VOLUME 2

FOUNDATIONS

A monograph for professionals in science, mathematics, and technology education

Inquiry

Thoughts, Views, and Strategies for the K–5 Classroom

Division of Elementary, Secondary, and Informal Education

Directorate for Education and Human Resources

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About Foundations

Foundations is a monograph series published by the National Science Foundation's Division of Elementary, Secondary, and Informal Education (ESIE) in conjunction with the Division of Research, Evaluation and Communication (REC) to serve those working to better science, mathematics, and technology education in this nation. Foundations supports education reform by communicating lessons that have been learned from ESIE projects and activities to others in the field who may use and adapt them to build effective educational improvement strategies in their own classrooms and communities. Like the foundation of a schoolhouse, home, or other place of learning, the strength of what is above ground depends on the structural soundness of what lies below. Foundations will unearth the strategies that enable effective educational improvement at the K–12 level to take place. Welcome to Foundations…

In This Volume

Foundations examines opportunities and challenges for those at the front line of science education in elementary and middle schools. Designed as a resource for teachers and administrators who are interested in investigating inquiry-based science education, this volume serves neither as a textbook nor as the final word on the subject. It is rather a short introduction for those beginning the complex and difficult journey of science education reform based on the experiences of educators working in the inquiry field today.

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PREFACE

Humans are born inquirers. You can see it from the moment of birth: Babies use all of their senses to make connections with their environment, and through those connections they begin to make sense of their world. As children discover objects and situations that are puzzling or intriguing—things that provoke their curiosity—they begin asking questions and looking for ways to find answers, all in an effort to understand the world around them. This is the essence of the inquiry process.

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This book is designed to help anyone interested in science education reform—teachers, school administrators, policymakers, and parents—understand the philosophy and practical applications behind science inquiry learning in the K–5 classroom. This publication brings together the thoughts and skills of many experts in the field. It focuses on the real experiences of teachers and teacher educators who are charged with preparing our children for a future that promises to demand more and more scientific understanding.

There's no right way to use this book: you can read through the whole text, pick out the articles that interest you, or focus on specific practical lists and guides.

The PREFACE and INTRODUCTION present the concept of inquiry in science teaching and set the stage for the views and comments of experts in the field.

CHAPTERS 1 through 4 look at the history and philosophy of inquiry in science, exploring the ways in which children think and learn—on their own as well as in structured settings—and their natural habits of questioning and curiosity.

CHAPTERS 5 through 10 explore the challenges of teaching inquiry science, from a comparison of three different types of hands-on activities to the experiences of teachers who have successfully introduced inquiry into their classrooms.

CHAPTERS 11 and 12 address the important and sometimes difficult process of assessing learning in the inquiry classroom.

CHAPTER 13, the End Paper, concludes by exploring the importance of assessing our own state of knowledge.

We hope that these essays, written by individuals who have both experienced and experimented with science inquiry learning, will help answer questions, deal with concerns, and provide a foundation for those who are considering introducing inquiry into the elementary classroom, or who have already begun the process.

An Introduction to Inquiry

> Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills.
>
> —*National Science Education Standards*

As we grow up, we all develop everyday, common-sense views of the world. These ideas may get us through the day and help us make sense of what we see and experience on a practical level, but they aren't necessarily in concert with the current scientific view of the world. The earth, for instance, looks flat from our perspective; the sun appears to move across the sky. There's no real reason to think otherwise—unless we're helped to see and understand it differently. Children need to develop a scientific view of the world, and to really understand the meaning of scientific concepts. One critical aspect of science education is to help children develop the skills they need to think like scientists in their pursuit of understanding.

Children need to be nurtured to fully develop their abilities to become real thinkers—to puzzle through problems, to see multiple ways of finding solutions, to gather and weigh evidence, and to apply and test scientific ideas. They need opportunities to experience the joy of discovery and develop scientific attitudes such as perseverance, risk taking, curiosity, and inventiveness. These skills of inquiry can ultimately equip children with the ability to function effectively as adults, both at work and in the everyday world.

Courtesy Phil Hicks

What is inquiry?

Inquiry is an approach to learning that involves a process of exploring the natural or material world, and that leads to asking questions, making discoveries, and rigorously testing those discoveries in the search for new understanding. Inquiry, as it relates to science education, should mirror as closely as possible the enterprise of doing real science.

The inquiry process is driven by one's own curiosity, wonder, interest, or passion to understand an observation or solve a problem.

The process begins when the learner notices something that intrigues, surprises, or stimulates a question—something that is new, or something that may not make sense in relationship to the learner's previous experience or current understanding.

The next step is to take action—through continued observing, raising questions, making predictions, testing hypotheses, and creating theories and conceptual models.

The learner must find his or her own pathway through this process. It is rarely a linear progression, but rather more of a back-and-forth, or cyclical, series of events.

As the process unfolds, more observations and questions emerge, giving occasion for deeper interaction with the phenomena—and greater potential for further development of understanding.

Along the way, the inquirer collects and records data, makes representations of results and explanations, and draws upon other resources such as books, videos, and the expertise or insights of others.

Making meaning from the experience requires reflection, conversations, comparisons of findings with others, interpretation of data and observations, and the application of new conceptions to other contexts. All of this serves to help the learner construct a new mental framework of the world.

Good science education requires both learning scientific concepts and developing scientific thinking skills. Effective classrooms rely on many different ways of teaching science. This book is devoted to one approach, inquiry learning, which has proven to be a powerful tool in learning science and in keeping wonder and curiosity alive in the classroom.

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CHAPTER 1

Why Inquiry? A Historical and Philosophical Commentary by Peter Dow

There's nothing new about learning science through inquiry. Making observations, asking questions, and pursuing investigations has always been a fundamental human approach to understanding the world. This essay traces the history and philosophy of inquiry, the controversies—past and present—that have surrounded it, and its promise for the future.

Scientific inquiry has its roots in the inherent restlessness of the human mind. We humans have pursued our passion to explore far beyond any other inhabitant of the planet. Curiosity is the basic human trait that has ensured both our survival as a species and our continuous cultural evolution. In American society, scientific inquiry has been the source of both our technological superiority and our economic well-being. Is it surprising, therefore, that we should regard cultivating the skills of inquiry as central to the process of schooling?

In societies where inquiry has flourished, so has human progress. Athens of the fifth century B.C. comes to mind. The Agora—the marketplace where freedom-loving Greeks gathered to discuss the issues of the day—was a crucible of intellectual inquiry led by one of history's most celebrated teachers, Socrates. An indefatigable inquirer, Socrates challenged the youth of the city to think for themselves, to question the wisdom of their elders, and to probe the unsolved mysteries of the natural world.

For a time, Athens thrived on the intellectual ferment that ranged from the scientific and philosophical deliberations of Plato and Aristotle to the literary and artistic achievements of Sophocles and Phidias. Yet Socrates paid with his life for his endless probing and his uncompromising search for truth. In the end, even sophisticated Athens could not tolerate this unrelenting passion for inquiry.

Few of us can claim lives spent in Socratic dialogue, but we respect the work of this master teacher who took no pay because he claimed to know nothing, and who challenged the young people of Athens to learn how to think for themselves. Minds so trained, we believe, will contribute to the improvement of society and to the advancement of science. We have inherited this passion for inquiry not only from the ancient Greeks, but equally from the Renaissance of Galileo and Leonardo, and the Enlightenment of Locke and Rousseau.

The skills of skeptical questioning and independent thinking may be essential goals of schooling.

The 20th century has raised new questions about the power of scientific inquiry. No longer is it certain that the capacity of the inquiring human mind to unlock the secrets of the cosmos is always a net benefit to humanity. As we play out our restless urge to understand and control our surroundings, the power to destroy now rivals the power to invent. Perhaps now, more than ever before, the ability of average citizens to think for themselves may be the best protection in a world of increasing technological and scientific complexity. If so, the skills of skeptical questioning and independent thinking may be essential goals of schooling.

On the eve of World War II, our most celebrated 20th-century educator/philosopher, John Dewey, made a persuasive case for the importance of inquiry-based teaching as a way of preserving values in a world threatened by totalitarianism. The scientific method, he said, “is the only authentic means at our command for getting at the significance of our everyday experiences of the world in which we live” (1938, 111). Dewey believed that the ability to reason scientifically was an essential skill for coping with the complexities of modern life, and he warned that failure to cultivate such skills risked “a return to intellectual and moral authoritarianism” (p. 109). Today, we may need the skills of scientific thinking more than ever, as we cope with the challenges of factual overload in our information age.

For Dewey, inquiry teaching involved allowing children to learn from direct experience and cultivate their natural curiosity. He believed that the essentials of creative thinking were contained in the processes of science, and that intellectual activity was much the same whether in the kindergarten or the scientific laboratory. Organizing learning in this way, he argued, would enable teachers and students to integrate knowledge across the disciplines through the cultivation of disciplined habits of mind, and allow learning to unfold in a way that respected the intellectual growth and age-specific concerns of the child. Although Dewey died without witnessing the information explosion of our own time, he saw the need for cultivating the skills of lifelong, self-directed learning.

More recent educational theorists such as Jean Piaget and Jerome Bruner have added the weight of cognitive research to Dewey's philosophical propositions. Bruner and Kenney's *Studies in Cognitive Growth* (1966) contains a celebrated paper by George Miller, entitled "The Magic Number Seven, Plus or Minus Two," wherein Miller argues that the human mind can only hold approximately seven discrete bits of information at one time. Based on this finding, Bruner later argued for "filling those seven slots of memory with gold." By this he meant helping students grasp the deep conceptual structure that underlies the disciplines, rather than memorizing unconnected facts.

Biologist E. O. Wilson has recently made a similar point in *Consilience* (1998), in which he proposes replacing discipline-based instruction with a return to the unification of knowledge exemplified by the Enlightenment. How can we best accomplish this, in Wilson's view? By implementing (as Dewey argued) a learning process that focuses on examining the world by direct experience. This approach derives knowledge from prolonged observation and experimentation, and from the exploration of fundamental questions. How do organisms eat, avoid being eaten, and survive to reproduce? How do they ensure their survival and the survival of their offspring—thereby avoiding extinction in a world governed by the laws of natural selection? And what is the place of human beings in this world of biological imperatives?

In an inquiry-driven classroom, is there still a role for didactic instruction? This, too, is a question to explore. Clearly, teaching by telling is the most efficient way to get across important facts, concepts, and ways of thinking about things. Yet recent cognitive research would suggest that much of what we "learn" in such contexts has a relatively short half-life in memory. How can we ensure that what lasts in learning is the "gold" that Bruner proposes?

Unfortunately, pedagogy is not an exact science. Yet the science teaching reforms of the past 40 years have provided growing evidence that instruction designed around the careful examination of real phenomena, and the pursuit of significant questions formulated by both teachers and students, have delivered results in emotional engagement, memory retention, and cognitive understanding that challenge the results of didactic teaching. This is good news: if true, it could liberate schooling from the intellectual authoritarianism that Dewey feared.

If Socrates were alive today, and could visit an American school, there is much that would mystify him. He would be hard-pressed, for instance, to follow the discussion in an advanced-placement high school chemistry or physics class. Yet despite the level of knowledge displayed, he would probably be as critical of intellectual arrogance today as he was in his own time. And he would still argue that the essence of good teaching lies in framing the right questions, regardless of the sophistication of the subject matter.

Perhaps he would be happiest visiting a modern-day elementary school, or even a kindergarten, where learning involves firsthand investigation of the mysteries of the natural world, where the rules of social behavior are assimilated on the playground, and where teachers encourage their students to pursue their own questions and figure things out for themselves. Is this not the Socratic method? And has it not been through most of human history—long before the development of civilization—the primary way to learn?

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CHAPTER 2

What Children Gain by Learning Through Inquiry
by Hubert Dyasi

Curiosity is a fundamental human trait. By valuing this natural impulse to learn, the inquiry process can give children the direct feedback and personal experiences they need to shape new and enduring views of the world. This essay points out how inquiry can make a difference in the way children acquire and understand scientific concepts.

Where do butterflies come from?
What causes clouds?
Where does the sun go at night?
Do ants bite?
Why does it get dark quickly in the winter?
How do you make a flashlight light?

From an early age, humans puzzle over phenomena of nature they encounter and ask many questions about them. Whether asked verbally or in actions, these questions indicate curiosity—an intense desire to know or to find out. Curiosity is thus a fundamental human trait. But how does one find answers to these questions? Is it by inquiring into them directly, or is it by obtaining answers from those who already know them?

What we do to get an answer to a question, and how we know when an answer is "correct," are also indications of human curiosity. Since curiosity is at the center of inquiry, these questions too are an integral part of inquiry, which in turn must be a human habit of mind and learning.

The *National Science Education Standards*, developed by the National Research Council (1996), elaborate major components of learning and teaching science through inquiry. "Students at all grade levels and in every domain of science," it states, "should have the opportunity to use scientific inquiry and develop the ability to think and act in ways associated with inquiry, including asking questions, planning and conducting investigations, using appropriate tools and techniques to gather data, thinking critically and logically about relationships between evidence and explanations, constructing and analyzing alternative explanations, and communicating scientific arguments" (p. 105). Although this definition refers to qualities of inquiry that are especially related to the learning and practice of science, inquiry also relates to learning in other areas of study.

Communicating Through Action

Inquiry is at once a practical and an intellectual activity. In young children, inquiry frequently focuses on tangible items that are of immediate interest. For example, when a toddler slides off a couch and for the first time lands on her feet instead of falling flat on the floor, she may climb back onto the couch and repeat the activity. The child might do this several times, exhibiting delight each time she lands on her feet. It is as though the toddler is wondering: "If I do it again, will I land on my feet? And will it happen that way if I do it yet again, and again, and again?" The child builds upon this knowledge to successfully accomplish other tasks—hopping from one point to another, for example, without falling flat on the ground. This kind of behavior is one of the early indicators of human inquiry and of how humans utilize inquiry experiences to aid their intellectual development.

But although the toddler might successfully hop from one place to another, the experience by itself does not provide her with an explanation of how she accomplished the task. An explanation is the result of combining intellectual activity with discrete facts gathered through inquiry. The development of explanations is an essential component of science inquiry activity.

When they engage in learning activities characterized by inquiry, children provide a window through which we can "see" their thinking and analyze the knowledge and dispositions they bring to bear on their activities. In turn, by having direct contact with children's questions and with children's ways of answering them, teachers gain valuable knowledge regarding developmental stages reached by their students. They can assess the children's questions—what they are and how they are framed. They can observe the children closely to see the tools they use, the data they collect, and what they consider in their attempts to answer their questions. They can listen to the children's conversations and discussions of the processes, outcomes, and science meanings of their inquiries.

