Inquiry Strategies for Science and Mathematics Learning

It's Just Good Teaching

Northwest Regional Educational Laboratory

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Science and Mathematics Education

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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.

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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

Inquiring into pendulums in Manhattan, Montana

A May blizzard has thrown a heavy blanket of snow over Manhattan, a small farming community 25 miles west of Bozeman, Montana. This morning, the sun is edging out the storm clouds, and the Bridger Range mountains are again in view.

Inside Manhattan Middle School, seventh-grade students are settling into their chairs in Mr. Walter Woolbaugh's science room. A chess game is concluded. The motion machine is given a tap, and the caged tarantulas are given a peek. At the back of the room, behind the laboratory stations, the doves coo in anticipation.

It's near the end of the school year. So far, these seventh-graders have studied geologic processes, and plant and animal life. Now, they are learning about mechanical energy. At the front of the classroom, a long string hangs from the ceiling with a bronze weight tied to its end. On the chalkboard is written a question: What affects the period of a pendulum?

Mr. Woolbaugh steps forward.

"Okay, what kinds of things did we talk about yesterday?" he asks. The class reviews yesterday's introductory lesson about potential and kinetic energy, and the vocabulary term, the *period* of a pendulum.

Woolbaugh repeats a demonstration for determining how many swings a pendulum makes in one second. As Brenda readies the stopwatch, Woolbaugh pulls the weight back, and releases it.

Brenda calls out, "Stop!" and Woolbaugh grabs the weight in mid-swing.

"Okay, we had this problem yesterday," says Woolbaugh. "What's the problem with this method?"

The students conclude that one second isn't long enough to measure the full swing of the pendulum. They suggest timing the swings for at least 15 seconds in order to capture a full swing and to collect enough data to accurately calculate the measurement. Woolbaugh accepts their strategy, then introduces a new problem, setting the stage for the next activity.

"Remember, good science starts with a problem," he says. "Here's the problem that I want you to address over the next three days: What affects the period of a pendulum? Is there anything that would make the number of swings per second change? Or is it always the same? That's what you and your lab partner are going to solve."

Before the students break into small groups, Woolbaugh leads them in a brainstorming session. He writes their ideas about what might influence the swing of a pendulum on the chalkboard.

"Air pressure," suggests Tony.

"Okay, if we did this experiment on another planet, or someplace that had more air pressure, that might change it," agrees Woolbaugh, "but that's a variable that's going to be hard for us to control."

"Length of string," offers Daniel.

"Okay, that's a good one. Would a really short string have a short or fast period? Any discussion about the length of string before I go on?" He waits a few seconds before continuing, "Are there others?"

"How heavy the weight is," says Melinda.

"Excellent idea," says Woolbaugh. "I like that one. The weight, yeah! Would a real heavy weight make a slower period or would it make a faster period? How could we test that?"

"Try different weights," says Greg.

"Right!" Woolbaugh is clearly pleased, but he presses for more ideas. "Other hypotheses about the period of the pendulum?"

"The diameter of the string might affect it," says Matthew.

"String might matter. Okay, good idea. I don't have a lot of different string widths, so that's not a variable that everyone will be able to test, but if you want to try it, Matt, after you test the other variables, that would be an interesting experiment to do."

Another student says, "Aerodynamics could make a difference."

"What do you mean by that?" probes Woolbaugh.

"It could increase the drag on the pendulum."

"Okay, that would be good to test, too."

"What about friction at the top of the string, where the string is attached to the wire on the ceiling?" asks Brenda.

"Good. Friction at the point where the string meets the wire."

The students move into small groups to set up their own experiments on pendulums. Immediately, they start searching through drawers, shelves, closets, and cabinets for materials with which to conduct their investigations: string, wire, weights of all sorts. They are familiar with this routine; only occasionally does Woolbaugh prepare materials for them in advance. With materials in hand, they search around the room for interesting places to fasten their pendulum: ceiling hooks, faucets, and laboratory stanchions. Everything from bronze weights to a pair of scissors serves as the pendulum weight.

Members of each group take turns manipulating their pendulum, timing its swings, and recording data. After

25 minutes, they return to their desks to report the data they have collected. As it turns out, the students have experimented with only two variables: length of string and the weight.

"Looking at the data, what do you think?" asks Woolbaugh. "Give me some hypotheses."

"I don't think weight affects it a lot," says Melinda, wrinkling her brow.

