# Science for All Children

## A Guide to Improving Elementary Science Education in Your School District

NATIONAL SCIENCE RESOURCES CENTER
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# Introduction

The *National Science Education Standards,* published in 1996 by the National Research Council, presents a strong case for the importance of scientific literacy for all Americans. The *Standards* emphasizes that "everyone needs to use scientific information to make choices that arise every day. Everyone needs to be able to engage intelligently in public discourse and debate about important issues of science and technology. And everyone deserves to share in the excitement and personal fulfillment that can come from understanding and learning about the natural world."

Scientific literacy is also increasingly important in the workplace. More and more jobs require that people be prepared to think critically, solve problems, and use technology effectively. Furthermore, we need a scientifically literate public if we are to compete successfully in the global marketplace.

One proven way to achieve these goals is to begin to teach science in elementary school, as early as kindergarten. Through a particular approach to science education, called *inquiry-centered science,* children learn to ask questions, experiment, develop theories, and communicate their ideas.

This book outlines a model of a science education system that fosters the teaching of inquiry-centered science. The model, which is based on research and practice, consists of five elements: a research-based, inquiry-centered curriculum; professional development; materials support; appropriate assessment strategies; and community and administrative support. These elements all work together as a unified whole, yet each element is significant in itself and must be understood on its own terms. Therefore, the book not only explores each element but also describes how they work together.

To further illustrate the ideas put forth here, the book includes a series of case studies that show how the model is being implemented in different school districts nationwide. The case studies provide evidence that by implementing the National Science Resources Center (NSRC) model for science education reform, school districts also go a long way toward implementing the recommendations in the *National Science Education Standards*.

**Organization of *Science for All Children***

This book is divided into three parts. **Part 1: Building a Foundation for Change** explains the rationale for inquiry-centered science and provides some basic tools for planning for such a program. It includes the following four chapters:

**Chapter 1:** The Value of Science Education
**Chapter 2:** How Children Learn
**Chapter 3:** Sharing the Vision of Exemplary Elementary Science
**Chapter 4:** Planning for the New Elementary Science Program

Chapter 1 opens with a discussion about inquiry-centered elementary science and what the research says about its effectiveness. Chapter 2 explores how inquiry-centered science builds on what we know about how children learn. Chapter 3 presents an overview of the five elements of an effective elementary science program, and Chapter 4 discusses how school districts can begin the strategic planning process.

**Part 2: The Nuts and Bolts of Change** explains how to implement an inquiry-centered science program by focusing on the five elements of the NSRC model for science education reform. This section includes the following chapters:

**Chapter 5:** Criteria for Selecting Inquiry-Centered Science Curriculum Materials
**Chapter 6:** Professional Development for Inquiry-Centered Science
**Chapter 7:** Establishing a Science Materials Support Center
**Chapter 8:** Assessment Strategies for Inquiry-Centered Science
**Chapter 9:** Building Support for the Science Program

*Science is for all students: First-graders discover the wonders of insects during a science module on organisms.*

**Part 3: Inquiry-Centered Science in Practice** is a collection of eight case studies of efforts to implement the model of inquiry-centered science described in Part 2. The school districts and programs profiled are Montgomery County Public Schools, Montgomery County, Maryland; Spokane School District 81, Spokane, Washington; East Baton Rouge Parish Public School System, East Baton Rouge Parish, Louisiana; Cupertino Union School District, Cupertino, California; Hands-On Activity Science Program, Huntsville, Alabama; Pasadena Unified School District, Pasadena, California; City Science (San Francisco Unified School District), San Francisco, California; and the Einstein Project, Green Bay, Wisconsin.

Each of these districts came to reform in a slightly different way. Some were self-motivated and began the reform process within their own school districts; other reform efforts were spearheaded by a corporate sponsor. Still other school districts worked with members of the scientific community through a partnership with an academic institution. Finally, some school districts joined together to form consortia, another effective way to implement change.

Recommendations for further reading are included at the end of each chapter. The appendixes provide additional resources. **Appendix A** describes professional associations and government agencies involved in science education reform. **Appendix B** describes exemplary elementary science curriculum materials.