Inquiry is thus a powerful strategy through which children can communicate the state of their knowledge. When students connect batteries and wires to successfully light a bulb, for instance, not only do they communicate the state of their knowledge about the physical aspects of electric circuits, they also provide valuable opportunities for a teacher to help them build upon that knowledge. As the children's cumulative knowledge and experience increase, they are better able to acquire additional science concepts associated with their work on electrical circuits, such as resistance and current flow.

Making Decisions and Acquiring Concepts

Generally, children have limited opportunities to make important decisions—especially those which are taken seriously by adults. Learning through inquiry continually provides children with the opportunity to make firsthand decisions. They can decide which questions to raise at various points, which ones to follow in depth and why, what science tools to use for various tasks, how to organize data, how to portray the patterns created by the data, and what conclusions to accept or reject as they work. It is also of significance that children learn to develop their decision-making capacities in collaboration with their peers, and with a teacher's assistance.

Children's engagement in science inquiry gives them the opportunity to receive accurate feedback directly from the outcomes of their own inquiry.

One important ingredient of intellectual and scholastic development is being aware of one's own state of knowledge. Children's engagement in science inquiry gives them the opportunity to receive accurate feedback directly from the outcomes of their own inquiry. For example, when children try different ways of connecting batteries, bulbs, and wires to produce light, they get feedback directly from the materials they use: the bulbs may or may not light, or the light may be dim or bright, depending on the materials used and how the parts are connected.

Through inquiry, children acquire concepts in an authentic fashion and can, therefore, be aware of the level of conceptualization they have achieved. For example, in a video documentary on children's classroom science investigations developed by WGBH, a public television station in Boston, Massachusetts, children learned how to test for the presence of sugar in a variety of edible liquids. Contrary to the expectations of one child, milk tested positive when it was checked for sugar. The child knew that the milk came from a cow, and to her knowledge, cows didn't eat sugar! On the basis of this observation, the child surmised that something must have happened inside the cow to introduce sugar into the milk. The child's acquisition of concepts about chemical indicators, and her observation of the results of tests on milk, led her to formulate a further concept about a probable chemical change in the cow.

From their explorations, the children learned a variety of information about the properties of liquids. They learned that the concept of "flow" implies continuity of material and direction of motion; they learned that in many ordinary cases, a liquid is not just one thing, but a combination of substances. As they inquired further, their knowledge base and conceptual understanding about liquids increased. The children could then use these concepts to develop other science concepts. The results of the children's own investigations provided direct feedback to them.

The Many Benefits of Inquiry

When children learn science through inquiry, they communicate their thoughts and ideas through practical action as well as through symbols (i.e., speech, writing, numbers, drawings). With multiple ways of communicating the same information, teachers can have direct and accurate knowledge of each child's level of science learning. It also gives teachers direct knowledge of the child's capacity to successfully carry out inquiry. As a result, teachers are thus better able to help children advance their knowledge of science, science inquiry, and of the nature of doing science.

Inquiry contributes to children's social development, as well as to their intellectual development. Science inquiry in school is carried out in a social context. Children discuss plans and work collaboratively in carrying out inquiry activities. As they work, they keep science notebooks containing written and pictorial records and reflections. They also prepare themselves and present their work in a public forum to their classmates, who serve as critical friends.

These activities not only foster collaboration among children, they also help develop language and literacy capacity. In addition, inquiry requires children to access written material in order to compare their own "discoveries" with authentic science knowledge. By reading and comprehending this material, children join the larger scientific community on the topics they study.

Conclusion

At first, children's inquiries center on directly observable and often accessible phenomena. Through the processes of asking questions, obtaining answers, attaching meaning to the results of their investigations, and relating the meanings they make to established scientific knowledge, children build a repertoire of knowledge, skills, and habits of mind that affirm their human capacity to productively use inquiry for their development. They also acquire significant science concepts. The interplay between children developing the ability to do inquiry and acquiring the concepts of science—one building upon the other—is indispensable in successful inquiry learning.

When schools adopt an inquiry approach to science education, they also align with children's natural impulses to learn. Science learning thus becomes an extension of the characteristically human approach to knowledge acquisition. It is also an affirmation of a person's capacity to learn, an essential ingredient in every child's wholesome intellectual and cultural development.

Reference

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

CHAPTER 3

An Introduction to the National Science Education Standards
by Dennis M. Bartels

Today, with the increasing demands on schools and the growing importance of science and technology, the nature of science education—what children should know and how they should learn it—may be the most important discussion of all. It is not a new question or a settled one, but it is the obvious starting point for rethinking the science education enterprise. This chapter introduces the* National Science Education Standards, *a document designed to establish a common direction for the science education system and help guide teachers and schools in achieving specific educational goals.

The American education system's greatest asset—and its worst liability—is that it is a quintessentially democratic institution. Any opinion about education, especially about what is taught and how it is taught, has a place to be heard somewhere in the system. And we all have some opinion about the American education system, because most of us are products of it.

From a teacher's point of view, this cacophony of commentary may take the form of requirements from principals, mandates from school boards, expectations from parents, guidelines from state boards of education, recommendations from superintendents—even laws from legislators. Then there are the textbook publishers, test makers, and professional development providers who have their own take on what is needed in the classroom. In the words of the old radio men, the "noise-to-signal ratio" is very, very high.

At best, these messages are mixed; at worst, they're out-and-out contradictions. So what does a teacher do? One teacher might react to these competing signals by closing the door, shutting the noise out, and doing whatever he or she feels is best for the students anyway. Another teacher might grab the nearest basal text, start from page one, and work as far through the book as possible before the school year runs out. Under the circumstances, these are both reasonable strategies.

Analysis of the Problem

This problem of policy fragmentation has resulted in a state of affairs in which a teacher (or any worker) must sort out conflicting demands from multiple constituencies and bosses. In the absence of any clear direction provided by the education system, each teacher must decide how best to navigate a course on his or her own. While some people may look to the teachers and the students when educational results do not measure up to expectations, much of the fault actually lies with those of us whose job it is to help them.

However, this picture of the problem is incomplete. It is not true that teachers lack any standards about what to teach or how to teach it. We have *de facto* standards. They are provided by textbook publishers and commercial test makers. Any teacher will tell you that what they teach, and how they teach it, is most influenced by the instructional materials they use and what their students are asked on “the tests that count.” Those tests, of course, are the ones we all read about in the daily newspapers: the SAT, Stanford-9, Iowa Test of Basic Skills, and so on.

What is wrong with this picture? For commercial producers of texts and tests, the problem is a simple marketing dilemma: What is the education marketplace buying? In the absence of any standards, the response is *everything*! If I am a commercial producer of textbooks and every state has different (or no) standards, and there are 14,400 school districts, each with its own educational goals, and 85,000 schools all wanting different books with different concepts emphasized, my best strategy is to put everything under the sun into those texts and tests.

The result of this strategy is the creation of materials that provide a superficial treatment of most things, and in-depth coverage of very little. Hence the primary criticism pointed out in the latest Third International Mathematics and Science Study (TIMSS), that the American school curriculum is a “mile wide and an inch deep” (Schmidt, McKnight, and Raizen, 1997, p. 122).

Think back to the days when you or your parents attended school. Science textbooks averaged half an inch to one inch in thickness. Today, the average is more like two inches—and growing.

In fields like science, where new knowledge is doubling every few years, this is an acute problem. You could keep a student in class for 12 straight years, 7 hours a day, just studying science, and still not cover the whole expanse of the topic. Moreover, by the time the student finished, half of what he or she just learned would have become obsolete! So who decides what science is most worth learning and why? What is essential knowledge in science?

Enter the Standards

What if we had nationally developed standards in each of the academic disciplines that were concise and clear and generally acceptable to everyone? We might agree, for instance, that by the end of the third grade, students should understand that there are three states of matter—liquid, solid, and gas; or by the time they graduate from eleventh grade, they should be able to explain the social, economic, and political factors that led to any major American war. In order to develop these standards, we would need to determine, in a rigorous way, what types of knowledge are most essential to each discipline, and then convince the majority of the rest of us that these are reasonable things for most of us to learn.

The best standards are a step or two ahead of where the rest of us are.

That is exactly the process that the National Research Council embarked on in 1992 to produce the *National Science Education Standards* (see sidebar on page 22 for details). It is also similar to the process that most every other academic discipline initiated during the late 1980s and first half of the 1990s.

The first thing to note is that these are not federal standards, as some may believe. In every case, the national education standards were driven by the primary national professional association in the discipline, such as the National Council of Teachers of Mathematics or, in the case of science, the National Academy of Sciences. These organizations are driven by the professional interests of practicing mathematicians, scientists, and teachers of these disciplines. The key to their credibility and success in creating the standards was finding the most eminent scientists, leading researchers of learning, and successful classroom teachers to draft the documents.

The best standards are a step or two ahead of where the rest of us are. They are not intended to be true consensus documents, nor do they stray into untested waters. Rather, they represent the place where the best of us have already tread. Documents of complete consensus would, by definition, represent the mathematical mean: in other words, they would be what we already have. Standards documents are meant to be vision-setting documents. That is why most, even today, remain somewhat controversial, as they ought to be.

Most important to note is that standards documents do not change educational outcomes. People do. This gets at the heart of how standards documents such as the *National Science Education Standards* are intended to be used. We do not create a state of educational nirvana by simply producing standards documents. Creating the *Standards* is the easy part (and none too easy if you ask any of those directly involved). It does not, in itself, change the systems, institutional structures, and material resources that determine instructional priorities in the classroom.

Standards documents do not change educational outcomes. People do.

So what good are the *Standards?* Herein lies some of the current debate. Some observers and critics argue that the science *Standards* are designed for teachers' direct use: to compare current classroom curriculum and instructional practices against specific pages in the documents. I believe this is a naive view. Teachers are bound by the policies, instructional materials, tests, and professional development experiences provided to them by others. That is why, in additional curriculum guidelines, most national standards documents also address changes to the policies, materials, assessments, and teacher preparation experiences necessary to implement these student learning standards.

With so many issues beyond their control, it does little good for teachers to compare the *Standards*, point by point, to their own teaching practice. In my view, the *Standards* are most appropriate for the rest of us in the system: staff developers, school board members, college professors who teach teachers, test makers, producers of instructional materials, and so on. If those of us outside the classroom could align ourselves with a single set of standards, the teacher's world would make much more sense. We could have system agreement and a unity of purpose at both the school and classroom level. In short, all of our actions—individually and collectively—are necessary for the *Standards* to have a positive effect on student learning.

Looking Forward

How can the science *Standards* be useful to us? Here are five contributions that the *Standards* can make for any science instructional program in the process of improvement.

1. ***To simplify the curriculum.*** The extraordinary push for coverage is one of the greatest problems in American education and leaves more and more students in the dust. No teacher has either the expanse of collective scientific expertise or the time, for that matter, to determine what is most essential for students to learn. The *Standards* should be used as much to determine what should be pruned out of the curriculum as what should be grafted in its place. We cannot keep adding without taking away. By its nature, the *Standards* solve the problem of deciding what is most important or essential to learn.

2. ***To provide a common point of reference for different and sometimes divergent interests.*** One cannot expect that teachers, parents, school administrators, political office holders, instructional materials producers, or commercial test makers will have the same interests at heart. Test makers and publishers want to sell the most units. Principals want to look good on tests. Politicians want to look like they are doing something about education reform. Teachers want their students to do well. However, to the extent that we can get all these disparate groups to agree on one thing—what is most important for all students to learn—the rest of us can arrange our world to deliver that and still win in our individual domains. This seems like a monumental task at the national level. I believe it is more possible at the local program level. Student learning standards is the right place to establish some common ground.

3. ***To argue about the right things.*** As noted, not everyone agrees with everything in the science *Standards.* But the *Standards* do provide something essential that has been sorely lacking in the education reform debates of the past: discussion about the most important parts of schooling—curriculum, instruction, and assessment. They are at the heart of the matter.

   In the 1980s, school governance, finance, restructuring, longer school days, and longer school years were all targeted for possible reform. These, I think, are interesting projects, but secondary areas of concern. They are off the mark. What good is a longer school day or year if it is just more of the same old type of instruction that produced the earlier failures and dissatisfaction? It is as if an automobile manufacturer decided to improve the performance of its cars by adding another shift to its plants. The *Standards* can help local programs stay focused on the most important products of their enterprises—student learning—and make everything else in the system subordinate to it. Arguments about what students learn, and how they learn, are worth our time.

4. ***To ensure everybody the opportunity to learn.*** Without challenging school systems to make some fundamental changes, we ensure that some students will continue to have better educational opportunities than others. In the absence of pre-set academic standards, it is easy for the educational system to allow qualitatively different learning experiences for different sets of students. The tendency is to remediate by slowing learning down, rather than accelerating a student's learning to help him or her catch up. This is not an impossible task. The military, for instance, has managed to come up with ways for (almost) all its soldiers to reach some specific standards. Without standards, excuses are easy to come by, and accountability is easy to avoid.

5. ***To lift our sights.*** Much theoretical debate has ensued in the Standards community about whether the *Standards* should be ultimately obtainable or not. Should they exemplify the Platonic state of ideals that we unrelentingly strive for, or should they be easily obtainable by most students in the near future? If you accept the argument that these are vision documents a bit ahead of their time, then some standards ought to be a great challenge to us.

That is the case for including inquiry as part of current science *Standards.* In that document, inquiry is seen as being a way to approach three important aspects of science learning: the content of science; the skills needed to carry out inquiry science; and the teaching methods used to introduce children to science inquiry. “Learning is something students do,” the document says, “not something that is done to them” (p. 20).

Teaching and learning science using inquiry methods is not an unreachable goal, as examples from classroom practice (including those recounted in this book) have shown. But it is a challenging one for most of us. The *Standards* should reveal at the local level some new territory or goals that stretch science instructional programs toward genuine excellence.

The “Next Word” in Science Learning

At a recent meeting at which the nation’s governors and business leaders discussed academic standards, some governors suggested that standards were not necessary for education improvement. Many business leaders were incredulous. Without standards, they asked, how do you measure success? How do you guide an enterprise to what is most important to accomplish? The question was never raised again.

It may be more important to raise the question of what all of us can do with these science standards now that we have them. The *Standards* are the “next word,” not the “final word,” in our attempts to improve science programs. In the true scientific sense, the *Standards* are our best working hypothesis of where we need to go. As the data from experience come in, we need to revisit and revise this working hypothesis. If excellence and scientific literacy for the general populace are our genuine goals, the *Standards* are the obvious place for us to start.