"Why do you say that?" asks Woolbaugh.

"Because the results for each trial are about the same."

"Yes, the periods were almost exactly the same, although we changed the weight in all three trials. Maybe you're right, maybe the weight doesn't make the pendulum swing any faster or slower," says Woolbaugh. "How about length of string?"

"The shorter the string, the faster the period," says Jennifer.

"It appears that way, doesn't it?" says Woolbaugh. "As we get the string shorter, it appears to go faster. Does that mean it's true? We can't be sure, because only one test was done on each variable. Tomorrow, when we repeat our experiments, we'll need to test each length of string four or five times. This will give us enough data points to reach a more accurate average for calculating the period of the pendulum."

Woolbaugh reviews the day's activity. "Today, we followed the scientific process—we brainstormed ideas about what might affect the period of a pendulum; we did a few tests of each variable, collected and averaged data; and then drew some conclusions based on that data," he says. "Although our findings aren't conclusive, we've generated some testable hypotheses. Tomorrow, we're going to retry our experiments. We want to test each variable a number of times so that we have enough data to be confident of the accuracy of our measurements."

Trina raises her hand, and asks, "What if you were to hang the weight from two strings attached to the ceiling, like a swing?"

"Good one! Nobody's ever suggested that variable," says Woolbaugh. "Why don't you try that tomorrow?"

Trina smiles and collects her books as the school bell rings. The next class of students is already pouring in the doorway as Trina and the others leave Mr. Woolbaugh's classroom, until tomorrow.

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.

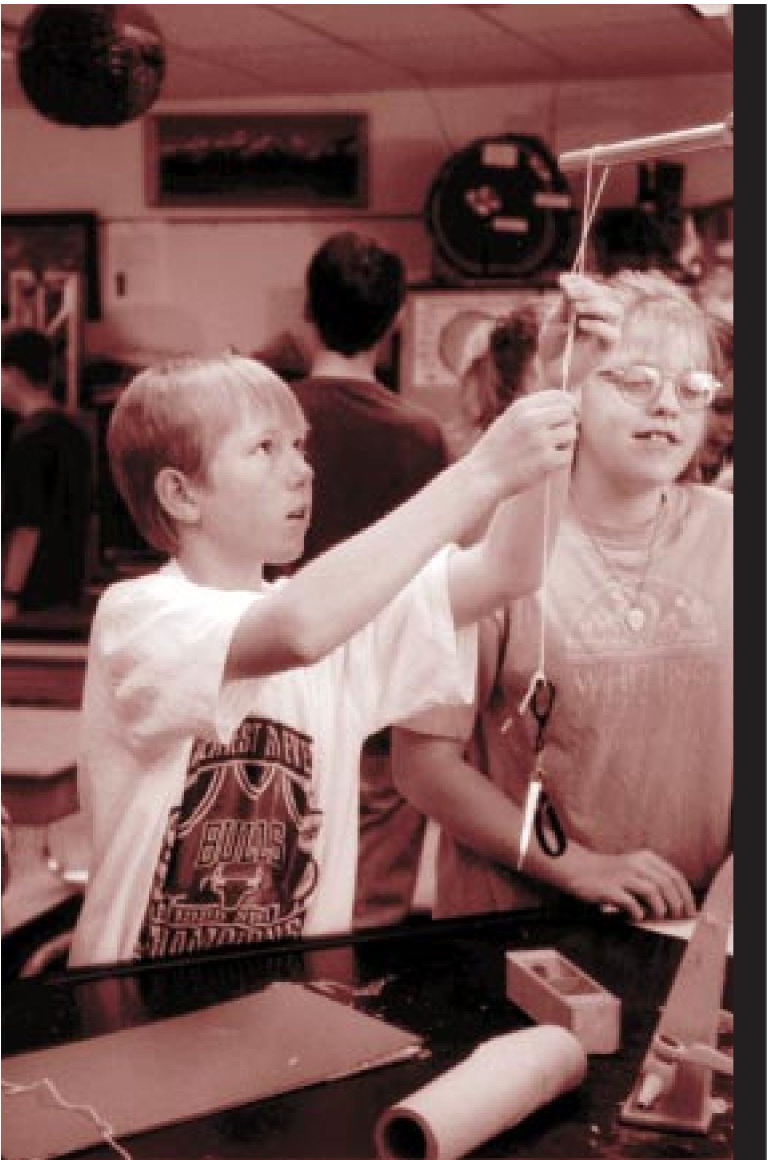
"Now I'm thinking about the fact that Hawaii's in the middle of the Pacific Ocean, and I say, 'Where do you think Hawaii is?' And she says, 'It's off the coast of Texas. Remember that map we had at school? Hawaii is off the coast of Texas!' She never understood that that was a graphic inset. So there's 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

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).