### How to Use *Science for All Children*

This book may be used by many members of a school district or community, including teachers, administrators, school board members, parents, and scientists. Therefore, readers may wish to focus on the sections of greatest interest. For example, a school board president, a concerned parent, or a PTA activist may choose to read Part 1 (Chapters 1–4) carefully. It presents research data confirming the effectiveness of inquiry-centered science as well as other arguments supporting teaching in this way. This section can help you build a case to take to your school administration or community members.

Teachers and school administrators committed to inquiry-centered science will find Part 2 particularly useful. Chapters 5–9 explain how to implement an inquiry-centered science program. Important information about selecting curriculum materials, creating opportunities for professional development, setting up and maintaining a materials support center, and developing new strategies for assessing student learning is included here.

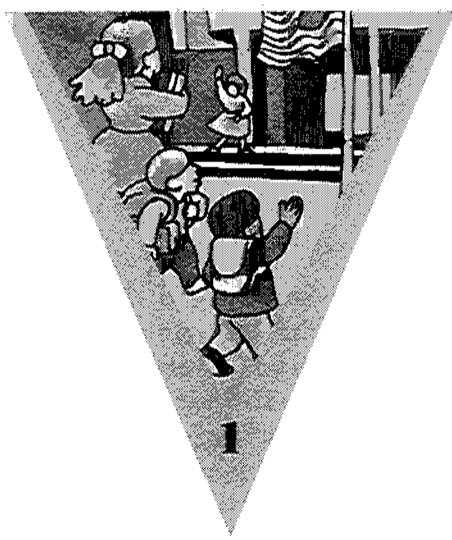
Everyone involved in education will find Part 3 helpful. The case studies explain how eight programs have implemented science education reform and explore some of the "ups and downs" that school officials and community activists have experienced along the way.

We hope that everyone who works with children and is interested in their education will find this book both useful and informative. Furthermore, we hope that it will inspire educators to become engaged in implementing inquiry-centered elementary science programs in their school districts.

Part

1

# Building a Foundation for Change



# 1 The Value of Science Education

*The utilization of subject-matter found in the present life-experience of the learner towards science is perhaps the best illustration that can be found of the basic principle of using existing experience as the means of carrying learners on to a wider, more refined, and better organized world.*

— John Dewey, *Experience and Education*, 1938

Every fall, several million children mark the beginning of their formal education by entering kindergarten. These five-year-olds are full of enthusiasm and excitement. They will ride the school bus like the big kids and have a chance to see what school is all about. Parents, too, see this moment as a turning point. School provides an opportunity for children to discover the answers to questions they often ask, such as, How are rocks made? and Why do ships float? All those close to children hope that school will continue to spark children's natural love of learning.

Teachers use many strategies to keep that love of learning alive. To stimulate their students' natural curiosity, some teachers arrange field trips to wetlands, rivers, and lakes as part of their study of natural ecosystems. To keep young imaginations flourishing, other teachers bring duck eggs to school and encourage students to care for them and imagine what the ducklings will be like when they hatch. To instill a love of experimental inquiry, teachers use materials such as batteries and bulbs or rocks and minerals as the starting point for asking questions, experimenting, developing theories, and communicating their ideas.

All of these learning activities are part of *inquiry-centered science,* sometimes called simply *inquiry.* According to the *National Science Education Standards,* inquiry involves "making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations, and predictions; and communicating results."[1] These activities are deeply rooted in both the scientific tradition and educational theory.

Nonetheless, inquiry represents a new approach to science education to many school districts and teachers. The reason that inquiry appears new is that many districts have come to rely on textbooks as the major vehicle for conveying information to students. While textbooks may include basic information about a science subject, they typically overemphasize vocabulary and factual information. Because teachers feel pressured to make sure that students "get it all," they often ask students to memorize these words and facts. Experience has shown that memorizing words and facts not only neglects the most important parts of science but also seems boring and irrelevant to young learners.

