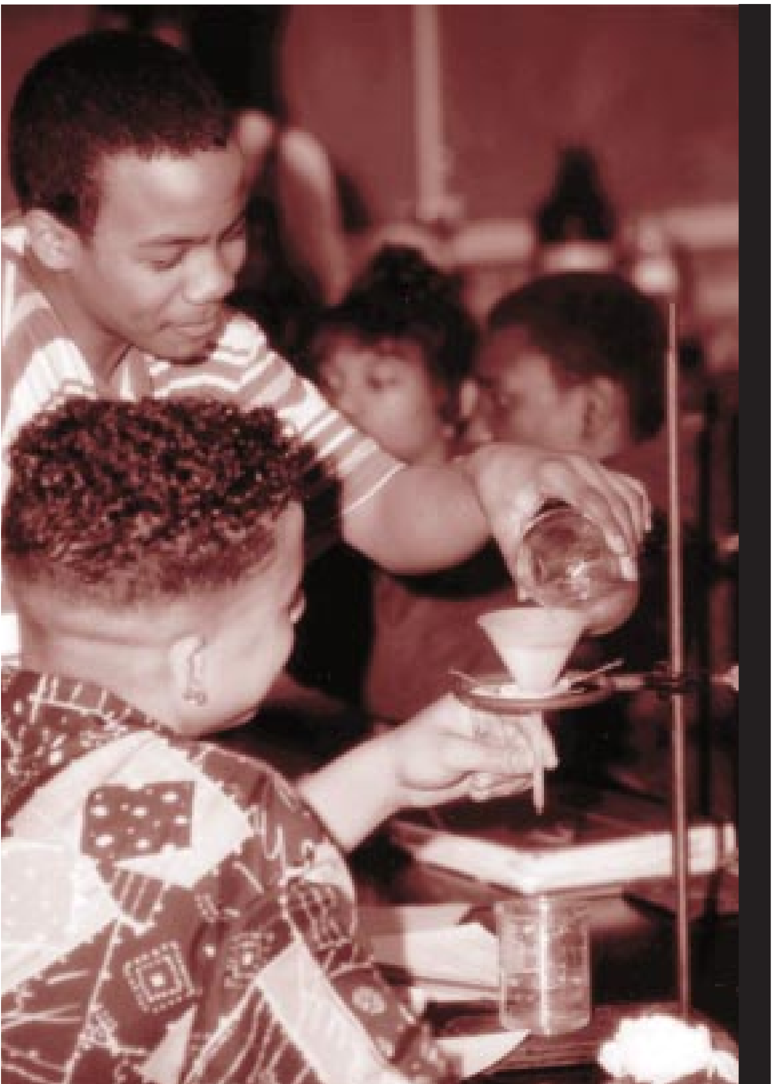
Scientific inquiry is more complex than the traditional notion of it. Rather than a systematic method of making observations and then organizing them, scientific inquiry is a subtle, flexible, and demanding process, states the *Benchmarks for Science Literacy* (AAAS, 1993).

From a science perspective, inquiry oriented instruction engages students in the investigative nature of science, says David L. Haury in his article, *Teaching Science through Inquiry* (1993). Haury cites scientist Alfred Novak's definition: "Inquiry is the [set] of behaviors involved in the struggle of human beings for reasonable explanations of phenomena about which they are curious." In other words, inquiry involves activities and skills that focus on the active search for knowledge or understanding to satisfy a curiosity, says Haury.

Inquiry is also central to mathematics. Today, mathematics education encompasses more than arithmetic and algorithms. It is a diverse discipline that involves data, measurements, and recognition of patterns (NRC, 1989). "The process of 'doing' mathematics is far more than just calculation or deduction; it involves observation of patterns, testing of conjectures, and estimation of results," states the National Research Council in *Everybody Counts,* a report to the nation on the future of mathematics education (1989). "Mathematics reveals hidden patterns that help us understand the world around us."