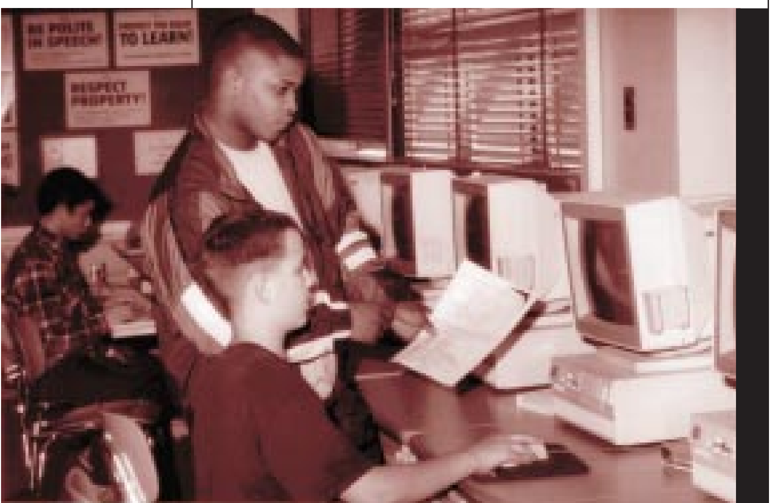
Depth of understanding is facilitated when the concept is reinforced or expanded during the application phase, often through the use of hands-on activities. (Activities in this phase will often do double duty, serving as the initial activity in the exploration phase of a new, closely related concept 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?"

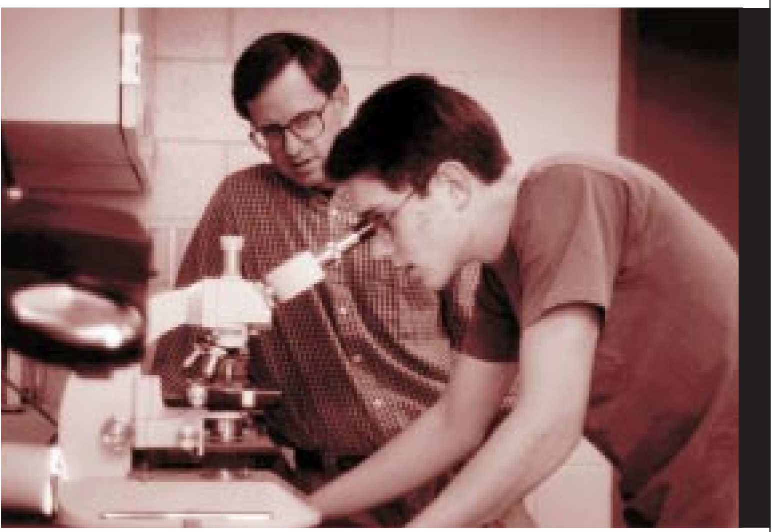
- Ask students to compare two or more objects, statements, illustrations, or demonstrations, and to identify similarities or differences between them. While identifying similarities, students will begin to establish patterns that can lead to understanding of a concept or generalization.