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ABOUT THE NATIONAL SCIENCE EDUCATION STANDARDS

In 1996, the National Research Council published a 250-page report called the *National Science Education Standards.* This document has two primary organizational dimensions. The first focuses on the content of science itself and is organized by grade levels. The second focuses on major features of the educational system that need to change to bring "coordination, consistency and coherence to the improvement of science education" (p. 3).

The *National Science Education Standards* identify the essential concepts in building an exemplary instructional program in science, from kindergarten through grade 12. It also declares two fundamental tenets that establish the intent of all its recommendations: first, that the *Standards* are for all students; and second, that every student must be given the opportunity to learn science—meaning they should have access to skilled teachers, adequate classroom time, a rich array of learning materials, and so on. Both of these conditions are necessary if science understanding is to change from the province of a select minority (in particular, the college-bound), to a literacy skill for the vast majority.

The *Standards* also make the case that given current changes in the workplace and economy, science is now a basic literacy skill. It reinforces the moral commitment that everyone deserves to share in the excitement of science and technology. And, perhaps most compelling, it points out the need to make sure that every student has the opportunity to learn both the information science offers and the critical process and reasoning skills that support informed everyday choices and decisions.

In terms of science content standards, Chapter Six of the document outlines three grade-level clusters (K–4, 5–8, and 9–12), and divides each into the same eight categories:

- Unifying concepts and processes
- Science as inquiry
- Physical science
- Life science
- Earth and space science
- Science and technology
- Science in personal and social perspective
- History and nature of science

These categories outline standards for each of the grade levels identified. One standard under "physical science" for grades K–4, for instance, is for students to understand that "Light can be reflected by a mirror, refracted by a lens, or absorbed by the object" (p. 127).

The document stresses, however, that the content standards are not intended or designed as specific curricula. Instead, they "provide criteria that people at the local, state, and national levels can use to judge whether particular actions will serve the vision of a scientifically literate society" (p. 3).

Accordingly, the document also sets out criteria for all the other parts of a teacher's world. Specifically, four to seven standards are outlined for each of these five areas of the education support system:

- Science teaching
- Professional development for teachers of science
- Assessment in science education
- Science education programs
- Science education systems

"Learning essential science content through the perspectives and methods of inquiry" (p. 59) is one example of a standard for teacher professional development.

The document goes on to describe, in greater detail, what each of these standards mean by way of descriptions, examples from actual classrooms and schools, and references to research.

CHAPTER 4

The Power of Children's Thinking
by Karen Worth

The earth is flat. Fluttering leaves make the wind. The moon follows you as you walk. Based on how they understand everyday sensations and experiences, even young children create theories to explain the world around them. As this essay points out, guiding children to discover a more scientific view of the world means helping them learn through those same sensations and experiences—something that inquiry does particularly well.

Two grandparents were out walking with their young grandchildren. They came to a rabbit hutch with three rabbits inside, an adult male and female, and what seemed to be a baby. As the children watched, a leaf fell on top of the cage. The female rabbit reached up, pulled the leaf into the cage, and dropped it on the ground. At that moment, one of the other rabbits started to eat it. Four-year-old Tommy, the littlest child, was intrigued. He picked up some leaves, put them on top of the cage, and watched the rabbit pull them inside.

When they got home the grandmother asked, "Well, what did you think of those rabbits? What do you think was going on in that cage?" Tommy said, "The mommy rabbit taught us something when she pulled those leaves down. The mommy rabbit was really a teacher and you and grandfather and the other rabbits, we were all the students."

There are many stories in which children reveal their attempts to make sense of the world. They are important, not because they are cute, but because they tell us something about the power of children's thinking.

Young children can and do inquire, and it is important not to underestimate the power of this inquiry. They do so in different ways, depending on developmental level, prior experience, and context. From what we know from cognitive research, the context has to be concrete; the phenomena and objects must be ones children can explore with their senses. But at all ages, children do observe and investigate, collect data, think, reason, and draw conclusions.

Children are natural scientists. They do what scientists do, but perhaps for some slightly different and less conscious reasons. They are anxious to understand the world just as adults are. There is a terribly interesting, but rather confusing, world full of stimuli all around them. Many adults, however, have learned to ignore some of that world rather than investigate it. Young children ignore very little. They are very curious; they ask questions constantly. They are willing to look and to inquire about the world. This is not the idealized world of scientific theories, principles, and models, nor is it the precise world of the laboratory. Children draw their understanding from the messy world around them. As a result, it's a messy exploration, and it takes place within the context of the child: the child's frame of reference, his or her prior experience and developmental stage, and the adults around that child.

The theories children build, whether they are right or wrong, are not capricious. They are often logical and rational, and firmly based in evidence and experience.

As they explore, children organize what's around them, building their own schemes and structures and conceptions. We have lots of research as well as anecdotal evidence of this. The child who visits another country, sees a half-moon there, and decides that the other half must still be back home has a pretty interesting idea of what the moon is all about. The 3-year-old watching the fluttering leaves on a tree decides that the movement of the leaves is what makes the wind. This is, of course, a very natural and logical explanation for a phenomenon that the child has experienced often, yet cannot touch or manipulate.

The theories children build, whether they are right or wrong, are not capricious. They are often logical and rational, and firmly based in evidence and experience. The experience may not be deep and broad enough, the thinking capability may not be enough to formulate what we call a scientific theory, but the process by which the children form these ideas is very scientific indeed. Some call these early ideas children form misconceptions; others label them naive conceptions, or alternative conceptions. They are simply the children's conceptions and do not deserve the negative connotations associated with these terms. We all try to organize and structure the world around us; we do it on the basis of what we have available to use. We don't wait to be told. We don't take it all in equally. We try to figure it out. I believe that it is the same thing for young children. It is a kind of common sense—2-year-old common sense, or 50-year-old common sense, it doesn't matter.

For young children, this organization and structuring is very personal and has certain characteristics. Children tend to be centered on themselves and heavily reliant on the immediate context and the data of their senses. Their thinking is perceptually dominated, drawn from direct experiences, rather than conceptually dominated. It is difficult for them to step outside themselves and to look at the world beyond them. The idea that the moon follows you as you walk through the streets, for instance, is very common for the 4-, 5-, or 6-year-old. The notion that the earth is flat and the sun moves around us are other common understandings among older children. The immediate context is all that they have, tightly linked to personal experience. But the ideas that they develop are, in the right context, transferable across experiences, as were 4-year-old Tommy's when he applied his idea of teacher and pupil from his experiences of school to the rabbits.

Young children are often more linear in their thinking about causality than adults are. It's hard for them to juggle too many factors at the same time. They are not terribly upset, in the primary years, if theories contradict one another. They can have one theory over here and another one over there, and that's okay, for the moment. They haven't quite taken hold of the notion that you can't have contradictions. It doesn't necessarily mean that their thinking is illogical or irrational. It may simply mean that they do not need consistency or see the connections. Nor do young children tend to value parsimony, or elegance and simplicity of explanation. They may have very complicated explanations of how and why something happens. They may not care whether it is as elegant or simple as it could be. Simplicity is a more adult constraint on theory formation, not necessarily one of young children.

Another characteristic of children's thinking is tenacity. Children do not want to give up the concepts and theories they work so hard to make. They take their experiences and struggle to come up with understandings that work in their daily lives. They are not about to drop their ideas just because someone says so, or because an event disproves what they have come to believe. As anyone familiar with the history of science can attest, even adults have trouble changing theories that are well grounded in experience. If a child's theory works, if it has been productive and the child has worked hard to build that theory, she will not give it up unless she has a lot of new experiences that provide reasons to do so.

When we look at very young children before they have had the structures and rules of formal schooling imposed upon their learning, or when we see them in informal settings such as museums, playgrounds, and parks, we see a spontaneously driven activity to make sense of the world through observation, investigation, and social interaction. But children working by themselves are not going to learn everything they need to know. There is a clear role for teaching and for structured settings. To define those settings and the nature of the teaching, we need to add an understanding of the goal and content of science education to our understanding of children's learning.

The goal of science education, as stated in the *National Science Education Standards*, is "to educate students who are able to experience the richness and excitement of knowing about and experiencing the natural world; use appropriate scientific principles in making personal decisions; engage intelligently in public discourse and debate about matters of scientific and technological concern; and increase their economic productivity through the use of the knowledge, understanding, and skills of the scientifically literate person in their careers" (p. 13).

The *Standards* also describe the subject matter content of science education—the knowledge and understanding students must acquire. They state that "scientific knowledge refers to facts, concepts, principles, laws, theories and models," and understanding science is described as the "integration of a complex structure of many types of knowledge, including the ideas of science, relationships between ideas, reasons for these relationships, ways to use the ideas to explain and predict other natural phenomena, and ways to apply them to many events" (p. 23). The *Standards* also describe the understanding of and ability to do scientific inquiry as a critical component of the content of science education, defining inquiry as "the diverse ways in which scientists study the natural world and propose explanations based in the evidence derived from their work" (p. 23). Inquiry also refers to the "activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (p. 23).

Fundamental to this kind of teaching and learning is the willingness to work with children "where they are," and to understand with what they are struggling.

With this view of learning, goals, and content, we can begin to construct our understanding of inquiry-based science teaching. Fundamental to this kind of teaching and learning is the willingness to work with children "where they are," and to understand with what they are struggling. In his book *Informed Vision* (1974: Agathon Press), David Hawkins, philosopher of science and director of the Elementary Science Study (ESS) during the 1960s, has said that we must try to understand "the map" of children's minds. There are some interesting studies, for instance, on whether children think the earth is round. If they look outside, they see a flat world. But they also know that the world is round because they have heard it, and seen it in the movies and on TV. There are studies of first graders and second graders who will say, yes, the earth is round. But their image of "round" is the shape of a pancake, not the round sphere that adults speak of. Slightly older students may produce an image of an earth that is definitely round, but may see themselves inside it. They imagine that they live on a flat surface inside some kind of sphere. They are struggling with some very basic concepts—up is up and down is down, but the earth is a round something in space. It is up-down and flat, and yet round. The students are trying to reconcile what they "know" with the round world about which they are learning, and they have wonderful ways of doing that.

It is not always easy to see what a child is struggling with. We may be teaching them all about the planetary system, while they are still struggling with whether the world is round or flat and what that means. By offering children open-ended experiences and discussion, and by carefully observing and listening, we can come closer to knowing not only what their conceptions are, but the source of their struggle. If we don't, they may draw a picture of a round world, but not believe or understand what that really means.

To help children move toward better understanding and more powerful constructs than the ones they can make by themselves, we create classroom opportunities that are designed to allow children to approach learning much as they do when they confront materials and phenomena in unstructured settings. But we provide much more: focus, structure, breadth, and dialogue.

As children explore phenomena and materials, they focus on what is immediately important to them, not necessarily on what is important from a scientific point of view. Structured programs in a school environment make the phenomena and objects somewhat less messy and encourage students to look more closely at particular elements of what is going on. Teachers also guide children's inquiry to help them be more orderly and systematic than they might be on their own, and so they can draw on other resources such as books, people, media, and technology.

Children's early conceptions arise from their experiences, which are limited by time and circumstance. In school, teachers can select a range of experiences that provide children with new data and encourage them to challenge their existing ideas and build new ones. School also provides the opportunity for children to learn how to record what they are doing in many different ways, how to communicate and share with others, and also how to develop models for understanding as they get older. In school, children can also work with and learn from one another.

In the best of good science teaching, the role of the teacher is crucial no matter how good the curriculum materials are. To support children's learning in science, teachers must be willing to try to understand the ideas and formulations children have made and are making and to guide their instruction accordingly. This means the teacher accepts and supports a wide variety of views and encourages real dialogue and debate among the children. This also means creating a rich physical and social learning environment in which new questions, explorations, and investigations can arise, and in which every step is not dictated. In such an environment, the teacher allows the children to gather data and approach ideas from multiple contexts. He or she allows the children time for trials, repetition, and mistakes, and creates a balance between adult guidance and time for children to be guided by their own questions, predictions, and explorations.

Children need these experiences in both formal and informal settings. We can give them information, demonstrations, books, and step-by-step experiments, but these cannot replace the kinds of experiences they need to develop tenacious and deep understanding. If children are struggling with an idea, they need time to come to a physical understanding of it before they can really use it in their world. If they do not have these opportunities, they may learn the words and information they need for school. They may get all the answers right on a test. And they may also create another kind of understanding on their own. They may come to believe that there is something called "science," in which they are told what to see, what to know, and what to think, and that it is rather unrelated to the world they experience outside of school. They may doubt their experimental abilities when the "results" they are told to expect are not necessarily what they really do see. They also may come to the conclusion that there is a whole realm of knowledge that they themselves cannot understand, and that they must simply take, unquestioned and not understood, the facts as given from an adult or a textbook.

Alternatively, if we accept the challenge of the *National Science Education Standards* and use what we know from research and practice, we can provide environments in which teachers are teaching through inquiry. When children have the opportunity to cultivate their own skills and construct their own ideas and concepts, then they can develop an understanding of the world that is deep and real, and begin to enjoy, understand, predict, and generate new knowledge on their own.

CHAPTER 5

Lessons Learned: Addressing Common Misconceptions About Inquiry
by Lynn Rankin

In this chapter, one teacher's discovery of the power of inquiry, and her experiences integrating it into the classroom, shed some light on common questions and concerns of science educators considering inquiry in the classroom.

For the past 20 years, I have been experimenting with various approaches to hands-on learning with both students and teachers. As my experience and confidence have grown, my teaching has evolved from a more structured and prescribed hands-on approach (teacher-centered) to providing opportunities for more open-ended inquiry (student-centered). The shift has been gradual and incremental as I have reflected, practiced, refined my thinking, and collaborated with colleagues to explore new territory. In the process, I have had to become both a teacher and a learner—looking ever more closely at the inquiry process. In essence, I have become an inquirer into inquiry.

Although the word "inquiry" is mentioned a lot these days, there is quite a bit of confusion about what it means and how it is best done. Few educators have had the opportunity to experience inquiry first-hand: We didn't learn this way when we were students, and we weren't taught to teach this way. Most recently, I have been working as a professional developer, helping educators from all over the country find ways to infuse inquiry into K–5 classrooms. What follows are thoughts that address some of the most common questions and concerns I hear about inquiry.

Inquiry is not an either/or proposition.

Although inquiry-based teaching is indicated as a central feature of science education in both the *National Science Education Standards* and *Benchmarks for Science Literacy*,[1] neither document recognizes it as the sole approach. Science teaching should encompass a wide range of methods. Even within the realm of inquiry teaching, there is a wide spectrum of approaches.

Teachers must decide on a method that is most productive for accomplishing their particular objectives in learning, such as developing conceptual understanding, being able to do inquiry investigations, and experiencing what science is. Hands-on activities, reading, class discussions, teacher demonstrations, skill-building activities, films, videos, inquiry investigations, and so on are all important tools when used appropriately. For educators, the goal is to create a balance in terms of pedagogical approaches, student-driven investigations, and teacher direction. We weaken the possibility for successful science education reform when we draw too tight a line between inquiry and other educational methodologies.