Inquiry is on a continuum. In practice, inquiry often occurs on a continuum. On one end of the continuum of inquiry might be the use of highly structured hands-on activities and "cookbook" experiments; in the middle might be guided inquiry or the use of science kits; and, at the farthest end, students might be generating their own questions and investigations. A teacher's goal should be to strive for the farthest end of the continuum where students are involved in full inquiry. There are times when she will find it necessary to employ lower-level inquiry strategies to meet specific goals. However, a teacher should not assume that a structured hands-on activity will necessarily have all of the elements of inquiry.

When choosing from the continuum, teachers will need to consider a number of variables such as their own teaching skills; student readiness, maturity, and ability; and pedagogical goals. Occasionally, the teacher will move back and forth on the inquiry continuum to meet certain goals and circumstances. Berk Moss, science curriculum coordinator for the Beaverton School District in Oregon, provides an example of how a teacher's progression toward full inquiry might proceed:



- Activities focus on textbooks, library reports, and worksheets
- Demonstrations are done for students
- Students conduct "cookbook experiments" (student replications, not discoveries)
- Students do laboratory activities that lead to student discoveries
- Students answer questions generated by the teacher from open-ended laboratory activities
- Students answer questions of their own from open-ended laboratory activities

"Each step represents significantly more risk taken by the teacher and increasingly complex classroom management," says Moss. "I celebrate each move along the continuum."

"It is quite reasonable to supply some of the inquiry steps to students so that they can focus their learning on other steps," says Moss. "For example, we might supply the question and ask them to devise the investigation or give data and ask them to analyze and test a given hypothesis. The complexity of these activities will vary with student age and experience, but there are entrances for every child."

Students can do investigations requiring data collection that don't require complex laboratory preparation by the teacher, says Moss. "All inquiry experiences do not need to involve a mop and apology to the custodian."

Students engaged in full inquiry are doing the following, says Moss:

- Learning in a rich environment
- Thinking of a question, and shaping it into something they can investigate
- Hypothesizing
- Planning an investigation
- Collecting data
- Analyzing that data

- Forming a conclusion
- Communicating their findings

Inquiry is "just good teaching." Research has identified effective teaching strategies, many of which are core elements of inquiry. In the book *Effective Teaching: Current Research* (Waxman & Walberg, 1991), Kenneth Tobin and Barry Fraser identify teaching strategies that are used by exemplary mathematics and science teachers. According to research, exemplary teachers ensure that activities are set up to allow students to be physically and mentally involved in the academic subjects. Activities are based on the use of materials to investigate questions and solve problems. Teachers use verbal interaction to monitor student understanding of the content, and facilitate peer interactions by setting up small-group discussions.

"ALL INQUIRY EXPERIENCES DO NOT NEED TO INVOLVE A MOP AND APOLOGY TO THE CUSTODIAN."

At all levels, teachers are effective in a range of verbal strategies which include asking questions to stimulate thinking; probing student responses for clarification and elaboration; and providing explanations to students, say Tobin and Fraser. The most successful teachers have deep content knowledge in the subject areas that they teach, and in the relevant pedagogical theories and strategies. They use skillful questioning to focus student engagement and to probe for misunderstandings. They provide clear and appropriate explanations. They use concrete examples and analogies—relevant to students' lives—to illustrate abstract concepts and to facilitate understanding. They anticipate areas of content that are likely to give students problems, and they conclude lessons by highlighting the main points (Tobin & Fraser, 1991).

Why use inquiry?

There is evidence that inquiry-based instruction enhances student performance and attitudes about science and mathematics, says David Haury (1993). At the middle school level, students who participate in inquiry-based programs develop better laboratory and graphing skills, and learn to interpret data more effectively, he says. He points to research that indicates inquiry-based programs foster scientific literacy and understanding of scientific processes; vocabulary knowledge and conceptual understanding; critical thinking; positive attitudes; higher achievement on tests of procedural knowledge; and construction of mathematical knowledge.

Improves student attitude and achievement. According to *Education Week* (Lawton, 1997), a poll by Bayer Corporation of Pittsburgh showed that students who used hands-on experiments and team problem solving in science classrooms have a better attitude about the subject than students who learned science through lectures and assigned textbook reading. Three out of five students, ages 10 to 17, said that they would

be "a lot more psyched" about science if they could do more experiments themselves and use a computer to communicate with scientists and other students. Fifty-four percent of the students using more inquiry-oriented methods said that science is one of their favorite subjects, compared with 45 percent of the students in traditionally taught classes. Also, nearly 25 percent of the students in traditional classes said that science is their most difficult subject, while only 18 percent of the students using inquiry strategies said so.