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

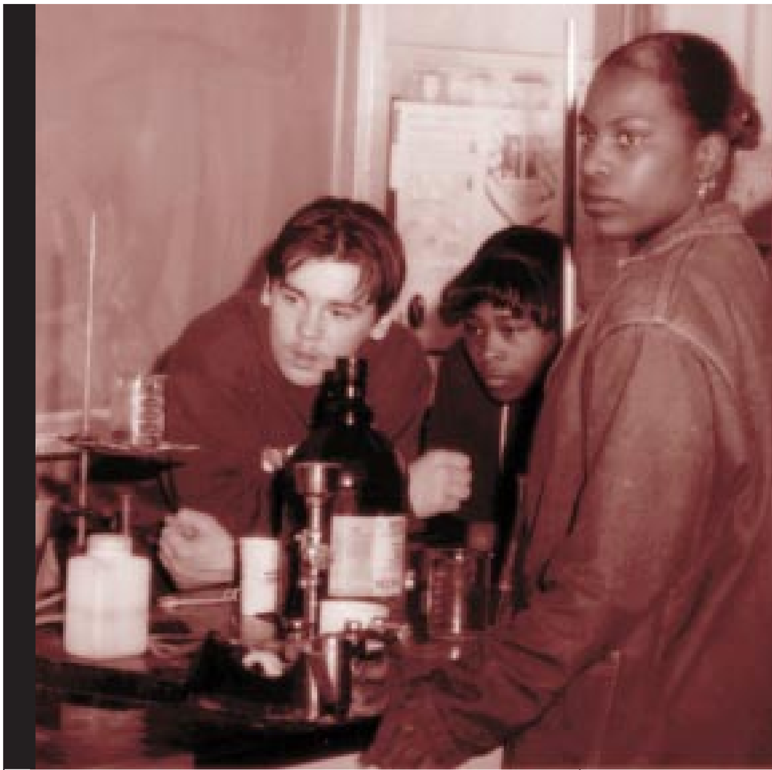
- Considering the time available to the end of the lesson and the end of the term

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.

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Organizations

American Association for the Advancement of Science (AAAS)
1200 New York Avenue, N.W.
Washington, DC 20005
(202) 326-6400
http://www.aaas.org/

The American Association for the Advancement of Science is a nonprofit professional society dedicated to the advancement of scientific and technological excellence across all disciplines, and to the public's understanding of science and technology. AAAS provides a variety of publications and resources, including *Inquiry in the Library,* a 1997 publication edited by Maria Sosa and Jerry Bell promoting student inquiry in the library and in the classroom.

National Council for Teachers of Mathematics (NCTM)
1906 Association Drive
Reston, VA 20191-1593
(703) 620-9840
Fax: (703) 476-2970
http://www.nctm.org/

The National Council of Teachers of Mathematics is a nonprofit professional association dedicated to the improvement of mathematics education for all students in the United States and Canada. All NCTM members receive council publications including regular issues of the *News Bulletin, Student Math Notes* and one or more of their four journals. NCTM also publishes books, videotapes, software, and research reports.

National Science Foundation (NSF)
4201 Wilson Boulevard
Arlington, VA 22230
(703) 306-1234
E-mail: info@nsf.gov
http://www.nsf.gov/

The National Science Foundation is an independent U.S. government agency responsible for promoting science and engineering by funding research and education projects. Information about NSF programs, activities, funding opportunities, current publications, meetings and conferences are available in a number of publications, including the *NSF Bulletin,* available online at http://www.nsf.gov/od/lpa/news/publicat/bulletin/bulletin.htm, and *Frontiers* newsletter, available online at http://www.nsf.gov/od/lpa/news/publicat/frontier/start.htm. Inquiries about subscribing to the print version of this newsletter should be sent to blombard@nsf.gov

National Science Teachers Association (NSTA)
1840 Wilson Boulevard
Arlington, VA 22201-3000
(703) 243-7100
Fax: (703) 243-7177
http://www.nsta.org/

The National Science Teachers Association is the largest organization in the world committed to promoting excellence and innovation in science teaching and learning for all. The Association publishes five journals, a newspaper, many books, and a new children's magazine, and conducts national and regional conventions.

Northwest Regional Educational Laboratory (NWREL)
Science and Mathematics Education
101 S.W. Main Street, Suite 500
Portland, OR 97204-3297
(503) 275-9500
Kit Peixotto, Unit Director, (503) 275-9594
E-mail: peixottk@nwrel.org
http://www.nwrel.org/psc/same/

The Northwest Regional Educational Laboratory provides leadership, expertise, and services to educators and others in the states of Alaska, Idaho, Montana, Oregon, and Washington. The Science and Mathematics Education (SAME) unit provides services in support of effective curriculum, instruction, and assessment, and maintains a lending library of books, videos, and other materials on a variety of topics, including inquiry-based teaching, equity issues, education reform, standards and assessment, and effective instructional practices.

Science and Mathematics Consortium for Northwest Schools (SMCNWS)
Columbia Education Center
171 N.E. 102nd
Portland, OR 97220-4169
(503) 760-2346
Ralph Nelsen, Director
E-mail: ralph@col-ed.org
http://www.col-ed.org/smcnws

The SMCNWS is one of 10 regional Eisenhower consortia that disseminates promising educational programs, practices, and materials and provides technical assistance and training in support of state and local initiatives for quality science and mathematics content, curriculum improvement, and teacher enhancement.