Even within the realm of inquiry teaching, there is a wide spectrum of approaches.

All hands-on is not inquiry; not all inquiry is hands-on.

There are many high-quality, hands-on science curricula and materials that are available for classrooms today. However, using hands-on methods does not always ensure effective science teaching, nor is it necessarily indicative of an inquiry-based approach. When children are doing inquiry, they have opportunities to raise their own questions, and then plan, design, and conduct investigations to help them answer some of those questions. They are given ample time to reflect, engage in dialogue to develop their conceptual ideas, and defend their findings to others.

To teach science as inquiry, a teacher has to allow children some ownership of the process—which means giving the children opportunities

[1] American Association for the Advancement of Science, Project 2061.

to get connected with questions that are of interest to them, and find ways to answer those questions. This does not mean that every child must work from his or her own question, or pursue an independent investigation. Very productive investigations can result from a class working on the same question, or small groups of children working on different questions.

Inquiry in hands-on learning is often distinguished by the amount of flexibility a teacher allows in order for children to develop individual curiosity and ways to solve problems. This is different from a situation in which a teacher poses a question and then directs all the students to take the same pathway to find a common solution. In the case of inquiry, the teacher may have a very good idea of what scientific concepts he would like the children to learn, but he allows for a lot of variation in the children's investigations, recognizing that there may be many solutions to the same problem.

While an inquiry approach implies active learning and the development of higher-order thinking skills, hands-on methods are not the only ways to achieve these goals. Other resources are important for stimulating questions and providing information. Books, articles, information on the Internet, and personal conferences or interviews can all be used to provoke initial interest in a topic from which research or investigations may emerge. On the other hand, these same resources might become secondary materials, providing additional support once investigations have begun.

No dichotomy exists between content and process.

In this era of science education reform, there are many conflicting viewpoints about the nature of effective science education: Should the primary focus be content or process? Both are critical, and emphasizing one to the exclusion of the other is not beneficial to students.

Engaging in inquiry provides opportunities to help children develop ways of understanding the world around them. In her book *Primary Science, Taking the Plunge*, Wynne Harlen says that children have to "build up concepts which help them link their experiences together; they must learn ways of gaining and organizing information and of applying and testing ideas. This contributes to children's ability to making better sense of things around them....Learning science can bring a double benefit because science is both a method and a set of ideas: both a process and a product. The processes of science provide a way of finding out information, testing ideas and seeking explanation. The products of science are ideas which can be applied in helping to understand new experiences."

Ideally, the processes used in doing scientific inquiry and the development of conceptual understanding and knowledge work in concert; they must go hand in hand. However, the seamless interweaving of process and content depends on both the teachers' and the students' experience and confidence in doing inquiry. Teachers find that they often move back and forth, emphasizing process skills and scientific content, bringing one into focus for critical examination while the other remains in the background. Teachers have to help students develop skills to be good investigators. With ample practice, these skills develop and grow over time.

Inquiry teaching is not chaotic— it is a carefully choreographed activity.

Although inquiry teaching demands a different relationship between teacher and student than more traditional methods, it requires a high level of organization, planning, and structure, both by the teacher and the students. In essence, a classroom environment that is supportive and conducive to doing inquiry must be consciously developed. The teacher must create a climate for doing inquiry.

In order for inquiry to be effective, a teacher must lay a foundation in which students can begin to take more responsibility for their own learning.

The teacher's role in the inquiry classroom is a very active and dynamic one. Acting as a facilitator, or guide, the teacher identifies a set of carefully crafted "big ideas"—a conceptual framework from which children develop their investigations. This conceptual framework is the basis for guiding students to learn something deeper about a scientific concept.

During the inquiry process, the teacher walks around the room, interacting with groups of students as they experiment. He listens to their questions and ideas, continuously assessing their progress and determining the appropriate next steps for their learning. He gathers the class together at strategic moments to give additional information through lectures, demonstrations, or discussions.

In order for inquiry to be effective, a teacher must lay a foundation in which students can begin to take more responsibility for their own learning. He must create a rich physical environment in which children learn how to organize and manage materials. And he must develop a supportive social environment in which students can work collaboratively in small and large groups, participate in discourse, and learn to respect each other's ideas.

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CHAPTER 6

Recognizing Inquiry: Comparing Three Hands-On Teaching Techniques
by Barry Kluger-Bell

Inquiry teaching often involves the use of interactive, or hands-on, activities. Different types of hands-on activities can all be valuable in science learning, but don't necessarily indicate that inquiry is taking place. By comparing three styles of instruction, this chapter gives readers a feeling for how different hands-on methods can lead to different educational results.

> "Inquiry into authentic questions generated from student experience is the central strategy for teaching science."
>
> —*National Science Education Standards*

> "We have adopted an inquiry-based curriculum to meet our world-class, inquiry-based standards."
>
> —*School District Administrator*

> "Our kits are full of inquiry lessons with student worksheets to accompany each of them."
>
> —*Curriculum Company Salesperson*

Everywhere you turn these days, the words "inquiry" and "inquiry-based science" are being tossed around. Inquiry is being used to describe a vast array of science-teaching strategies. All of these strategies can be valuable when used at the right place at the right time. But are they all inquiry?

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Part of the confusion stems from the fact that inquiry entails a range of practices, many of which are also carried out to a greater or lesser extent in other styles of teaching. But how do you characterize these practices? How do you recognize the degree to which they are being employed?

Getting the Feeling with Foam

A number of years ago, the Exploratorium Institute for Inquiry created an activity designed to help teachers identify the characteristics of different types of hands-on science instruction. Using a simple, readily available material—soap foam—we created three activities intended to give teachers a feeling for three different methods of hands-on instruction:

- a guided worksheet activity,
- a challenge activity, and
- an open exploration activity.

Today, we use this exercise in workshops designed to help teachers and school administrators experience and reflect on the inquiry process. This exercise not only gives these teaching professionals information about how to best use different kinds of hands-on instruction, it also gives them some insight into the learning process as they experience the same feelings of optimism, frustration, competitiveness, and potential for learning their students feel in each of these situations.

During a typical Foam Workshop, I can watch these different situations unfold…

Room 1: Guided Activity

In Room 1, participants working on the guided activity each have a worksheet with instructions and clear expectations about what they need to accomplish. The activity asks participants to mix detergent and water in two different bowls, beat one bowl 200 strokes and the other 600 strokes, and then compare the results in a series of simple experiments.

Walking into the room, I see that the instructor is just completing the brief directions: "Work in teams of two," she says. "Make sure you read the instructions carefully. Send one person from your group up to get the materials. You have 20 minutes to complete the activity and fill out your sheet. Begin."

Some students begin to read their instructions while their partners go to collect the materials. The teams begin whipping their soap foam with eggbeaters, as instructed, and carrying out the required trials. What they are supposed to be doing seems very clear to all. Most groups seem very focused on getting through the worksheet. I can see some people checking the clock frequently to make sure they finish in the allotted time.

There is little conversation in this room. These are good students and mainly "on task." I hear exchanges like this:

Doreen: "What are we supposed to do next?"
Angela: "It says we have to support these sticks in the foam."
Doreen: "Okay. Let's start with the smallest one."

Much of the discussion is like this, tending to be centered on how to complete the task at hand.

On the other hand, I also hear conversation of a different sort. From the corner I hear, "Did you see what Maureen is wearing? I wonder where she got that?" This is an indication of a team coasting along and losing interest. From another team I hear, "I don't get it. Are we supposed to be learning that bigger bubbles make weaker foam? I see big bubbles in both of our mixes. This doesn't make sense." The instructor overhears this and comes by to try to steer them back on track, but I detect some lingering skepticism when she leaves.

Toward the end of the allotted time, most groups are feeling good about completing their activities. But one last group is rushing to complete their work. From them I hear, "I don't know what was wrong with our stuff. Everyone else seemed to get a lot more foam. Well, let's see if we can figure out how to finish up anyway." There is a feeling of failure in those words.

Finally, time is called. The teacher checks the worksheets to make sure everyone got the right answers. Each team gets a chance to compare two different foams in prescribed ways, and all team members leave having had a common experience.

Room 2: Challenge Activity

I drift over to Room 2, where a new round of the challenge activity is starting up. These students had just been told that, working in pairs, they are to build a 12-inch-high tower of foam. They seem very clear on the assigned objective, but the method for meeting this challenge is up to them to find.

Right from the beginning, this room feels more lively than the one I just left. Hand-beaters and electric mixers are whirring like mad, making big bowls of soap foam. Some folks are starting to pile the foam onto plastic plates. All seem very engaged in the activity.

One group's strategy seems to be to make the thickest, densest foam they can. "Thick foam is strongest," Tracy says. "It's the only thing that can hold up such a tall tower." But as they work, they see that the base of their tower keeps flowing out from underneath, and they ponder changing their approach.

Another group asks the teacher for a whisk, which she rounds up for them. Jim says, "Whisks whip more air into our bubbles. I think airy bubbles will be easier to support." They continue to work hard with their whisk, but get very little foam with which to build.

As time goes by, the anxiety level in the room mounts. Only a few groups are getting near the goal and all are hurrying to make it before time runs out.

Michael's group is almost done. "Quick, come over and measure ours. I think we've got it!" The teacher comes over and measures the height of their foam tower. "Just half an inch more," she encourages. Michael adds a bit of light foam at the top. "You've got it," says the teacher. The group breaks out in a cheer. "We're number one! We're number one!" Some of the other students look defeated. Others redouble their efforts on their own towers.

As the groups continue to work, the teacher walks around, making suggestions and reminding participants about the rules. One group begins to make more noise as they excitedly get close to their goal. But something looks wrong. The teacher pokes her finger into their tower and finds an upside-down cup inside. "That's cheating." she says. "You're supposed to be building a soap tower, not a soap-and-cup tower." The group looks a bit sheepish but continues on.

A second group meets the challenge. They and the first group are now competing to build the tallest tower. Meanwhile, as time comes to an end, all the other groups still have not met the challenge. Over in the corner, I hear Joe say, "This isn't fair. The next group coming in will have had some practice with foam. We didn't have any." Sure enough, when I check in later with the group that did the open exploring before they did the challenge, the rate of success is considerably higher. The teacher tries to address Joe's concern, explaining that it is not building the tallest tower that is important, but what you learn while trying to do so. Still, one participant from a failed group says, "I should have expected this. I never could do science anyway."

Good science inquiry involves learning through direct interaction with materials and phenomena.

Room 3: Open Exploration

Next, I walk into Room 3, where the open exploration activity is going on, and there I encounter a very different setup. The teacher has just completed a whole-group discussion in which the students have brainstormed a list of all the foams they know. She is pointing out, in detail, the primary materials with which students can work. Most of the materials are located on a main supply table; additional materials for other questions that may arise are located on a secondary table. The teacher says, "Working in groups of two or three, using these materials, see what you can find out about foam and what makes it strong."

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This sort of open prompt to explore is unfamiliar to many of the students. Some love the freedom. They jump right in, collect materials, and start to work. Others seem to have a difficult time getting started. The lack of explicit instructions creates anxiety for those not used to finding their own starting place. The teacher sees their confusion and helps them find something they want to try.

In a short time, the room gets very lively. There's lots of cross-talk, both within and between groups. I hear exchanges like:

"Maria! Come look at this shaving cream under the microscope! The bubbles are round and you can barely see them."

"That's strange. The bubbles we whipped up are more like little hexagons. I wonder if that affects how strong they are?"

Later, I see Maria inviting people from other groups over to see her discovery.

At another table, a group seems to be putting everything they can find into their mixture: detergent, water, root beer, shaving cream, cream of tartar, baking soda. It seems to be a "let's see how big a mess we can make" experiment. As I watch, the teacher comes by and talks with the group.

"So what are you finding out here?" she asks.

"I'm not sure." Norman says. "It seems that whatever we put in, we still get foam."

"So are you trying to see what might make it foam less?" she asks.

"I guess so," answers Norman.

The teacher continues to guide them along a productive path.

In most of the room I see and hear signs of active, engaged exploration. But over in one corner I see a group where things are not going nearly so well.

"What are we supposed to be doing here? What's the point?" Rachel asks Don. "We made some soap suds with a mixer. So what now?"

Don shrugs. "This sure isn't as clear as the challenge. I don't know what to do either."

This group is not yet at ease with setting their own tasks. They struggle to continue, but are clearly frustrated. Later, I notice the teacher coming by to check in with them. She is working intently trying to talk them through their impasse.

As I spend time in this room, I see a much more active role for the teacher. She is constantly walking around, checking that things are going well in the groups, asking a question here, making a suggestion there, and directing students to look at each other's work.

With the help of the teacher's facilitation, each group seems to have found their own path of investigation. One group is looking at different proportions of detergent and water. Another is

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comparing different brands of detergent. Another is looking at the difference between hand-beaten bubbles and electric-mixer bubbles. At the end of the allotted time, the teacher brings the whole group together to share information. As a whole, the groups have explored quite a range of variables.

The Inquiry in Each Method

Each of the approaches described above represents appropriate teaching methods when used at the right times and under the right circumstances. A guided worksheet may be just what you need when you want to illustrate a particular fact or teach a specific skill. A challenge activity can be a good way to engage students early in a unit, or may be useful to assess students' abilities to apply their learning at the end of a unit. Open exploration can be used well when students are well-versed in hands-on work and have learned to be self-directed.

These approaches may also be used in combination. There is no single proper sequence for these combinations. In one case, you might start with an open exploration to gain familiarity with materials, and then move to a challenge in order to focus the group on one critical concept. In another case, you may use guided activities to lay the groundwork for an open

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exploration, and assess learning with a challenge at the end. In any case, it is important to match characteristics of each experience with the learning goals you have for your students.

All of these activities also entail some degree of inquiry practice, although none illustrate the full range of inquiry. In general, the open exploration shows the greatest degree of inquiry and the guided worksheet the least.

Good science inquiry involves learning through direct interaction with materials and phenomena. One important sign of inquiry is the relative level of control that the students have in determining various aspects of the learning experience.

In looking at these issues, we look at who controls the questions, who controls the design of the investigation, and who decides on what is an acceptable answer. In the guided worksheet activity, nothing is under the student's control except the actual manipulation of the materials. In the challenge activity, the teacher presents the question or challenge, but the students have to determine the path toward solution. The nature of the challenge, however, tends to provide a narrow focus to that path. Correct answers are limited to working solutions to the challenge. In the open exploration, the students have control over a wide range of questions within the area defined by the teacher's instructions. The student also has control over the means and practice of the investigation, subject to facilitation by the teacher. Finally, a wide range of results are acceptable, giving the student a good deal of control over the answer, as well.