To illustrate some of the pitfalls of the passive learning environment created by a textbook-driven science class, consider the following example, which is excerpted from a monograph written by Howard Hausman, *Choosing a Science Program for the Elementary School:*[2]

> Twenty-six third-graders are seated at tables. The teacher asks Carla to read aloud from page 56 of the textbook, which shows a picture of a farm with animals and a windmill. Carla

reads that the farm has many animals and that they need water. However, the picture shows that there is little water on the land, implying that the water will have to come from wells powered by windmills. She reads the question directly from the textbook, "What does the windmill do?"

The teacher repeats, "Can anybody guess what the windmill does? Yes, Joey." Joey, who has been skimming to the next paragraph of the text, says, "The windmill turns from the force of the air and works a pumping machine. This lifts water from the well into a water tank for the animals."

"Very good, Joey," says the teacher. "Now Carla, can you read the next paragraph?" Carla proceeds to read: "The windmill turns from the force of the air and works a pumping machine. This lifts water from the well into a water tank for the animals." She reads on about windmills operating machines to supply electric power. Then come other examples of "energy from moving air."

Several children are moving restlessly, playing with pencils and whispering. The teacher calls for attention, as he has done twice before.

"What work was being done?" the teacher asks. No answer. "Did the wind do any work?" "It blew a windmill," someone says.

The restless movements persist. There is another call for order, a period of enforced quiet. The books are collected and shelved.

## The Limitations of Traditional Classrooms

Why did this lesson fail to hold the children's interest? Why were the children restless and seemingly unmotivated to explore the ideas presented during the science lesson?

For one thing, the children did not do science. They did not examine objects, observe phenomena, design experiments, collect data, or discuss their ideas. There were no opportunities for independent thinking and problem solving. Instead, they simply read about science. The children gained very little, because the book they were reading was describing things they knew or cared little about. Most children today have never seen a windmill firsthand and have no idea what a pumping machine is. The fact that a windmill can generate electricity is also meaningless to these children;

to them, electricity is something that happens when they turn on a light switch. "Work" and "energy" are abstract ideas that have never been made concrete or meaningful to them. Because these ideas are beyond the realm of their experience, the children have little desire to explore them further.

*Experience* is the key factor. Research on children's learning has revealed that when children do not have firsthand experiences with the things they are learning about in school, the information that the curriculum seeks to convey will often not make sense to them. Jean Piaget, a Swiss psychologist, devoted his life to observing children and drawing conclusions about their intellectual growth. His work laid the foundation for further studies of how children learn, a field that is now called *cognitive science.* One key finding that has emerged from this work is that children learn actively and they do so through direct experiences with the physical world.

Part of the pressing need for hands-on experiences stems from the fact that as today's children grow, they have increasingly little contact with the natural world. The lack of concrete experiences means that children have fewer resources to draw on in their efforts to make sense of the world. This is a drastic change from the way things were a few generations ago, when more children lived on farms and had numerous opportunities to experience firsthand many aspects of science, such as helping to plant crops and discovering the importance of rains to the harvest. Children today may see such things on television or explore these ideas by playing games on computer screens, but they seldom experience them directly. As Philip and Phylis Morrison explain:[3]

> In Abraham Lincoln's day, most of the students were from farm families. They came to school knowing firsthand about birth and death, about the full moon, about how to lever up a heavy rock, how to sharpen a blade, and how milk soured. They didn't have to learn those things in school, because they encountered them all the time. What they went to school to learn was symbols—words and forms; how to read, write, and cipher; what scholars and leaders in the past had said; how to express and reason about the world and themselves.
>
> Children still come to our schools with plenty of knowledge. They bring a wide visual acquaintance with the world

near and far, a flood of images, fact and fiction. They see print everywhere, too; signs and posters surround them; magazines and books are commonplace, with all their pictures. Television has made the wide world familiar to children. But what is deeply missing is an inner sense of the world's real constraints, of the difference between desire and performance. Pushing a button is not like leaning on a crowbar.