The College of Natural Sciences at the University of Iowa (1997) administers a project called Physics Resources and Instructional Strategies for Motivating Students (PRISMS). The project blends such inquiry-based strategies as exploratory activities, concept development, and application activities into a learning cycle. The college compared the academic achievement of students who participated in the PRISMS project with students who did not. The studies showed that the PRISMS students achieved at a higher level, used higher level reasoning skills, and had more positive attitudes about physics than those taught by more traditional methods (University of Northern Iowa, 1997).

Facilitates student understanding. Students develop critical thinking skills by learning through inquiry activities. They learn to work collaboratively, to articulate their own ideas, and to respect the opinions and expertise of others. They learn inquiry skills that they can use in other aspects of their lives and intellectual pursuits.

Building on John Dewey's premise that students need to be engaged in a quest for learning and new knowledge, and Jean Piaget's statement that, "Experience is always necessary for intellectual development; (therefore) the subject must be active," researchers in the past two decades have developed a new understanding of learning (Brown & Campione, 1994; Rosenshine, 1995; Roth, 1993; Nowell, 1992). Constructivist theory states that knowledge is constructed through one's personal experience by assimilating new information with prior knowledge (King & Rosenshine, 1993).

This theory has shifted researchers' perspective on knowledge, learning, and teaching, says Raffaella Borasi in her book, *Learning Mathematics Through Inquiry* (1992). Borasi is an associate professor at the Graduate School of Education and Human Development at the University of Rochester and has written extensively on mathematics and inquiry. Knowledge is viewed not as a stable body of established results, she says, but as a dynamic process of inquiry, where "uncertainty, conflict, and doubt provide the motivation for the continuous search for a more refined understanding of the world." In this view, learning is a generative process of meaning making that is personally constructed and enhanced by social interactions, she says. Teaching is viewed as facilitating students' own search for understanding by creating a rich learning environment that stimulates student inquiry.

Learning is also a social process (AAAS, 1990; King & Rosenshine, 1993; Magnusson & Palincsar, 1995). Students need to interact with their peers and the teacher on inquiry-based investigations. They need ample opportunities to discuss their own ideas; confer and debate with their classmates; then to have time to reflect on the feedback they've received,

to make adjustments, and to retry their experiment or activity. They need to have experiences with the kinds of thought and action that are typical of scientists, mathematicians, and technology professionals (AAAS, 1990). In short, students need to understand science, mathematics, and technology as ways of thinking and doing, as well as bodies of knowledge (AAAS, 1990).

Facilitates mathematical discovery. As the *Benchmarks for Science Literacy* (AAAS, 1993) points out, the role of inquiry in the study of mathematics is just as central as it is in science.

"It is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful," states the *Benchmarks*. "Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others... It is essential to keep in mind that mathematical discovery is no more the result of some rigid set of steps than is discovery of science."

According to standards written by the National Council of Teachers of Mathematics, inquiry is one of the most important contexts in which students learn mathematical concepts and knowledge: by exploring, conjecturing, reasoning logically, and evaluating whether something makes sense or not. During discourse, students develop ideas and knowledge collaboratively, while the teacher initiates and orchestrates discussion to foster student learning. This collaboration "models mathematics as it is constructed by human beings: within an intellectual community" (NCTM, 1991).

Creating an inquiry-based classroom

Teachers should design and manage learning environments that provide students with the time, space, resources, and safety needed for learning. Opportunities for active learning and access to a rich array of tools and resources are critical to students' ability to do inquiry (NRC, 1996).

Engage students in designing the learning environment. Ask students for their ideas and suggestions on such decisions as how to use time and space in the classroom. This is part of challenging students to take responsibility for their learning. Also, as students pursue their inquiries, they need access to resources and a voice in determining what is needed. Students often identify excellent out-of-school resources. The more independently students can get what they need, the more they can take responsibility for their own work (NRC, 1996).