Good science inquiry provides many entry points—ways in which students can approach a new topic—and a wide variety of activities during student work. In this way, inquiry provides many more ways to capture the interest and enthusiasm of students, and also gives them access to learning along a number of alternative pathways. With the guided worksheet, students all start at the same point and show little variation in their work. The challenge activity also has a single entry point for students. It has variety in the student work, but the range is limited. In the open exploration, the entry points are limited only by the materials. As a result, students are engaged in a wide variety of activities.

Inquiry science requires student discussion with others—working cooperatively and sharing ideas. In addition to these being important skills to learn, dialogue and socially gathered and shared information is a powerful means toward building individual conceptual understanding. With the guided worksheet activity, student discussion is limited to small groups. Within those groups, there is cooperative work, but it is limited to the task of completing the worksheet. In the challenge activity, the competitive nature of the task strictly limits the communication and sharing of ideas outside of the small groups. The open exploration is designed to encourage sharing of ideas, both formally, with whole-group discussions, and informally, with the teacher encouraging groups to talk to each other.

Access to and use of a wide range of materials also characterizes inquiry science. This gives students a greater degree of responsibility and control over design and execution of their experimental work. For the guided worksheet activity, students use a set of materials designated on the worksheet. In the challenge activity, free access to a wider range of materials is made available to students. However, in order to make the challenge fair, the choices were limited. At the open exploration, there were even more materials available and freely accessible to students. Supplementary materials were placed on a table removed from the main supply table so as not to overwhelm the students with too many choices. Additional materials that were not on the supply table were made available at the discretion of the teacher.

The role of the teacher is also quite distinct in inquiry. The teacher defines a domain of study, orchestrates environment, materials, and time, and moves between groups to facilitate their work. Facilitation involves checking how things are going—asking questions here, making suggestions there, helping groups move on when they get stuck, and directing students to look at each other's work. In the guided worksheet, the teacher's role is to make sure students are following instructions. At the challenge, the teacher plays a very active facilitating role, encouraging groups and making suggestions. At the open exploration, the teacher played a very active facilitating role, helping groups to have productive explorations.

This example of open exploration illustrates only one phase of inquiry. In order to achieve more complete conceptual learning and develop the full range of science skills, there must be an opportunity to do longer-term inquiry. In such inquiries, student work becomes more focused than it is in the open exploration activity. Students design and conduct investigations as they pursue a line of questioning. As they move along, students create tentative explanations (hypotheses) of the phenomena they are observing and direct their investigations to test these explanations. As part of these investigations, students learn and practice a number of skills that help them make some sense out of what they are seeing. For instance, a student might learn to use an instrument or tool for a specific purpose—from a ruler to chart a plant's growth to a voltmeter that measures the voltage of a homemade battery. They learn to organize data and make graphs to help interpret the results of their investigations. Perhaps, even more importantly, they learn to persevere and overcome obstacles when results are not readily forthcoming.

Good science inquiry provides many entry points—ways in which students can approach a new topic—and a wide variety of activities during student work.

Communication becomes an even more important element in extended inquiry. The information that students can share with one another is critical to the building of understanding by individuals—and by the group. In addition, information that students can get from additional references, from books to experts in the field, can serve an important role at the appropriate time.

Many of the elements of inquiry can be mixed into different types of instruction. A challenge, for instance, may be structured so that students plan their own investigation into the solution. A guided activity may leave room for the students' own exploration of material. In any case, the degree to which inquiry is being practiced can be gauged by a number of factors, from the level of control and responsibility students have for their own learning to the teacher's design to foster and support student learning.

Reference

For more information on the Institute for Inquiry's Foam Activity, see the Web site at http://www.exploratorium.edu/IFI/activities/foam/foam1.html.

CHAPTER 7

The Process Skills of Inquiry
by Doris Ash

By being aware of the parts that make up the whole, a teacher can help children learn the skills necessary to plan and carry out successful inquiry investigations. While the inquiry process can be represented in many different ways, this chapter gives one interpretation that can help teachers identify and use the valuable "process skills" of inquiry.

> "When education is viewed as inquiry, important things happen. The focus of education becomes learning and the task of teaching becomes one of supporting the inquiry process."
>
> —*Harste (1993)*

Imagine kindergarten children exploring how potatoes grow. The children start by carefully looking at potatoes. One of the first things they notice is that the potatoes have sprouts. They wonder about the sprouts and what they might do. The teacher elicits more observations and questions. Among other things, the children suggest that potatoes grow under the ground. They wonder if potatoes have seeds, and what a potato seed might look like.

The teacher helps the children generate a list of their questions:

- What is a sprout?
- How can you get plants without planting seeds?
- Do the sprouts have anything to do with getting new potatoes?
- Should we plant all or part of the potato?

In order to answer some of these questions, the teacher suggests that students investigate in more detail. Based on their questions and observations, he organizes the children into similar interest groups so that they can work together in small groups of two or three. The teacher then asks the students to begin by creating a plan that includes a list of the materials they think they will need and drawings of what they will put into the dirt—a whole potato, half a potato, the part with or without a sprout, and so on. The child who wondered about the seeds wants to include seeds in his plan. On his own, he has found a book in the classroom that supports his theory that potatoes have flowers and seeds. The teacher suggests that he research this piece after the initial experiments are underway.

Next, the children plant their potatoes according to their plans. When the plants begin to sprout, the students uproot them to look for evidence of change. They notice that some of the potatoes they planted have rotted, but others have grown. They see roots and the beginnings of new little potatoes attached to these roots under the ground. They hypothesize that the potato pieces that originally had sprouts were the ones that grew into the plants with the little potatoes attached to their roots.

The children have many more questions, and again the teacher lists these for the class.

- How long would it take to grow a larger potato?
- How many potatoes would grow from each plant?
- Can one of the new little potatoes be used to grow another potato plant?
- How much of the potato needs to be buried in order to grow a small plant?

It is near the end of the year, so the teacher suggests that the children try some followup experiments at home during the summer.

The Parts of the Process

When learners interact with the world in a scientific way, they find themselves observing, questioning, hypothesizing, predicting, investigating, interpreting, and communicating. These are often called the “process skills” of science. Process skills play a critical role in helping children develop scientific ideas.

A sometimes bewildering variety of interpretations of process skills, including their number, order, and relative importance, exists in local, state, and national science education standards. Here we suggest one possible interpretation of seven of the process skills of science (Harlen and Jelly, 1997):

- ***Observing***—watching carefully, taking notes, comparing and contrasting
- ***Questioning***—asking questions about observations; asking questions that can lead to investigations
- ***Hypothesizing***—providing explanations consistent with available observations
- ***Predicting***—suggesting an event in the future, based on observations
- ***Investigating***—planning, conducting, measuring, gathering data, controlling variables
- ***Interpreting***—synthesizing, drawing conclusions, seeing patterns
- ***Communicating***—informing others in a variety of means: oral, written, representational

Observing

Observation of real phenomena begins the inquiry process and continues throughout all its phases. For the kindergartners studying potatoes, observation, the starting point for their endeavors, also led them from one step to the next.

In making observations, the learner gathers evidence and ideas about phenomena and begins to identify similarities and differences. He may also begin to see patterns or understand the order in which events may have taken place. Close observation provides the evidence that allows ideas

"The Eyes Have It: The Growing Science Inquiry Teaching Cycle," a video by the National Gardening Association, Burlington, Vermont.

to be checked, and it therefore needs to be detailed and relevant. The learner must have confidence that her observations are valuable.

Because observation skills can more easily be developed than other process skills, they are often more consciously practiced with younger students. But, as shown above, even kindergartners have the ability to move beyond observation to other areas of investigation.

Questioning

Curiosity drives the inquiry process—it generates questions and a search for answers. In inquiry, the process of asking a series of questions is the first step in finding answers. Questioning, therefore, is the basis from which inquiry continues. It is at the heart of the inquiry process. It is a habit of mind that can be encouraged in any learning setting. An ethos of questioning in the classroom allows learners the freedom to move into uncharted territory and begin to explore what they don't know or need to better understand.

The questions the kindergartners asked about the potatoes arose from watching real phenomena in an unhurried fashion. These questions recurred regularly throughout the children's exploration. As they worked, each question led to an action, which in turn led to the use of other process skills, including asking more questions. This is the nature of inquiry, which is not a linear process.

Equally important to raising good questions is the process of selecting questions that might be followed with fruitful investigations. In the school setting, one of the most important skills we can develop is to understand better which questions can be answered by experimentation, and which cannot. Children become aware of this gradually. Part of the inquiry process is determining how to turn non-investigable questions into investigable ones, and learning how to recognize questions that are generative, long lasting, and interesting enough to foster a rich investigation.

"The Eyes Have It: The Growing Science Inquiry Teaching Cycle," a video by the National Gardening Association, Burlington, Vermont.

Hypothesizing

Our kindergartners, by their actions, suggested that perhaps the sprout itself was associated with the growth of the potato. This is a tentative explanation for the function of the sprout. It is based on available evidence, and it is, essentially, a hypothesis.

Hypothesizing suggests an explanation consistent with available observations, questions, and evidence. When a student makes a hypothesis, he links information from past experiences that may explain both how and why events occur. (See "To Hypothesize or Not to Hypothesize?" on page 61.)

Inquiry starts when something catches our interest and we take time to observe it very carefully. Hypothesizing arrives after we have an opportunity to observe, comment, raise questions, and explore with materials. We raise questions based on experience and observations and continue to gather experiences with the particular phenomenon. Along the way, hypotheses are created, but they may arrive well into the experience and act as a way of pulling together accumulated information.

Predicting

Predictions are central to the process of testing whether or not a hypothesis is on the right track. This process takes away the need for guessing. A prediction goes beyond available evidence to suggest what will happen in the future. A learner who says, "If I do this, then that will happen" has a way of finding out how something works.

There are a variety of ways to use evidence. Young children may make conclusions that are only slightly related to available evidence. Older children may use evidence in more sophisticated ways, including recognizing patterns of data from which to extrapolate or interpolate. The greater the use of evidence to link the original ideas to future behaviors, the more useful and testable the prediction.

Typically, a prediction is based on evidence from past knowledge and/or experience, and upon immediate evidence gained through observation. It is important to know how to gather evidence and how it can be used to best advantage. Predictions invite the orderly gathering of evidence for a specific purpose.

Investigating

Measuring, gathering data, and performing "fair tests" are used to gain the evidence necessary to provide a consistent interpretation. With meaningful evidence, we can answer a question or test a prediction with some certainty that the appropriate variable is being tested and systematically measured. This means the investigator is able to understand which variable will be held constant and which will be undergoing change, a concept that is often difficult for the young or inexperienced investigator.

An investigation typically takes many unanticipated twists and turns. Solving one problem may lead to another, so investigations may take many different paths. Our kindergartners experienced this as they planned their own potato investigations. One group's investigation led to a rotted potato; another group's investigation led to a healthy potato plant. In each case, meaningful information was gathered, but along different paths.

Interpreting

Once the kindergartners had done their tests, they needed help in making sense of them. They needed to get beyond the mere gathering of data and begin to interpret what they'd found.

Interpreting includes finding a pattern of effects and synthesizing a variety of information in order to make a statement about their combined meaning. It may include making associations between variables and making sure that the data support the hypothesized connections. It is critical to relate findings to initial questions and observations.

"The Eyes Have It: The Growing Science Inquiry Teaching Cycle," a video by the National Gardening Association, Burlington, Vermont.

Communicating

An inquiry classroom relies on open communication. For the students, that means talking to others, listening to their evidence and explanations, and representing their own results in a clear manner. It includes taking notes in the course of an investigation. It also includes choosing the appropriate way to translate knowledge to others, by making representations such as charts or diagrams, for example, that illustrate data and results.

Communication in the inquiry classroom goes beyond simply exchanging knowledge. It implies that socially gathered and shared information informs individual learning.

"The Eyes Have It: The Growing Science Inquiry Teaching Cycle," a video by the National Gardening Association, Burlington, Vermont.

MODELING INDEPENDENT LEARNING

One of the most important roles of the teacher as facilitator is to gradually allow the learner to take more responsibility for the learning process. In a school setting, the process of inquiry is always guided by the teacher, who gradually transfers responsibility for aspects of the investigation to the student. Ultimately, a student who has effective guidance can learn to ask his or her own questions. The same is true for the rest of the skills that make up inquiry. Step by step, students can take on responsibility for planning, conducting investigations, using evidence, etc. As students master these skills, they can take responsibility for assessing issues for themselves, making judgments based on their assessments, taking action to initiate their own inquiries, and collecting and interpreting evidence on their own.

The gradual shift of responsibility from teacher to learner is a complex one that is at once natural and carefully designed. Over time, the teacher models the kinds of behaviors he or she would like students to learn, such as collaboration, posing questions, careful use of materials, self-reflection, and language skills. At first, the teacher is directive, acting as a guide until students demonstrate their own abilities to work independently. Like a parent modeling the complex living skills a child will need through life, the teacher models the skills and techniques of independent learning. In a process often referred to as "scaffolding," the teacher gradually fades from control of certain areas as students take on the skills in their own way.

Putting the Pieces Together

There is no one way to use a process skill. Each skill has characteristic, developmentally appropriate abilities for different ages, from novice to advanced. With practice, these abilities can be developed over time. In our potato investigation example, for instance, the kindergartners used all the process skills of science, at a level appropriate to their age.

Research suggests that some process skills are more regularly practiced in the elementary classroom than others. In particular, there may be more observation and questioning than hypothesizing and interpreting. Because all the skills are necessary to full inquiry, and because they all fit together in a coherent fashion, it is important to develop all the process skills early on.

Process skills are not used for their own sake. Rather, they are used in order to further the learning process and are an important way to link previous and current knowledge. During their investigations, for instance, the kindergarten children were observing, questioning, gathering information, and performing some initial tests that would propel them in many new directions. As students use these skills, they build up new conceptual understandings. They learn the content of science.

When doing inquiry, we assume that curiosity, respect for evidence, and a willingness to change ideas are attitudes of scientific thinking. These go hand in hand with the idea of a fair test and respect for evidence. Use of evidence involves both the processes, the content, and the attitudes of science, for it is useless to gather evidence if one does not have a willingness to change beliefs if the evidence is contrary to expectations.

The inquiry process takes advantage of the natural human desire to make sense of the world… This attitude of curiosity permeates the inquiry process and is the fuel that allows it to continue.