The symbols still need teaching; the three R's, the history, the maps, the tales remain urgent. But they lack any foundation beyond word and image. The schools have a big new task that they have not entirely realized: it is to bring in the hands-on world, the real uncertain thing that induces questioning, that stubbornly resists or wonderfully confirms what one does. What children need is to grow plants (and see them wilt for lack of water), to complete the cycle by planting the seed they themselves harvest from the plant they grew. They need to build bridges of soda straws that can hold up the weight of many milk cartons. They need to try which connections between bulb and battery produce light, and for how long.

It would be an error to blame schools for our growing lack of physical contact with the physical world, but an even bigger error not to do something about it. We are all in this bind together; it is the result of a maturing technological world where production is taken farther and farther away from the consumer. The capacity to judge from evidence when things are right, when they work or when they don't work, doesn't apply only to circuits or other matters of science. It also applies to political programs or to buying consumer goods. It is an understanding that begins with active experience in the natural and technological world.

So let us teach our children how to read, write and cipher—but let us also help them explore something of how the material world works. They need to sense through hand, eye, and mind the limits of what can be done, and how even within stern natural limits new opportunities can open.

## A Glimpse at an Inquiry-Centered Classroom

Many teachers across the country today are providing the kind of inquiry-centered science experiences that the Morrisons describe.

### A Problem-Solving Investigation

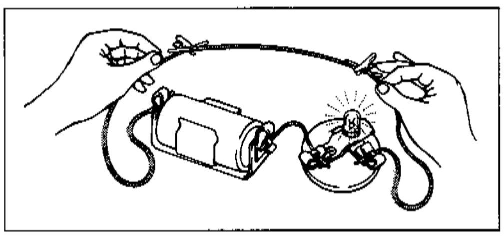
The students approach the problem by discussing how they could use a model of a simple circuit tester—a battery attached to a bulb with wires—as a tool to determine what's inside the mystery box. Perhaps, the students reason, they could touch the wires to the terminals on the box to see whether the device inside causes the bulb to light. Discovering whether the bulb will light will provide the students with important information about what's inside the box.

Proceeding according to their plan, the students touch the wires of the circuit tester to the terminals on the box. The bulb lights up. From this evidence, they conclude that a wire must be connected between the terminals inside the box.

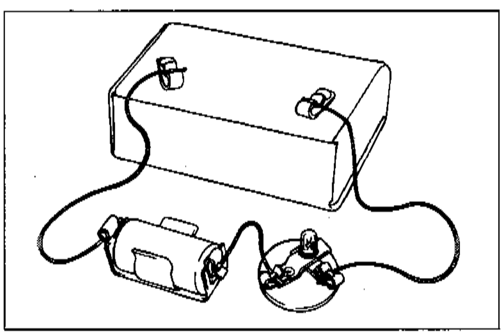
As the students work, their teacher circulates throughout the classroom. She stops to talk with a pair of students. While she commends them on their work, she suggests that they take their investigation further. What kind of wire might be inside the box? Is it a copper wire or a nichrome resistance wire? Or could there be a bulb connected to the terminals inside the box? Would copper wire make the bulb shine more or less brightly? The teacher recommends that the students think about these questions, discuss possible explanations, and find a way to test their ideas through experimentation. She also suggests that the students record their conclusions, either through writing or drawing.

The students begin discussing the problem. Through the active exchange of ideas, they conclude that a copper wire would produce a brighter light than a resistance wire or a bulb. In earlier investigations, they found that both resistance wire and a bulb conducted electricity, but that neither allowed the bulb to burn as brightly as the copper wire did. Therefore, it seems likely that either a resistance wire or a bulb is in the box.

To test this theory, the students develop the following strategy: First, they will place a piece of copper wire in the circuit tester and observe the brightness of the bulb. They will hook up the circuit tester to the terminals on the mystery box. They will observe the brightness of the bulb and see whether it is brighter or dimmer than before. They will repeat this process with the resistance wire and the bulb. When the brightness of the bulb in the circuit tester matches that of the mystery box, the students will be able to determine what's inside the box.