Reflect the nature of inquiry. The learning environment should reflect the intellectual rigor, attitude, and social values that characterize the way scientists and mathematicians pursue inquiry (NRC, 1996; Borasi, 1992; Brown & Campione, 1994). According to the *National Science Education Standards* (NRC, 1996) and literature on inquiry and guided discoveries (Borasi, 1992; Brown & Campione, 1994), inquiry facilitates students' development of skills and dispositions that will serve them throughout their lives. To create a classroom environment that reflects the nature of inquiry, teachers will want to:

- Display and demand respect for diverse ideas, abilities, and experiences (NRC, 1996).

- Model and emphasize the skills, attitudes, and values of scientific inquiry: wonder, curiosity, and respect toward nature (NRC, 1996).

- Enable students to have a significant voice in decisions about the content and context of their work, such as setting goals, planning activities, assessing work, and designing the environment (NRC, 1996).

- Nurture collaboration among students, and give them significant responsibility for the learning of everyone in the community (NRC, 1996). Foster communal sharing of knowledge (Brown & Campione, 1994).

- Structure and facilitate discussions based on a shared understanding of the rules of scientific discourse, such as justifying understandings, basing arguments on data, and critically assessing the explanations of peers (NRC, 1996).

- Extend the community of learners to include people, organizations, and facilities away from school (Brown & Campione, 1994).

Integrate science laboratories into the regular class day. It is essential to teach students that doing science is not separate from learning science, says science teacher Walter Wool-

baugh of Manhattan Middle School in Manhattan, Montana. Woolbaugh conducts workshops on inquiry-based teaching and is an adjunct professor at Montana State University in Bozeman where he teaches classroom management and methods.

"Science should *be* lab. Science should be a verb as opposed to a noun," says Woolbaugh. "Why separate learning science from doing science? That doesn't happen in the profession. A paleontologist at the Museum of the Rockies (in Bozeman) doesn't say, 'I think I'll go back to the lab.' It's all integrated. So isn't that the model we ought to use when teaching students from kindergarten on?"

Use inquiry in the mathematics classroom. Raffaella Borasi (1992) recommends several strategies for creating an environment that is conducive to initiating and supporting students' inquiry in mathematics:

- Use the complexity of real-life problems.
- Focus on nontraditional mathematical topics where uncertainty and limitations are most evident.
- Use errors as "springboards for inquiry."
- Create ambiguity and conflict that compels students to ask, "What would happen if things were different?" or "What would happen if we changed some of the traditional assumptions, definitions, goals, in mathematics?" Encourage students to pursue such questions, and to have a sense of the significance of the results of their inquiry.
- Generate reading activities to sustain inquiry and to teach students to use sources of information other than the teacher. This will help them learn to become independent learners, problem solvers, and critical thinkers. Sources could include historical and philosophical essays, reports describing specific mathematical applications, and biographies.
- Provide students with opportunities to reflect on the significance of their inquiry.
- Promote exchanges among students.

Use management strategies to facilitate inquiry. There appears to be a critical link between classroom management, teaching, and learning (Tobin & Fraser, 1991; Flick, 1995). Research on inquiry and teaching methods indicate that effective teachers use "significant managerial skill while promoting the active participation of students" during inquiry activities (Flick, 1995).

While an inquiry-based classroom allows students significant freedom to create, chart their own learning, debate, and engage in activities (NRC, 1996), their explorations should be within a structure. The teacher provides this structure with management strategies that help her to create a safe, well-organized, and effective environment where all students can learn. She orchestrates discussions so that student participation and thinking are at a high level. She also ensures that students understand the core content in every lesson.

Student-teacher interaction is another important element of effective classroom management (Wang & Walberg, 1991). In a classroom with effective management strategies in place, the teacher considers one of her primary curriculum goals to be developing students' autonomy and independence (Tobin & Fraser, 1991). She maintains control-at-a-distance over the entire class, and actively monitors student behavior by moving around the room and speaking with individual students. Students work both independently and cooperatively in groups.

"SCIENCE SHOULD *BE* LAB. SCIENCE SHOULD BE A VERB AS OPPOSED TO A NOUN."