For children, the process of asking questions, investigating phenomena, gathering evidence, and solving problems begins when they realize that they can find things out for themselves. The inquiry process takes advantage of the natural human desire to make sense of the world. It relies on a willingness to come up with questions that reflect these interests. This attitude of curiosity permeates the inquiry process and is the fuel that allows it to continue.

In the scenario above, the children learned important scientific ideas about how plants grow and also discovered new information on their own. By linking new ideas to existing ideas, children can change conceptual models and build up a rich array of experiences. With these experiences, they can go further—making hypotheses, posing questions, making inferences, and ultimately coming to a deeper understanding of science.

TO HYPOTHESIZE OR NOT TO HYPOTHESIZE?

by Jerry Pine

As a research scientist who is involved with elementary science education, I often notice teachers recalling from their past education a "scientific method" that usually includes many attributes of scientific inquiry, among them observation, collection of data, analyzing data, drawing inferences, and reaching a conclusion. Very often this method is presented as a linear sequence of activities, which it need not be. Scientists move back and forth among processes to refine their knowledge as the inquiry unfolds. Inquiry is an artistic endeavor, and not the following of a recipe.

Frequently, the scientific method as taught by non-scientists requires that a scientific inquiry must stem from a hypothesis, which in fact is not usually true. Did Darwin board the *Beagle* with the hypothesis of natural selection in hand? Did Galileo experiment with falling bodies with the hypothesis that they would all exhibit the same acceleration? Did Mendeleev invent the periodic table based on a hypothesis that there should be one? In these three cases, as well as a great majority of other crucial scientific inquiries, there was an exploration of the unknown, with not nearly enough previous knowledge to support an initial hypothesis on which to focus the exploration.

If we don't begin with a hypothesis, then what does initiate a scientific inquiry? A question. Sometimes it can be a very specific question: "Do bean seeds germinate better in the light or the dark?" Sometimes it can be a much more general question: "How do crayfish relate to one another?" If we have a great deal of previous knowledge, we might hypothesize. After some study of electric circuits, we might hypothesize: "Two lengths of resistance wire in parallel will have less resistance than either one." But we could just as well have asked the question, "How does the resistance of two lengths of resistance wire in parallel compare to that of either one?"

We can begin every scientific inquiry with a question. If we insist on a hypothesis we will often merely force an unscientific guess. If there is a valid hypothesis it can always be stated as a question, for example, "Is it true that (insert the hypothesis here)…?"

So, the answer to our initial inquiry is: To hypothesize or not to hypothesize? Don't. Pose a question instead.

Reprinted courtesy of Jerry Pine, Caltech Precollege Science Initiative.

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Scenarios adapted from *Windows on the classroom*, a four-part video series by the National Gardening Association, Burlington, Vermont.

For more information, see the Web site at http://www.exploratorium.edu/IFI/activities/processcircus/circus.html.

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CHAPTER 8

Setting the Stage for Inquiry
by Doris Ash

Doing inquiry in the elementary classroom takes practice and preparation—for the teacher as well as for the student. Where does a teacher begin? This essay follows the experiences of one second-grade teacher who has devised her own set of techniques for preparing her students and their environment for doing inquiry investigations.

For the past 4 years, Wendy, a second-grade teacher with many students of limited English-speaking ability, has been grappling with teaching inquiry in her classroom. Each year, she develops new strategies based on the events of the past year.

When I entered her classroom recently, I was struck by the fact that there were a number of established structures in place that allowed her students to do investigations in small groups. The children were also well versed in the variety of skills and strategies that allow them to begin to plan and carry out their own investigations. I asked Wendy how she'd come to design this arrangement, what the components were, and how she prepared her students. The strategies and skills that she had learned, I realized, could help any teacher interested in inquiry set the stage for inquiry investigations in his or her own classroom.

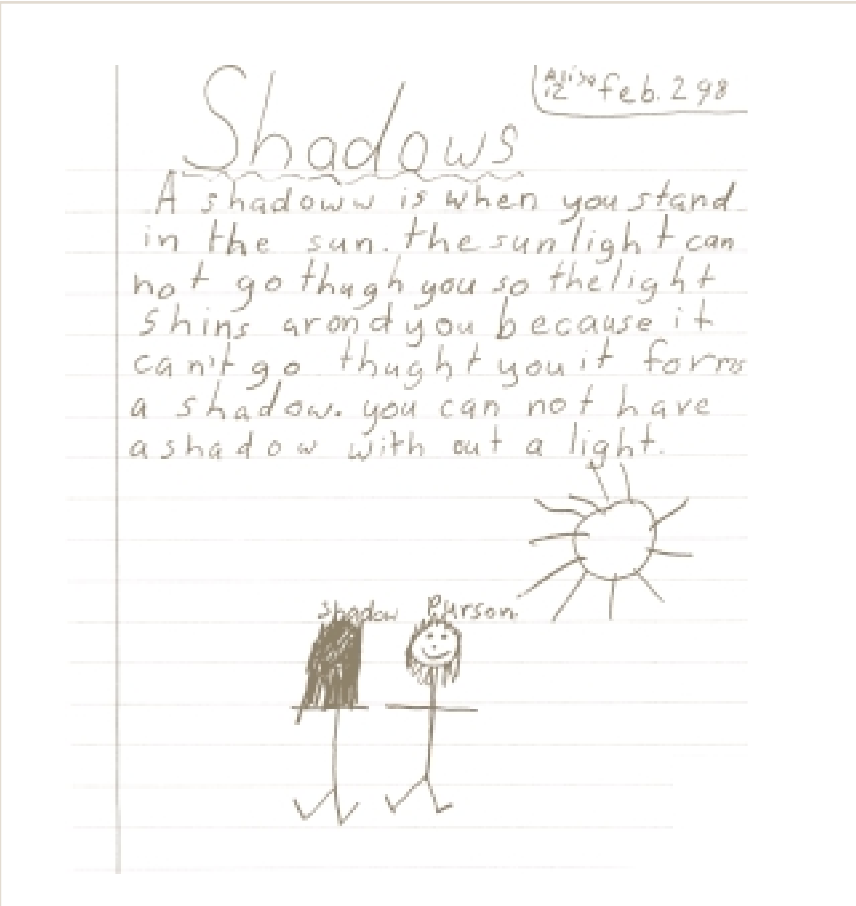
Wendy's plan to support inquiry in the classroom began with three essential elements. She had put in place:

- a definite progression of preparatory events,
- different student expectations at the different phases of inquiry, and
- the ability to pull together all the pieces near the end of the year.

Getting Ready for Inquiry

At the beginning of the school year, Wendy begins by preparing her students for doing inquiry investigations. For the students, the result is an increased ability to ask questions, observe, listen to each other, get along socially, and collaborate.

Building Socialization and Communication Skills. Throughout the school year (but most especially during the first few months), the students practice their social skills, through activities designed to help them learn how to work well with one another. At first, Wendy is more worried about student communication—talking among themselves, listening to each other, respecting ideas and opinions—than she is about content.



"Shadows," courtesy Betty Mott's third-grade classroom, Tamalpais Valley School, Mill Valley, California.

Activities that support these skills build up the classroom climate and culture, and Wendy keeps careful note of how these activities work. As the children begin to work collaboratively, she organizes them first in pairs, and then in larger groups.

Modeling and Practicing. All the while, Wendy talks constantly with the children. She finds out what they understand and where they're getting stuck, and helps them through any problems they may be having. She also helps them understand the particular usefulness of any skill they may be using. For example, she may model the meaning of the terms "most" and "least" for the children. After some time practicing the use of these terms, she will help the children use their new terminology in other areas of content.

Process Skills. In order to prepare her students for doing investigations, Wendy spends a considerable amount of time helping them develop their process skills—illuminating the processes they will be using to do inquiry. For example, she purposefully plans activities that include observation and questioning, and she models how they work. The students get to try out their own observing and questioning skills, and reflect on what they're doing. In this way, Wendy helps her students practice both social skills and process skills, but always in a particular content area. Early in the school year, she also has her students work in journals. They practice describing, observing, and keeping records in science, as well as in other curriculum areas.

Questioning. Wendy allows extra development time for her students to practice the skill of questioning. At the end of every activity, she allots time for asking questions. At the beginning of the year, she models appropriate question forms, focusing on the "five Ws" of who, what, when, where, and why. At first the children practice asking open-ended questions; later they ask more specific science questions. This process builds gradually, until the students are comfortable asking such questions as: "What will happen if I do this?" and "How long will it take if I do that?" Over time, the students also learn how to categorize their questions into groups. A question may be investigable or it may already be answered, or a student may be unsure about the category it fits into. Again, Wendy models how this is done, and investigable questions are selected for future investigation.

Language Use. Wendy always models the use of appropriate scientific language with her second graders. At the beginning of the year, this may involve the use of words for specialized materials, such as hand lenses or petri dishes. Over time, she infuses additional terms into the conversation as they naturally appear in investigations. As a result, words such as vibration and pitch become part of the students' day-to-day vocabulary.

The "Do, Talk, Reflect, Write" Cycle. When the students begin to explore science topics, there is a regular pattern of events that they can expect. First they are asked to do the activity. Then they gather together to share their ideas and questions. They reflect on their work, and then write their ideas and questions into their science notebooks. Using this process, each activity takes about 90 minutes. During the group share time, Wendy assesses the students' ideas and offers suggestions and challenges for further work. Essentially, she redirects their work based on this formative assessment of events.

Trying It Out for the First Time

Once the foundation pieces for inquiry have been put in place, Wendy integrates them in a particular way. She usually begins by selecting an instructional unit, a prepackaged set of sequenced activities designed to develop a progression of content ideas and skills in the classroom.

During my visit, a variety of musical instruments (from a "Sound" module) were set out on tables placed around the room. Wendy asked her students, who were in small groups of twos and threes, to try out the instruments. While they were experimenting, Wendy asked a number of open-ended questions. She asked the students to think about what they had to do to get each instrument to make a sound, and then what they had to do to change that sound. She asked them to notice the materials the instruments were made of, and if the instruments had any special features. These questions were designed to stimulate the children's thinking. They also served as formative assessment, providing information about what the children could do and what they still needed to learn. Working together, the children had a variety of experiences, shared ideas, suggestions, and points of view.

When Wendy examines an instructional unit for an activity like this, she selects some basic scientific concepts she wants to highlight—such as the idea that sound is a vibration, which is one focus of the module. She is explicit about the process skills that she wishes to reinforce with her class.

She reflects back to them what she sees them doing, with comments such as, "I noticed that you decided to compare the sound the big tuning fork makes with the sound that the little tuning fork makes…." Over time, the children begin using the words she has modeled and internalizing the requisite concepts and skills.

During the first lessons, the children all generally do the same activities. With each activity they follow the basic "do, talk, reflect, write" cycle. During these beginning phases, children focus on the same process skills and move toward selected big ideas. After each round, the children come together to discuss what they have discovered, and then they write down their results. By doing this, Wendy helps students develop their abilities to observe closely and ask questions within a defined content area.

With each new cycle, Wendy allows students more and more latitude to expand their experimentation—for example, in asking questions or making predictions. At the beginning of the year, Wendy directs activities, modeling each of them explicitly. In the middle of the year, she begins to allow students to take more responsibility, as appropriate. As they work, she carefully monitors small- and large-group discussions in order to discover where the children's abilities and interests lie. This structure gives her a manageable way to allow students to work more independently.

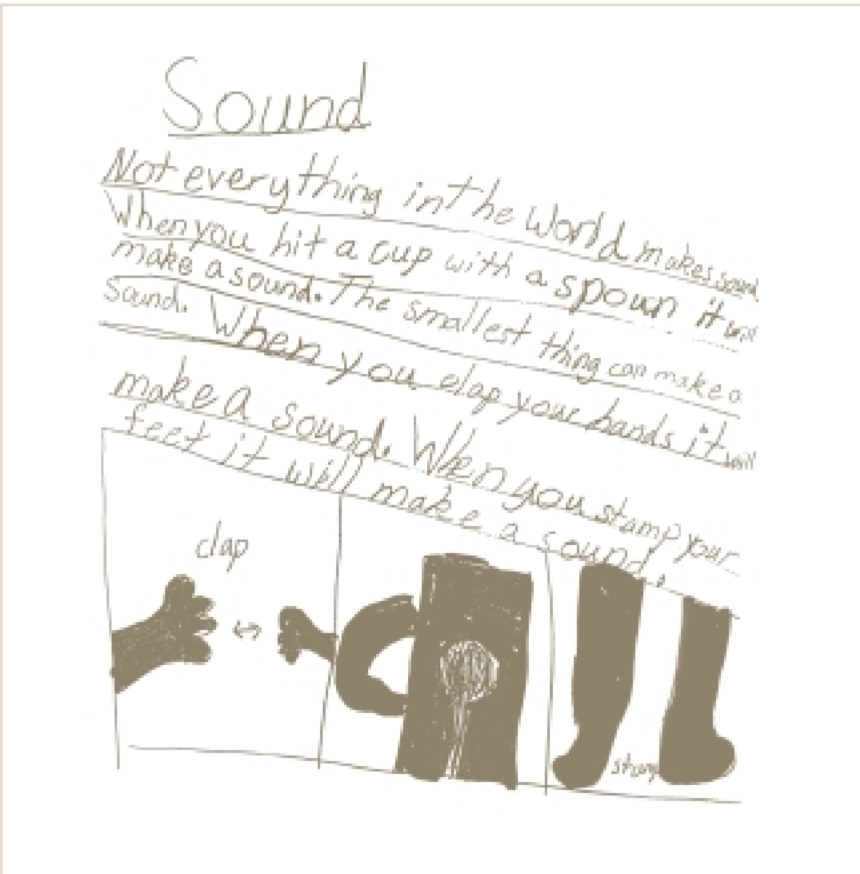
They have had the opportunity to work on developing their social and process skills, they know how to use individual discoveries and observations to build up their conceptual understandings, and they know that their observations and questions have value.

Doing the Investigation

Later in the year, students are ready to undertake independent investigations. By this point, they have had the opportunity to work on developing their social and process skills, they know how to use individual discoveries and observations to build up their conceptual understandings, and they know that their observations and questions have value. Now they are ready to embark on independent small-group investigations.

After the initial activities that set the stage for any inquiry, the students are encouraged to ask questions. Wendy groups together similar questions to emphasize relationships between ideas. The children with the same interests form small groups and begin working together. They begin their planning collaboratively by listing the materials they will need and fine-tuning the designs of their investigations. This takes time.

Later in the year, Wendy's students may be working on a unit about mixtures and solutions. In one activity, students explore the characteristics of acids and bases. They have done some preliminary exploring with vinegar and baking soda, and they introduce new materials, such as salt or



"Sound," courtesy Wendy Cheong's second-grade classroom,
Jefferson School, San Francisco Unified School District, San Francisco, California.

baking soda, as they go along. Wendy uses this as an opportunity to explore the idea of variables.