*Testing copper wire with the circuit tester*



*Testing the mystery box with the circuit tester*

The students begin working. They notice that the bulb in the circuit tester shines more brightly than the one in the mystery box when copper wire is connected in the tester. This comparison is clear-cut, and the students easily reach the conclusion that copper wire is not inside the box. But comparing the resistance wire and the bulb proves to be more difficult. In both tests, the bulb is shining dimly, and it is hard to see any differences.

After further deliberation, the students begin to develop their conclusions. One student writes a summary indicating that the mystery box contains either a piece of resistance wire or a bulb; the student reached this conclusion because she could not tell, on the basis of the "bulb test," which of these two devices is inside the box. Another student draws a picture showing resistance wire; she feels confident that only resistance wire could create such a dimly lit bulb. When the students open the mystery box, they discover that a piece of resistance wire is inside.

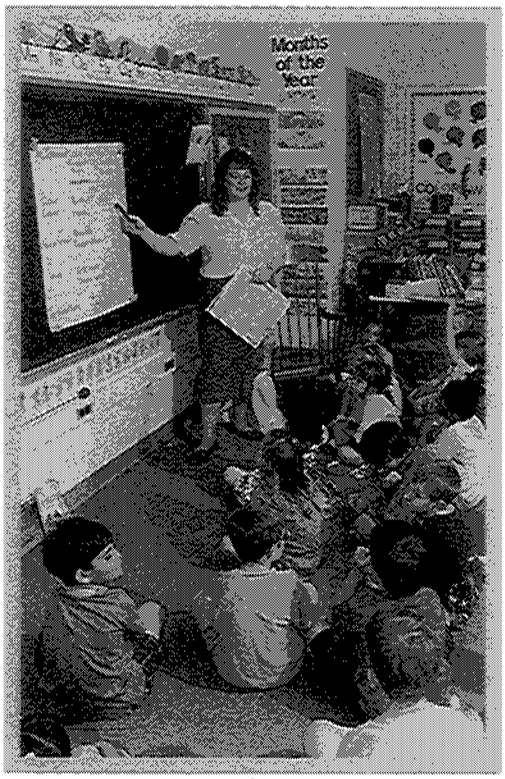
The boxed example (pp. 12-13) illustrates how some fundamental concepts about electricity can be taught through an inquiry approach. The students, who are in fifth grade, have already constructed simple circuits using flashlight batteries, wires, and flashlight bulbs. They have also explored electrical conductors and insulators. In this lesson, students continue their study of electric circuits by teaming up in pairs and working with mystery boxes—plain white boxes with two terminals on top that contain an unknown electrical device. The students' challenge is to find out, through experimentation and reasoning, what electrical device, if any, is connected to the terminals inside the box.

## The Benefits of Inquiry-Centered Science

For many adults, science conjures up an image of a research investigator in a white coat testing a mysterious substance in his laboratory. They see the scientific process as esoteric, with results as elusive as the potions in the researcher's test tubes. But, as the boxed example shows, science does not have to be shrouded in mystery and assumed to be too complex for most of us to master. Simply put, science is the process by which we discover how the world works, "a way of thinking, . . . the method by which the creative mind can construct order out of chaos and unity out of variety."[4] It is a process in which children have been engaged virtually since they were born, and it is mirrored effectively in inquiry-centered science programs. For that reason, it is not surprising that in the second classroom described, children were still engaged in the activity after an hour of intense work.

What conclusions about the value of inquiry can be drawn from the boxed example? The following list describes several benefits of inquiry-centered science:

**1. The children are actively engaged.** By working with batteries and bulbs, the children were thinking, coming up with ideas, developing their reasoning skills, and increasing their ability to solve problems. Piaget discovered the importance of using materials as a vehicle for learning and of providing a learning environment that is rich in physical experiences. "Involvement," Piaget said, "is the key to intellectual development, and for the elementary school child, this includes direct physical manipulation of ob-




