

# **Inquiry Strategies for Science and Mathematics Learning**

**It's Just Good Teaching**

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## Preface

**I**nquiry-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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## 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

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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.

## 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 "cook-book" 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.

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?**

**T**here 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

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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.



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

**T**eachers 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