Along the way, as the group looks at their own questions, Wendy helps them refine their investigation and reflect on the nature of the activities involved. If they get stuck or need help, she models ways to ask new questions. As the children work, Wendy moves through the room. She spends time talking over the investigation with each group, clarifying materials and procedures and asking questions such as "Why did you choose to wrap that rock in paper?" or "Can you think of another way you could mix those two liquids together?" She paraphrases students' statements back to them and helps get them talking about what they are doing, and why. "Tell me about your exploration," she says, or "Is there something in particular you're thinking about?" This gives Wendy the opportunity to assess the children's understanding and reasoning.

To create a minimum of disorder, materials are strategically set around the room, and the children use them based upon their investigation plans. The lessons are structured so that a variety of materials are available, and Wendy guides the children's access to them.

In the first full inquiry of the year, Wendy maintains an emphasis on the use of process skills (questioning, predicting, hypothesizing, investigating, observing, interpreting, and communicating) while planning and conducting experiments, and knowing how to make sense of an activity. At this point, concepts such as acids and bases are important, but the major emphasis is on knowing how to perform a "fair test"—that is, knowing and thinking about variables. During the second inquiry investigation in the year, the emphasis shifts towards the larger scientific concepts, as well as testing the notion of variables.

Wendy's process is a good example of how one teacher has adapted inquiry teaching in a simple and effective way, even with young students. When the children leave Wendy's class at the end of the year, not only have they learned information about science, but they've also been introduced to skills that will help them become active, independent learners for the rest of their lives.

EXTENDING KITS TO DO INQUIRY

by Fred Stein

Many teachers use instructional materials that come prepackaged in the form of activity kits. Most kits provide students with valuable materials and a carefully chosen sequence of related activities that support the learning of science concepts and certain process skills. Kits can provide excellent starting points for teachers interested in moving toward more student-driven investigations. But kits don't often give students the opportunity to propose, plan, and carry out their own investigations. If a kit is taught as written, the questions and procedures are often predefined. The strategies here are just a few examples of ways in which teachers can extend kits to provide more opportunities for their students to do inquiry investigations.

Teachers can "open up" kits by giving students the chance to work from their areas of interest, and at the same time validating their questions and enriching their learning. By determining what questions interest students, teachers can give emphasis to those interests, referencing students' questions as they are addressed by the kit's activities. Teachers can also extend or even modify activities to address these interests and questions.

Another strategy focuses on directions a class can take at the conclusion of a unit. After using their kit, teachers can have students do short investigations based on questions that came up from their kit-based work. This method is a valuable way to reinforce and extend some of a kit's concepts. For instance, teachers can give students the opportunity to revisit one of a kit's core activities and think about next steps they would take: what they would want to investigate, what materials they would need to do their investigations, and how they would use those materials. After carrying out short investigations, teachers could have students share their discoveries with one another.

A third method is for teachers to have students base inquiry investigations on the scientific concepts presented by the kit. Teachers can begin by choosing one activity from the kit that is intriguing and that involves some of the kit's major concepts, and then help encourage students' questions about it. Students who are already proficient in using appropriate process skills can then be asked to carry out extended investigations based on these questions. Teachers can then group students according to their interests and ask them to propose plans for investigations, which they carry out after consulting with the teacher. After they complete their investigations, students can share their results, distributing the knowledge they have gained to the rest of the class. The teacher can use the remaining kit activities as needed to reinforce or complement what the students have learned so far.

Each of these approaches uses a kit as the basis for developing, identifying, and pursuing students' interests about the kit's materials and concepts. The process also helps teachers assess student progress. Working this way allows teachers to offer students ways to explore a complex subject in greater depth than they would normally be able to do.

Fred Stein is a science educator at the Exploratorium Institute for Inquiry.

CHAPTER 9

Lessons in a Pond: A Year-Long Inquiry Investigation

by Lynn Rankin

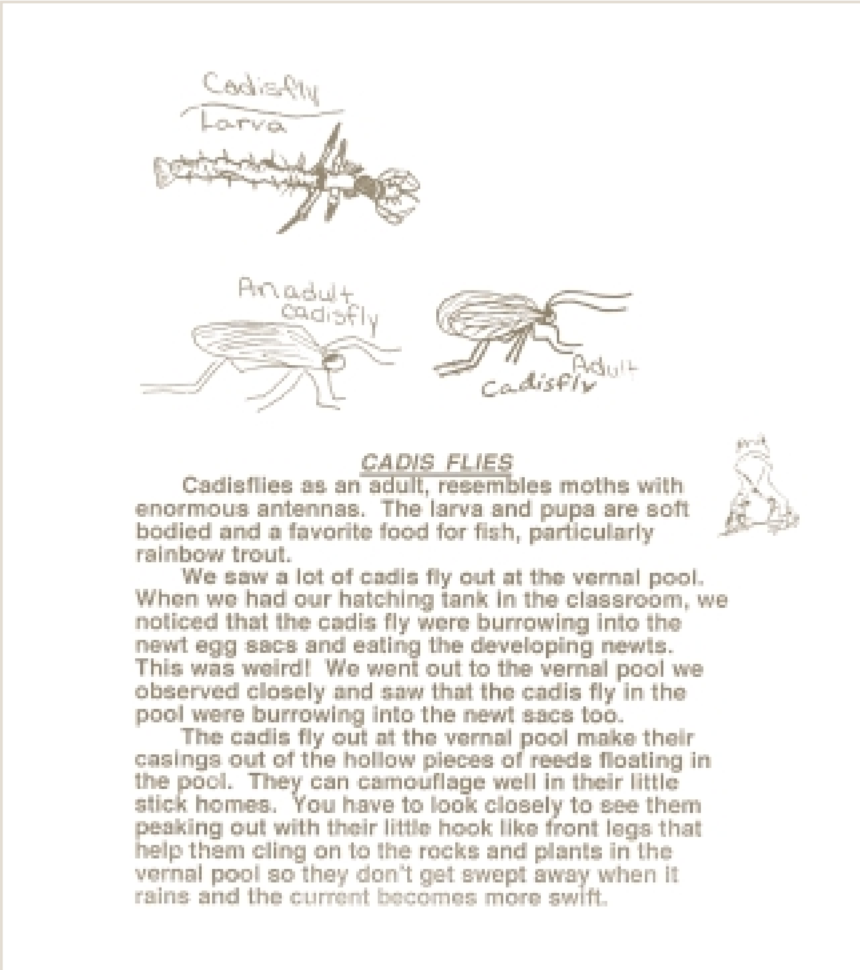
Once a teacher has established a foundation for doing inquiry in the classroom, science learning can take some unexpected paths. This essay follows the experiences of a fifth-grade teacher who allowed her class to pursue their questions and interests. The result was a full-year inquiry investigation that gave students insights, knowledge, and experiences that far exceeded their teacher's expectations.

Beth is a fifth-grade teacher in a suburban school in northern California. Over the past 3 years, she has been experimenting with inquiry in her classroom. Beth has moved toward inquiry incrementally, designing lessons and strategies that build a foundation for doing short-term (several-day) student investigations. Last year, Beth decided to embark on a month-long inquiry investigation. Quite by accident, the investigation grew into a year-long study as Beth followed the expanding curiosities and interests of her students.

Beth's regular science curriculum includes a unit on the study of diverse ecosystems and interdependency. As part of this study, she introduces her students to a nearby vernal pool—a seasonal pond that fills with rainfall and attracts amphibians, aquatic insects, and vegetation. Beth hopes to develop her students' appreciation and stewardship of this unique and precious local habitat.

During the first several months of the year, Beth creates a framework from which students develop process and social skills. These skills are designed to allow students to carry out productive investigations in which deep, significant conceptual learning takes place. By the time the vernal pool has filled with winter rain, Beth wants the students to be equipped with the process skills and previous knowledge that will allow them to investigate in a scientific manner. Beth draws upon her existing curriculum on the environment and uses other topics of study that are required.

Since Beth knows that inquiry begins with looking closely, she focuses considerable time on the skill of observation. Lessons are planned around the use of tools for observing, such as microscopes and hand lenses. Students spend time studying fish in an aquarium, learning to pay attention



CADIS FLIES

Cadisflies as an adult, resembles moths with enormous antennas. The larva and pupa are soft bodied and a favorite food for fish, particularly rainbow trout.

We saw a lot of cadis fly out at the vernal pool. When we had our hatching tank in the classroom, we noticed that the cadis fly were burrowing into the newt egg sacs and eating the developing newts. This was weird! We went out to the vernal pool we observed closely and saw that the cadis fly in the pool were burrowing into the newt sacs too.

The cadis fly out at the vernal pool make their casings out of the hollow pieces of reeds floating in the pool. They can camouflage well in their little stick homes. You have to look closely to see them peaking out with their little hook like front legs that help them cling on to the rocks and plants in the vernal pool so they don't get swept away when it rains and the current becomes more swift.

"Cadis Flies," courtesy Beth Kraft's fifth-grade classroom,
Lu Sutton Elementary School, Novato, California.

to and describe details and differences. Because questioning is a central part of exploring and understanding the environment, specific lessons focus on the art of asking questions.

Beth wants her students to begin recognizing the kinds of questions that lead to experimentation, as opposed to those that cannot be answered, or those that have to be answered by asking experts or reading books. When teaching literature or social studies, Beth takes opportunities to make connections between the way questions are used to develop understanding in these disciplines and how her students can ask useful questions in their own studies.

The students are taught how to keep records through writing, drawing, graphing, and charting. Often, Beth found that similar skills were being used, and relationships made, in math activities. She works with the students on controls, variables, and fair tests. Throughout this period of time, they are also taught the language of science. "I want them to understand what they are practicing," Beth says. "And that they are beginning to think like scientists."

To further prepare for investigations at the vernal pool, the class spends time gathering information about ecosystems and the interdependency of plants and animals in the environment. Beth invites guest speakers to talk about freshwater ecosystems and storm drain systems. The students do research by reading books, looking up information on the Internet, and watching videos. They do a series of focused experiments on water pollution, the water cycle, condensation, evaporation, and soil absorption. Questions and curiosities that emerge from these activities are recorded on a large question board kept where everyone can see it. "The questions kept spiraling," Beth says. "They started to guide the project."

Beth prepares herself by taking workshops offered by environmental education organizations. The class takes field trips to water sewage and treatment plants. They visit various environmental sites with experts from a native plant society and the California Department of Fish and Game. "All along the way," Beth notes, "I am learning with my students. I have to reach out to experts because I don't know all of this stuff."

During the winter and spring, the class visits the vernal pool every other week for about an hour. Before every visit, Beth talks with her students about the purpose of their visit. "I want them to understand why and what they are investigating," she says. For the first several visits, Beth allows the children to experiment on their own. This gives the children a chance to familiarize themselves with the pond and begin raising questions. They are asked to find out what they can about the vernal pool using their environmental observation tools (hand lenses, nets, collecting buckets, and so on), and to record their questions and observations.

After every visit, the students discuss their discoveries. As usual, questions are listed on the question board. These sessions give Beth an opportunity to assess points of interest and areas that might be fruitful for more study. At this point, Beth either chooses an area of study in which the whole class can participate or has smaller groups form to study particular aspects of the topic.

Over the next several months, the class moves back and forth between investigations at the pond and in the classroom. All along the way, Beth reinforces the children's understanding of the processes they are using to investigate and helps them build their conceptual understanding of the phenomena. She interacts with the student groups, continually assessing their progress and providing suggestions for adjustments when necessary. Periodically, she gives the children pertinent information in the form of a lecture or class discussion. The students regularly report their findings to each other.

This particular year, after several visits to the pond, the students decided to construct a similar environment of their own, so ongoing observations and investigations could take place inside the classroom. They carefully gathered samples of plants and animals, created a miniature hatching pool in the classroom, and watched what happened.

As newt and frog eggs hatched, the children were able to witness the animals' growth and development. After several weeks, some of the students noticed that a number of the aquatic insects were feeding on the amphibians and their eggs. This seemed strange, since the children expected the insects to be herbivores. As they puzzled about why this might be happening, they formed the hypothesis that the insects did not have enough to eat in the artificial environment, and so were being forced to change their diet. They decided to test their idea by observing insects at the vernal pool. After a few sessions, they determined that the eating behavior at the vernal pool was the same as in the hatching pool. It seemed that the insects were, in fact, carnivores.

Even with the evidence before them, the students had a difficult time believing this. "They saw it, but they didn't believe it," says Beth. She encouraged the group to do some research to find out more about the

THE VERNAL POOL

As you come and see the amphibians
at this magnificent vernal pool,
You will see the cycle of life happening
all around you.

Frogs and newts at your feet,
birds singing in a nearby bush.
Many animals,
all struggling to survive
living with their neighbors and enemies alike.

This is not just a vernal pool that you
should just pass by
thinking everything here is dead.
There are mysteries here waiting to be solved.

These are not slimy, ugly creatures,
they are an important part of life
and sadly, millions are dying every year.

Sometimes, if you are patient,
and you look at the grass
and stay very still,
you can see the frogs and butterflies.
So when you come to visit a vernal pool,
step lightly and look very closely,
the mysterious of life are waiting to be solved.

*"The Vernal Pool," courtesy Beth Kraft's fifth-grade classroom,
Lu Sutton Elementary School, Novato, California.*

feeding habits of aquatic insects. They called in a high school biology teacher, who was as puzzled as they were. They looked in books. Finally, they found a site on the Internet that gave specific information about the carnivorous behavior of certain aquatic insects and their role in feeding on the weakest amphibians.

This discovery led to a week's investigation on natural selection. The kids wondered if the same relationships existed in other ecosystems. Says Beth: "I certainly never imagined that we would be studying natural selection as part of this curriculum. It wasn't in my original plan, but it captured the students' interest."

At the pond, one group of students were fascinated by the water striders walking on top of the water. They wondered how this could happen. As children looked more closely, they began to notice that there were tiny depressions in the water at the base of each of the insects' feet. They also noticed similar depressions around floating leaves. This led to a study of surface tension. Beth set up a series of activities in which the students could experiment with floating various objects on the surface of the water (balsa wood blocks, paper clips, and so on). She talked with them about the physical characteristics of water and showed them pictures of the molecular bonds.

After noticing how the pond was diminishing in the late spring, another group of children wondered whether the chemistry of the water was being altered by the environment. They were watching amphibians growing, some plants getting taller, and some plants decomposing, and thought that the acidity of the water, and the oxygen and nitrate levels, would be affected by these changes. This led to a lot of work with water testing and very careful tracking of data. In the end, the children discovered that there were only marginal changes.