Southwest Educational Development Laboratory (SEDL)
211 East Seventh Street
Austin, TX 78701-3281
(512) 476-6861
http://www.sedl.org

The Southwest Educational Development Laboratory produces the publication *Classroom Compass,* which presents examples of instructional activities that illustrate each issue's theme. See the Fall 1995 issue: Volume 2, No. 1, *Science as Inquiry,* also available online at http://www.sedl.org/scimath/compass/v02n01/welcome.html.

Technical Educational Research Center (TERC)
2067 Massachusetts Avenue
Cambridge, MA 02140
(617) 547-0430
http://www.terc.edu

Produces the semi-annual publication, *Hands On!* For subscription contact: Communications@terc.edu

See Volume 18, No. 1, *Coping with Inquiry,* available online at http://www.terc.edu/handson/spring_95/copinquiry.html. The author, Tim Barclay, addresses succeeding and failing at inquiry, an inquiring attitude, and various teaching strategies.

Online Resources

Access Excellence: Classrooms of the 21st Century
http://www.gene.com/ae/21st/

This teaching and learning forum explores current issues in curriculum, instruction, and assessment, and connects science teachers with innovators who are developing creative ways to use technology as a tool in science classrooms.

Busy Teachers' WebSite
http://www.ceismc.gatech.edu/BusyT/TOC.html

This site is designed to provide K-12 teachers with direct source materials, lesson plans, and classroom activities with a minimum of site-to-site linking. Mathematics, science, and other topics are covered. Links to Internet Discussion Groups for Educators (and Students) are provided.

Eisenhower National Clearinghouse for Mathematics and Science Education
http://www.enc.org/

This is a nationally recognized information source for K-12 mathematics and science teachers sponsored by the U.S. Department of Education, Office of Educational Research and Improvement. Resources include curriculum resources, a monthly list of outstanding Internet sites, thousands of classroom-ready lessons and activities, and links to other sites.

iwonder — Inquiry-Based Learning and Teaching: Mathematics and Science through Museum Collections
http://iwonder.bsu.edu/

This site is devoted to inquiry-based teaching strategies and provides teaching tools, including lesson plans, workshops, classroom ideas and strategies, and interactive student links.

Make It Happen! Integrating Inquiry and Technology into the Middle School Curriculum
http://www.edc.org/FSC/MIH/

In the Make It Happen! approach, interdisciplinary teams of teachers design and implement inquiry-based I-Search Units and integrate technology into these units in meaningful ways. Make It Happen! is the result of 10 years of research, evaluation, and technical assistance at the Education Development Center, Inc. (EDC) in Newton, Massachusetts.

Materials World Modules: An NSF Inquiry-Based Science & Technology Educational Program
http://mrcemis.ms.nwu.edu/mwm/

The Materials World Modules (MWM) is a National Science Foundation funded project producing a series of interdisciplinary educational modules centered on aspects of materials science. The modules are intended for use in high school science and mathematics classrooms. Some modules are also suitable for use in middle school settings.

Mathematics Learning Forums
http://www.edc.org/CCT/mlf/MLF.html

The Bank Street College of Education hosts a series of online seminars focused on the "how to" of mathematics instruction for elementary and secondary teachers, providing ongoing support to teachers as they implement reform in their own classrooms. Participants actively exchange ideas, share concerns, and construct new understandings as they converse with colleagues. For a registration form and more information phone (212) 807-4207; e-mail cct@edc.org or visit the Web site.

Perspectives of Hands-On Science Teaching
http://www.ncrel.org/sdrs/areas/issues/content/cntareas/science/eric/eric-toc.htm

This book is posted on the North Central Regional Educational Laboratory's Pathways to School Improvement Internet server. It was published by ERIC Clearinghouse for Science, Mathematics, and Environmental Education, and written by David L. Haury and Peter Rillero in 1994. This book/site presents answers to frequently asked questions about hands-on approaches to science teaching and learning. A number of resources, curricula, programs, strategies, and techniques are cited.

Project-Based Science: Real Investigation, Real Science
http://www.imich.edu/~pbsgroup/

The goal of the PBS group is to improve the way science classes are taught by involving students in finding solutions to authentic questions through extended inquiry, collaboration, and use of technology.