*A typical first-grade classroom today.*

jects, the kind of manipulation so easily achieved in science lessons."[5] *Benchmarks for Science Literacy*, prepared by the American Association for the Advancement of Science (AAAS), also shares this view: "For students in the early grades, the emphasis should overwhelmingly be on gaining experience with natural and social phenomena. . . . By gaining lots of experience *doing* science, becoming more sophisticated in conducting investigations, and by explaining their findings, students will accumulate a set of concrete experiences on which they can draw to *reflect* on the process."[6] In addition, the *National Science Education Standards* establishes active learning as one of the underlying principles of science education. The *Standards* stresses that "learning science is something students do, not something that is done to them."[7]

**2. Inquiry-centered science brings the real world into the classroom and into children's lives.** By bringing materials like batteries and bulbs into the classroom, we are giving children the opportunity to experience for themselves the work that scientists do. They can work with the tools of science and develop their own questions and ideas. Jos Elstgeest, a science educator from The Netherlands, defines this approach to science education by identifying it as "a swing away from the factual syllabus. Instead of teaching about scientific facts which are the result of the scientific activity of others, it becomes an education through doing science.

Instead of trying to remember descriptions of the results of science, it becomes learning how such results are obtained. Instead of hearing and forgetting, it becomes doing and understanding."[8]

**3. Inquiry-centered science promotes teamwork and collaboration.** Inquiry-centered science requires that students learn to work collaboratively, a skill that is increasingly needed not only in school but also in the workplace. Corporate leaders have indicated that patterns in the workplace have changed from individual problem solving to team problem solving. By working together throughout school, students have opportunities to learn from others and to discover that collaboration is essential to effective problem solving.

**4. The inquiry-centered science classroom accommodates different learning styles.** Howard Gardner has documented that people learn in a variety of different ways, including through language, mathematical reasoning, and visual arts. Gardner writes, "Genuine understanding is most likely to emerge, and be apparent to others, if people possess a number of ways of representing knowledge of a concept or skill and can move readily back and forth among these forms of knowing. No one person can be expected to have all modes available, but everyone ought to have available at least a few ways of representing the relevant concept or skill."[9] Inquiry-centered science encompasses many learning styles and gives children experience shifting from one mode to another. In addition, students who may not learn most effectively through traditional vehicles—such as reading or listening—have other opportunities to excel.

**5. Inquiry-centered science encourages learning in more than one area of the curriculum.** Science can be a springboard for exploration in other parts of the curriculum. For example, one student in our example recorded her results in writing, an effective way to develop language arts skills. The other student made drawings to describe her findings, making a link with art. Students also may be called upon to graph their findings or perform calculations to interpret their data; both of these activities show the close link between mathematics and science.

**6. Children's grasp of new concepts and skills is reflected in their work during the activity.** By observing her students as they worked with the mystery boxes, the teacher was able to gain important information about what they really understood about the subject. Instead of relying exclusively on tests at the end of the unit, she could assess students' progress as they worked. She could use this information to create additional lessons that related directly to concepts students found hard to understand or to ideas they were interested in learning more about.

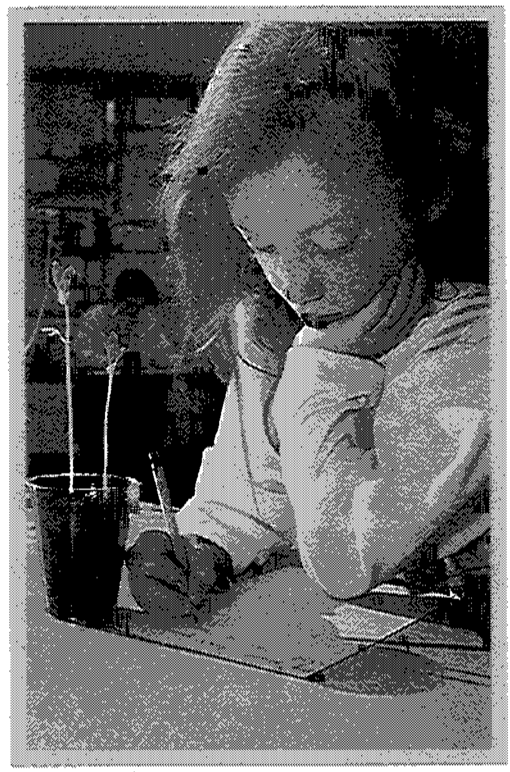
A key objective in science education is to improve students' thinking skills, and traditional tests are often inappropriate for measuring such skills. Lauren Resnick states that multiple-choice tests "can measure the accumulation of knowledge and can be used to examine specific components of reasoning or thinking. However, they are ill suited to assessing the kinds of integrated thinking we call 'higher order.'"[10] To measure the gains made during science class, educators are beginning to recognize that alternative assessments are needed. We will explore this issue in Chapter 8.