Rules are firmly in place but rarely needed, the authors say. When a student exhibits off-task behavior, the teacher quickly and quietly speaks to that student without disturbing others. She monitors student engagement and understanding, and establishes routines that enable her to cope with a relatively large number of students with diverse learning needs. She emphasizes students' active participation in their own learning, and chooses activities that ensure active thinking. Students are encouraged to try to work out difficulties on their own, consulting other resources such as textbooks and peers (Tobin & Fraser, 1991).

Woolbaugh remembers his early efforts at using inquiry in the classroom before he had management strategies in place. "It caused me problems the first year, because classroom management is such a key issue in inquiry," he recalls. "We make such a push in mathematics and science to do inquiry, when in reality it's probably something that teachers are going to be able to do consistently only in their third, fourth, or fifth year, because they need to get management skills down first. That first-year teacher may do an awful lot of pencil, paper, and open-the-book kinds of things, just for a management survival strategy."

Share control. Full inquiry is when students are actively engaged in an investigation, manipulating concrete objects, conferring with peers, pursuing their own line of inquiry, and creating their own solutions to a problem (NRC, 1996). It takes a skillful teacher to guide students' learning, to keep students on-task, to know when to let classroom discussions go off in a new direction, to make sure the lesson progresses coherently toward learning goals. It also takes a courageous teacher to encourage students to offer their own ideas, to make comments, to debate the validity of explanations and solutions, and to take part in the decisionmaking (Borasi, 1992).

Spark student motivation. Students' individual characteristics can be critical in determining their learning outcomes, say Margaret Wang and Herbert Walberg in their article, *Teaching and Educational Effectiveness: Research Synthesis and Consensus from the Field* (1991). Regulating and taking responsibility for one's own learning is the most important characteristic for high achievement, they say. Other important characteristics are perseverance on learning tasks and motivation for continual learning.

Science and mathematics teacher Rosalind Philips of New Century High School in Tumwater, Washington, speaks nationally about inquiry, and science and mathematics standards. One of her strategies for boosting student motivation is to provide them with a variety of tasks, activities, and objectives during the course of a 90-minute class period.

IN A COMMUNITY OF LEARNERS, TEACHERS AND STUDENTS WORK SIDE BY SIDE, COLLABORATIVELY CONSTRUCTING KNOWLEDGE.

"I try to interact with students, and I try to set up class so that we do about four different things over the course of the period," says Philips. "I lecture, we watch a video, and we have two activities that the students do. I try to keep class moving. There are days when I talk more than I probably should, and there are times when we go by without doing enough labs because of where we are in the curriculum."

Take on new roles. In classrooms where one of the teacher's primary goals is to help students become good problem solvers and critical thinkers, teachers and students assume new roles. The lists below depict those things that teachers and students will do in an inquiry-based classroom (NRC, 1996; NCTM, 1991; AAAS, 1990, 1993; Borasi, 1992; Flick, 1995):

What teachers do:

- Create a rich learning environment
- Identify important concepts students will investigate
- Plan the inquiry
- Present the inquiry
- Solicit student input to narrow the focus of the inquiry
- Initiate and orchestrate discussion
- Ask prompting and probing questions; pursue students' divergent comments and questions, when appropriate
- Guide students' learning in order to get at the core of the content
- Provide opportunities for all students to demonstrate their learning by presenting a product or making a public presentation

What students do:

- Contribute to the planning of an inquiry investigation
- Observe and explore
- Experiment and solve problems
- Work both as a team member and alone

- Reason logically, pose questions
- Confer and debate with peers and the teacher
- Discuss their own ideas, as well as develop ideas and knowledge collaboratively
- Make logical arguments and construct explanations
- Test their own hypotheses
- Communicate findings
- Reflect on feedback from peers and the teacher
- Consider alternative explanations
- Retry experiments, problems, and projects

Implications for curriculum

An inquiry-based teaching approach is time intensive. Significant implications are raised regarding how much of the curricula a teacher can "cover." Education reform literature recommends that teachers focus on essential topics (AAAS, 1990; NCTM, 1989), but most teachers are accountable to state-mandated curriculum goals. States are responding to this dilemma by reexamining the curriculum and goals they require teachers to follow. Most states in the Northwest are aligning their standards with national standards which call for teachers to ensure that students are actively and mentally engaged in mathematics and science content that has enduring value. According to *Science for All Americans* (AAAS, 1990), concepts should be chosen on the basis of whether they can serve as a "lasting foundation on which to build more knowledge over a lifetime."