Science Education
http://www.tiac.net/users/lsetter/index.htm#pageindx

This page is the culmination of a doctoral project completed by Linda S. Setterlund at the University of Massachusetts, Lowell College of Education. It provides a collection of links on inquiry, constructivism, problem solving and creativity, and other mathematics and science sites.

Science Learning Network
http://www.sln.org/info/

The Science Learning Network (SLN) is an online community of educators, students, schools, science museums, and other institutions demonstrating a new model for inquiry science education. SLN is an NSF project that incorporates inquiry-based teaching approaches, telecomputing, collaboration among geographically dispersed teachers and classrooms, and Internet resources.

The Supportive Inquiry-Based Learning Environment (SIBLE)
http://www.ls.sesp.nwu.edu/sible/

The Supportive Inquiry-Based Learning Environment project is developing software to support project-based science and learning in classrooms. The software is intended to be used by both teachers and students for developing science projects, supporting project tasks, and assessing projects.

The Why Files?
Science Behind the News
http://whyfiles.news.wisc.edu/

A project of the National Institute for Science Education, this site is an electronic exploration of the science behind the news. Designed for teachers and students, the goal is to aid inquiry and broaden the conversation among science, engineering, mathematics, technology, and the rest of society.

Student Sites

Interesting Places for Kids
http://www.crc.ricoh.com/people/steve/kids.html

This is an ongoing collection of links that might be interesting to children. Science and mathematics, museums, art, literature, and many other topics are listed.

Kid's Search Tools
http://www.rcls.org/ksearch.htm

Six search engines, including: Berit's Best Sites for Children, which includes over 590 sites; Pathfinder's SiteSeeker searches kid-safe Web sites; Magellen Reviewed Web Sites targets sites appropriate for young audiences; Librarians' Index to the Internet (Select Kids), and more.

Yahooligans! The Web Guide for Kids
http://www.yahooligans.com/

A special version of Yahoo designed specifically for eight- to 14 year-olds provides searching and browsing capabilities.

Suppliers

The suppliers listed below offer a variety of materials and resources useful for inquiry-based teaching. While presence on this list does not imply endorsement by NWREL, the entries are representative of those available.

Activities Integrating Mathematics and Science (AIMS) Education Foundation
PO Box 8120
Fresno, CA 93747-8120
(888) 733-2467
Fax: (209) 255-6396
http://www.AIMSedu.org/
E-mail: aimsed@fresno.edu

American Association of Physics Teachers
One Physics Ellipse
College Park, MD 20740-3845
(301) 209-3300

American Chemical Society
Education Division
1155 Sixteenth Street, N.W.
Washington, DC 20036
(800) 209-0423

Carolina Biological Supply Company
2700 York Road
Burlington, NC 27215-3398
(800) 334-5551
Fax: (800) 222-7112

Creative Publications
5040 West 111th Street
Oak Lawn, IL 60453
(800) 624-0822

Cuisenaire Company of America, Inc.
PO Box 5026
White Plains, NY 10601-5026
Customer Service: (800) 237-3142
Fax: (800) 551-RODS
E-mail: INFO@CUISENAIRE.COM

Dale Seymour Publications
PO Box 10888
Palo Alto, CA 94303-0879
(800) 872-1100
Fax: (415) 324-3424

Delta Education, Inc.
PO Box 3000
Nashua, NH 03061-3000
(800) 442-5444
Fax: (800) 282-9560

Great Explorations in Math and Science (GEMS)
University of California
Berkeley, CA 94720
(510) 642-7771

Heinemann
361 Hanover Street
Portsmouth, NH 03801-3912
(800) 541-2086
Fax: (800) 847-0938

Minnesota Educational Computing Company (MECC)
Brookdale Corporate Center
6160 Summit Drive
Minneapolis, MN 55430-4003
(800) 685-6322

National Aeronautics and Space Administration (NASA)
Education Division
Mail Code FE
Washington, DC 20546-0001

Request Publication: How to Access NASA's Education Materials and Services

NW Region's Teacher Resource Center
(415) 604-3574

Pitsco, Inc.
1002 E. Adams
PO Box 1708
Pittsburg, KS 66762-1708
(800) 835-0686
Fax: (800) 533-8104
http://www.pitsco.com

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