## Process Skills and Assessment

Inquiry-centered science has been shown to foster the development of certain skills needed for effective problem solving. These skills, often referred to as *process skills*, include organizing information, thinking critically, and applying knowledge to new situations. Inquiry-centered science fosters the development of process skills because it provides a firm content base from which children can draw.

Thinking skills cannot be developed in a vacuum; they evolve while people work on an interesting problem. Resnick echoes this view when she states, "Cognitive research has established the very important role of knowledge in reasoning and thinking. One cannot reason in the abstract; one must reason about something. Each school discipline provides extensive reasoning and problem-solving material by incorporating problem-solving or critical thinking training into the disciplines."[11]

Other researchers have performed longitudinal studies in attempts to measure the value of inquiry-centered science. For example, Arthur Reynolds and co-workers at Northern Illinois University found that students who had been taught science in inquiry-centered elementary school classrooms were more successful in middle school and high school science classes than were students taught in more traditional ways, such as by reading a textbook.[12] In addition, students who had experienced inquiry-centered science were more adept at problem solving than those who participated in traditional programs.



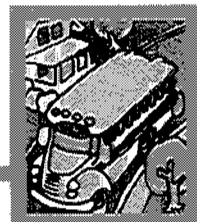
*Inquiry-centered science offers students time to reflect and work independently.*

Another researcher, Ted Bredderman, summarized and analyzed the experiences of 13,000 students in 1,000 classrooms, as reported in 60 studies of science learning.[13] He found that with the use of inquiry-centered science programs, students demonstrated substantially improved performance in science process and creativity; improved performance on tests of perception, logic, language development, science content, and math; and modestly improved attitudes toward learning science. The benefits of inquiry-centered science for economically disadvantaged students were pronounced.

In addition to fostering problem-solving skills, inquiry helps instill in children a world view that reflects an understanding of the importance of science to their everyday lives. Project 2061 of the AAAS has identified five attitudes that children should acquire through science education. These attitudes are 1) curiosity (questioning, wanting to know), 2) respect for evidence (open-mindedness, willingness to consider conflicting evidence), 3) critical reflection (weighing observations and evaluating what has been observed), 4) flexibility (willingness to reserve judgment and reconsider ideas), and 5) sensitivity to living things (respect for life and environmental awareness).

Science educators hypothesize that students who experience inquiry throughout school will become questioning adults, interested in hearing all sides of an argument before passing judgment. They will be keen observers, adept at evaluating what they have seen and drawing conclusions about it. Also, they will be more concerned about the natural world and more committed to protecting the environment than previous generations have been.

Although this hypothesis has not yet been tested on a large scale, there is evidence that inquiry will result in these outcomes for one key reason: It supports the way children naturally learn. Chapter 2 explores further the relationship between inquiry and the way children learn by focusing on the work of cognitive scientists. Their research underscores the value of inquiry in fostering intellectual development.



**Key Points**

- The inquiry-centered approach to science encompasses working with materials, asking questions, planning experiments, interpreting data, synthesizing results, and communicating those results.
- Inquiry supports the way children naturally learn, a very strong argument for using this approach to teach elementary school science.
- Inquiry-centered science is easily integrated with other areas of the curriculum, such as language arts and mathematics.
- Inquiry accommodates different learning styles, giving students who may not learn most effectively through reading or listening other opportunities to succeed.

## For Further Reading

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