It is unrealistic, says Borasi (1992), to expect students to "solve complex real-life problems, read about the history of mathematics, or study extracurricular topics where uncertainty and contradiction are especially evident, in addition to covering all the topics already included in the overcrowded state-mandated curricula for precollege school mathematics."

The open-ended character of inquiry requires a lot of flexibility in choosing curriculum content, she says. Teachers will frequently need to diverge from the original lesson plan to follow up on students' questions, to allow a debate to develop, or to follow a new lead. "Indeed, the best discussions and explorations are most often those that have not been pre-

planned, or even conceived as possible, by the teacher," she says.

For students to develop into critical thinkers, they need to experience the freedom—and responsibility—of directing and focusing their own inquiries, she says. The teacher must skillfully balance the overarching objectives of the course while providing students with genuine involvement in decisionmaking. This will affect the "extent, purpose, emphasis, and sequence" of the content covered, says Borasi.

Teaching the "facts." While allowing students optimum input into decisionmaking, the teacher must ensure that curriculum goals are met in meaningful ways. This sometimes means that the teacher will prepare his students for the inquiry activity by first teaching them some basic facts and vocabulary. Without these facts, students can be left with the impossible task of reinventing knowledge, or they may construct seriously flawed understandings.

"There's a misconception that in order to do an inquiry approach, you never teach kids facts, you never stand up at the board and lecture; you do all of this discovery learning," says Philips. "My feeling is that there is a basic body of mathematics that all kids should have memorized, because it helps a student to focus on what the problem is asking, and not on the routine grunt work.

"I think they should know these things because it means that when they're trying to identify patterns and solve a problem, those basic facts fall readily into place," she says. "If you can't recognize the common patterns of mathematics and science, then you can't have an inquiry approach in the class. You can't inquire about something unless you have a basis to found it on."

Philips offers an amusing, though troubling, anecdote illustrating how one can construct knowledge incorrectly. Years ago, a friend living on the East Coast wanted to meet Philips halfway between Boston and Seattle for a holiday. The friend suggested Hawaii.

"Now I'm thinking about the fact that Hawaii's in the middle of the Pacific Ocean, and I say, 'Where do you think Hawaii is?' And she says, 'It's off the coast of Texas. Remember that map we had at school? Hawaii is off the coast of Texas!' She never understood that that was a graphic inset. So there's an example of somebody who's constructed their own knowledge, used absolutely good reasoning, and used an appropriate tool, but she constructed a misperception that was left uncorrected. So, what we have to do with inquiry, if we're going to facilitate students' construction of knowledge, is to offer students a little bit of help."

Choosing an inquiry topic. What knowledge of enduring value should the student be guided to discover? This is the question posed by Ann Brown and Joseph Campione in their article, *Guided Discovery in a Community of Learners* (1994). Most teachers are accountable for the course requirements of their schools. Rather than allowing students to discover curriculum content on their own, "charting their own course of studies," the teacher sets bounds on the curriculum to be covered. While the teacher chooses the main themes, students are strongly encouraged to nominate specific topics within those themes (Brown & Campione, 1994).

For example, the teacher might select a theme on endangered species, say the authors. He solicits questions from students who discuss what they already know, and what they want to find out about endangered species. Then, their questions are written on Post-its™ and displayed on a bulletin board. After consulting books the teacher has selected, students generate more questions. Finally, the questions are grouped into subthemes from which topics are identified. This process fosters teamwork and helps students to feel ownership in what they select for study (Brown & Campione, 1994).

Teachers will want to ensure that the inquiry activities they plan require students to use high-level reasoning skills. According to research, inquiry activities that require high-level thinking have the following features (Flick, 1995):

- The path of action is not fully specified in advance, nor is it apparent from a single vantage point
- There are multiple solutions, each with costs and benefits
- Uncertainty exists; everything that bears on the task at hand is not known
- Higher-order thinking skills are required; students direct most of their own steps in the thinking process
- Considerable mental work is involved in elaboration and judgment

Getting at the core content.

Whether or not teachers are working under mandated goals, objectives, and content, they will want to examine the extent to which a curriculum includes inquiry. Engaging students in inquiry helps them to make a critical link between understanding science as a process, and understanding scientific concepts (NRC, 1996). Inquiry requires students to do more than observe, infer, and experiment. It requires them to combine scientific processes with content knowledge—they must use scientific reasoning and critical thinking to develop their understanding of science (NRC, 1996).

"I could do magic tricks all year long, and students would come out of here saying, 'This is the greatest science class we've ever had,'" says Woolbaugh, who is a professional magician as well as a science teacher. "But when you look at the nuts and bolts of the activities, there's no science content in it. The students had fun, and they used some processing (thinking) skills, but they didn't get at the science content. So we, as teachers, need to look at that scope and sequence, the 'big picture,' and the standards to make sure that we're covering what we need to be covering. I need to look at that core content, and then make adjustments—that's a never-ending job."

John Graves, who received a Presidential Award for Excellence in Science and Mathematics Teaching in 1996, teaches science and English at Monforton Middle School in Bozeman, Montana. Graves provides an example of when an inquiry activity misses the core of the content.

"Based on the Learning Cycle Strategy (see "Planning an Inquiry Lesson"), each one of the phases—exploration, concept introduction, application—is just as important as the other phase. The exploration is certainly key, but the concept development has to have equal weight," says Graves. "For example, we're doing Cartesian divers right now (a common experiment to demonstrate the effects of air pressure.) Here's how you can blow that inquiry lesson: Let the kids build their own divers—that's the exploration phase—but never ask students, 'How does this happen in real life?' 'Can you find a situation where the change of pressure in something causes it to move?' So the exploration is great, but if that's all you did, you'd really be wasting your time, and I think the kids' time."

Doing an inquiry activity that doesn't get to the core of the content also increases the possibility that students will construct flawed understandings, says Graves.

"To allow an inaccuracy to continue might mean that that student gets to be a senior in high school taking physics, and they are still holding a misconception that they developed in second grade," he says. "If teachers don't take them beyond the exploration phase, they do a real injustice to students' learning process."

Planning an inquiry lesson

Using the Learning Cycle Strategy. The Learning Cycle is a model that can be used to facilitate inquiry. Developed in the 1960s as part of the Science Curriculum Improvement Study (sponsored by the National Science Foundation), the strategy uses questions, activities, experiences, and examples to help students develop a concept, deepen their understanding of the concept, and apply the concept to new situations (Beisenherz & Dantonio, 1996).

In their book, *Using the Learning Cycle to Teach Physical Science* (Beisenherz & Dantonio, 1996), the authors identify three phases to the Learning Cycle:

KNOWLEDGE IS VIEWED NOT AS A STABLE BODY OF ESTABLISHED RESULTS, BUT AS A DYNAMIC PROCESS OF INQUIRY, WHERE "UNCERTAINTY, CONFLICT, AND DOUBT PROVIDE THE MOTIVATION FOR THE CONTINUOUS SEARCH FOR A MORE REFINED UNDERSTANDING OF THE WORLD."

exploration, concept introduction, and application. During these phases, students learn to use and understand such science processes as observing; comparing and contrasting; ordering; categorizing; relating; inferring; communicating; and applying.

At the beginning of the cycle, students actively explore materials, phenomena, problems, and ideas to make observations and collect data. An initial, less structured exploration allows students to explore objects and systems at their own pace and with little guidance. Students often become highly motivated when they are permitted to do hands-on explorations before the concept is introduced. Then another, more structured exploration allows students to reexamine the same objects and systems more scientifically. During this time, students generate questions, and form and test their own hypotheses (Beisenherz & Dantonio, 1996).

In the next phase, the teacher uses scientific vocabulary to introduce the concept related to students' observations. Together, the teacher and students organize the observations and experiences, and the resulting patterns often match