The final month of the school year was spent compiling information for presentation in a student book. Committees of student writers, artists, and researchers formed to develop narratives, graphs, diagrams, photographs, and poetry that could represent what they had learned.

After reflecting on the experience, Beth says, "I'm really convinced that one inquiry a year is important. It doesn't have to last a year; it could be a month. But there are things that the kids learn about their own learning that can't happen without it." Beth also talked about the importance of "building" the inquiry experience by developing the children's ability to be good investigators.

"In order to do this, you have to isolate the process skills, so the children learn to be good observers, good at questioning, etc. Of course, when you are investigating, these skills are more intertwined, but it's helpful to know, as a teacher, that you can develop the children's abilities for these skills.

"Doing inquiry is much more structured than you might think. You really have to be organized and think about what you're doing at every step of the way. But it's worth the effort because you get to know how your students think through this process. It renewed my faith that children of all ages have an innate curiosity. We marvel at how curious young children are and how their excitement for learning drops off as they get older. But I would say that my fifth graders were natural naturalists. They learned more about the environment, and about doing science, than I ever would have imagined."

WATER STRIDER

A water strider is a special insect that uses the small hairs on its feet to hook on to the surface of the water or the water's skin. They resemble tiny black carrots with long, long legs. They eat red water mites, which you will find on the next page.

If you have ever wondered how striders walk on the water here is you answer to the mystery: surface tension. If you put a feather in the water and then push it down, it sinks, but if you leave the feather alone, it floats beautifully. The feather is staying up on the surface of the water. It's the same with water striders.

We learned that staying on top of the surface of the water is different from floating. We learned that things like paper clips and straight pins can stay on the surface of the water and not break through the water's skin. When an object floats, some of it is above the water and some of it is below the surface of the water, thus breaking through the water's skin. TRY IT SOMETIME!! You'll see what I mean.

"Water Strider," courtesy Beth Kraft's fifth-grade classroom, Lu Sutton Elementary School, Novato, California.

CHAPTER 10

Identifying Inquiry in the K–5 Classroom

by Doris Ash and Barry Kluger-Bell

What does an inquiry classroom look like? How does it work? How can you tell if genuine inquiry is happening in the classroom? This chapter offers three practical guides to help educators who are trying to identify and support the specialized characteristics of the inquiry environment.

The elementary classroom is a complex social environment in which people talk, write, laugh, learn, and interact with one another. Teachers are asked to implement a variety of policies and standards in multiple content areas. They are expected to meet a variety of goals and needs and to respond to administrators, parents, policymakers, and the community. But first and foremost, teachers are expected to meet the needs of children.

As Karen Worth suggested in Chapter 4, inquiry is an excellent way to help foster children's learning. School districts around the country have begun requiring their administrators, teachers, and professional developers to better understand the nature of inquiry and how to implement it in the classroom. They also have a pressing need to help their teachers create inquiry in the elementary classroom.

Teachers, administrators, and others who experience inquiry as adult learners still wonder about the nature of inquiry in the classroom: What does it look like? What would the children be doing? What would the teacher be doing? How would the classroom environment feel? Over the past few years, professional developers have been developing "markers" designed to help teachers recognize when inquiry is occurring in the classroom. These indicators are shown below, in three guides that look at the special characteristics of the inquiry classroom.

INQUIRY INDICATORS: WHAT ARE THE STUDENTS DOING?

On-the-Run Reference Guide to the Nature of Elementary Science

Imagine yourself in an inquiry classroom. What would you expect to see? These guidelines from the Vermont Elementary School/Continuous Assessment Project were created by observing students as they did "hands-on, minds-on" exploration in the classroom. "The intent is not to use the guide as a checklist," they said, "but to use it as a statement of what we value in the areas of science process, science dispositions, and science content development."

When students are doing inquiry-based science, an observer will see that:

Students View Themselves as Active Participants in the Process of Learning

1. They look forward to doing science.
2. They demonstrate a desire to learn more.
3. They seek to collaborate and work cooperatively with their peers.
4. They are confident in doing science; they demonstrate a willingness to modify ideas, take risks, and display healthy skepticism.
5. They respect individuals and differing points of view.

Students Accept an "Invitation to Learn" and Readily Engage in the Exploration Process

1. They exhibit curiosity and ponder observations.
2. They take the opportunity and time to try out and persevere with their own ideas.

Students Plan and Carry Out Investigations

1. They design a fair test as a way to try out their ideas, not expecting to be told what to do.
2. They plan ways to verify, extend, or discard ideas.
3. They carry out investigations by handling materials with care, observing, measuring, and recording data.

Students Communicate Using a Variety of Methods

1. They express ideas in a variety of ways: journals, reporting out, drawing, graphing, charting, etc.

2. They listen, speak, and write about science with parents, teachers, and peers.
3. They use the language of the processes of science.
4. They communicate their level of understanding of concepts that they have developed to date.

Students Propose Explanations and Solutions and Build a Store of Concepts

1. They offer explanations both from a “store” of previous experience and from knowledge gained as a result of ongoing investigation.
2. They use investigations to satisfy their own questions.
3. They sort out information and decide what is important (what does and doesn’t work).
4. They are willing to revise explanations and consider new ideas as they gain knowledge (build understanding).

Students Raise Questions

1. They ask questions—verbally or through actions.
2. They use questions that lead them to investigations that generate or redefine further questions and ideas.
3. They value and enjoy asking questions as an important part of science.

Students Use Observations

1. They observe carefully, as opposed to just looking.
2. They see details, seek patterns, detect sequences and events; they notice changes, similarities, and differences.
3. They make connections to previously held ideas.

Students Critique Their Science Practices

1. They create and use quality indicators to assess their own work.
2. They report and celebrate their strengths and identify what they’d like to improve upon.
3. They reflect with adults and their peers.

Adapted from materials created by the Vermont Elementary Science Project and the Continuous Assessment in Science Project, ©1995. Courtesy of Gregg Humphrey.

INQUIRY INDICATORS: WHAT IS THE TEACHER DOING?

The Role of the Teacher in the Inquiry Classroom

In the inquiry classroom, the teacher's role becomes less involved with direct teaching and more involved with modeling, guiding, facilitating, and continually assessing student work. Teachers in inquiry classrooms must constantly adjust levels of instruction to the information gathered by that assessment.

The teacher's role is more complex, including greater responsibility for creating and maintaining conditions in which children can build understanding. In this capacity, the teacher is responsible for developing student ideas and maintaining the learning environment.

Besides the process skills that the student must hone in the inquiry classroom, there are also skills a teacher must develop in order to support student learning of scientific ideas. When you enter an inquiry classroom, you may see that the:

Teachers Model Behaviors and Skills

1. They show children how to use new tools or materials.
2. They guide students in taking more and more responsibility in investigations.
3. They help students design and carry out skills of recording, documenting, and drawing conclusions.

Teachers Support Content Learning

1. They help students form tentative explanations while moving toward content understanding.
2. They introduce tools and materials and scientific ideas appropriate to content learning.
3. They use appropriate content terminology, as well as scientific and mathematical language.

Teachers Use Multiple Means of Assessment

1. They are sensitive to what children are thinking and learning, and identify areas in which children are struggling.
2. They talk to children, ask questions, make suggestions, share, and interact.

3. They move around and make themselves available to all students.
4. They help children go to the next stage of learning with appropriate clues and prompts.

Teachers Act as Facilitators

1. They use open-ended questions that encourage investigation, observation, and thinking.
2. They carefully listen to students' ideas, comments, and questions, in order to help them develop their skills and thought processes.
3. They suggest new things to look at and try, and encourage further experimentation and thinking.
4. They orchestrate and encourage student dialogue.

Adapted from materials created by the Exploratorium Institute for Inquiry.

INQUIRY INDICATORS: HOW DOES THE ENVIRONMENT SUPPORT INQUIRY?

The Social and Emotional Environment of the Inquiry Classroom

Creating the proper environment is a necessary condition for maintaining an inquiry classroom, but it is not sufficient in itself. The environment of an inquiry classroom can look quite different from our "standard" picture of a typical classroom. An inquiry classroom may be very active and filled with materials. It may be filled with children having conversations about scientific phenomena, or it may be filled with evidence of independent investigations.

There are three major areas of development in any inquiry endeavor. These are:

- Content and conceptual understanding and development
- The skills and the activities of doing science
- Attitudes and habits of mind

It takes a very special classroom environment to support all these elements for children engaged in the inquiry experience. In addition to the guidelines expressed in the "On-the-Run Reference Guide to the Nature of Elementary Science" above, an inquiry classroom must make it possible, on a social and practical level, for students to pursue their investigations.

Walking into an inquiry classroom, an observer may see that:

Students Work in an Appropriate and Supportive Physical Environment

1. The room is set up to support small-group interaction and investigation.
2. Lists of student questions are prominent and available for all to see.
3. A variety of general supplies are available, both at desks and in easily accessed cabinets.
4. A variety of materials specific to the area being explored are easily accessible.
5. Student work is displayed in a variety of ways in order to reflect their investigations.

Students Work in an Appropriate and Supportive Emotional Environment

1. Their thinking is solicited and honored.
2. They are comfortable expressing ideas and opinions and speaking up.
3. They are comfortable interacting with one another, and with the teacher.
4. They are encouraged to share information and ideas with each other—as individuals or in groups.
5. They know what they are doing and why.

Students Work in a Variety of Configurations to Encourage Communication

1. Work may be done in student pairs, small or large groups, or in whole-class situations.
2. Students have many opportunities to respond to feedback and learn from one another.
3. Students become part of a "community of learning," supporting and affecting each other's thinking.

Adapted from materials created by the Exploratorium Institute for Inquiry.

Not every inquiry classroom will look and feel the same, but the major elements identified in these three guides will be manifested in some form.

It's not the form that makes an inquiry environment successful, however, but the underlying substance. There are many different ways to encourage communication, just as there are many different ways to support continued learning. Inquiry classrooms always involve engaging children's intellect in exploring and investigating interesting phenomena. The emphasis is on allowing and assisting children to find their own best pathway to learning. The indicators listed here are meant to be one way to begin to determine if genuinely exciting inquiry learning is occurring.

CHAPTER 11

Assessment in the Inquiry Classroom by Wynne Harlen

Because assessment information is a powerful tool for monitoring the development of student understanding, modifying activities, and promoting student self-reflection, the effective teacher of science carefully selects and uses assessment tasks that are also good learning experiences. These assessment tasks focus on important content and performance goals and provide students with an opportunity to demonstrate their understanding and ability to conduct science.

—*National Science Education Standards*

Assessment—the process of evaluating the quality of learning—is an integral part of classroom teaching. With children taking different paths as they learn, assessment in the inquiry classroom can be a difficult task. But, as this essay points out, the characteristics of inquiry give teachers the opportunity to determine what students are learning, recognize when they need help, and identify appropriate next steps to take.

"Any assessment is only as good as the action that arises from it."

—*M. James (1998)*

Picture the scene…

A fourth-grade class is involved in a topic on sound, investigating how it is produced and how we hear it. The teacher has collected a number of musical instruments—tambourines, recorders, several homemade one-string guitars, a real guitar, drums, castanets, triangles, and so on—deliberately including some that can be tuned and others that can't.

These are distributed to the students, who are working in groups. The students are asked to find out several things, including how to make a loud sound, a soft sound, a high-pitched sound, and a low-pitched sound. They are also asked how to stop the instrument from making any sound at all, and how to stop themselves from hearing the instrument when it is making a sound. The students are to discuss their findings and prepare to present what they have done and their ideas about it.

As the students work, the teacher circulates, listening to their talk. She encourages their thinking by asking questions, such as, What do you do that makes the difference between a loud and a soft sound? or Why do you think doing that makes a difference to the sound? She also encourages them to ask questions that they can answer by further investigation.

The teacher notes the way the students go about their inquiry. For example, she watches how systematically they investigate and how thoroughly they observe effects. During the group presentations, the teacher has a further opportunity to observe how the students communicate and explain what they did. She also notes what words they use.

Then, the teacher asks each student to select one instrument and write and draw their thoughts about it, how it makes sound, and how they hear it. Later, the teacher collects these products and studies them for evidence about the students' understanding of sound, their use of evidence, and their reasoning process. From this, the teacher decides on the appropriate next steps for the students—whether they are ready to move on to other investigations of sound or need to consolidate ideas about how sound is created and how it travels to our ears.

What this teacher has been doing in this lesson includes collecting a considerable amount of evidence about the students' ideas and skills. This evidence can then inform the teacher's decisions about next steps in the students' learning. This is assessment. When the assessment is carried out for the purposes of helping teaching and learning (as it is in this example), it is called *formative assessment.* When it is carried out in order to provide a report on where each student has reached at a certain point in time, it is called *summative assessment.*

What to Assess and How to Assess It

Here, we are going to focus for the most part on formative assessment, for two important reasons: first, because it is an integral part of any teaching which attempts to build ideas and skills progressively; and second, because there is solid evidence that effective teaching is characterized by good formative assessment.

Formative assessment is essential to inquiry teaching because the teacher must know what understanding of scientific ideas and process skills the students have already developed in order to decide what is needed to help the children's progress. It is this use of the assessment that makes it "formative." This view of teaching and learning acknowledges the role of the student in his or her learning. No one else can do the learning, but the teacher who wants to help the process will need to know where the student has reached. Gathering information about the learning as an ongoing part of teaching, and using it in deciding next steps, is thus a necessity.

In order to be useful, formative assessment must cover the important outcomes that are intended in inquiry learning. That is, it must be concerned with the process skills and with the understanding of scientific ideas. So the outcomes of inquiry learning have to be identified, and it is essential to know what is meant by progression in each of the skills, attitudes, and areas of understanding. These aspects can't be considered here in detail, but it is useful to list some of them.

The process skills include:

- observing
- explaining (hypothesizing)
- predicting
- raising questions
- planning and conducting investigations
- interpreting evidence
- communicating

The attitudes include:

- willingness to collect and use the evidence (respect for evidence)
- willingness to change ideas in the light of evidence (flexibility)
- willingness to review procedures critically (critical reflection)

The areas of understanding of scientific ideas include:

- characteristics of living things
- processes of life
- energy sources, transmission, and transfer
- forces and movement
- the earth and its place in the universe

Information about all of these intended outcomes of inquiry learning is needed at some point for teachers to use to help progress in learning. Furthermore, experience has shown that what is not assessed tends to be devalued and, in fact, may not even be taught.

Methods of Gathering Information

The teacher whose work was described at the beginning of this essay was using four main methods of gathering information:

- observing students engaged in inquiry
- asking questions designed to probe reasons and understanding
- looking closely at the evidence from class work
- setting special tasks or assignments

Let's look briefly at each method.

Observing Students at Work

Much can be learned about students' skills by observing them at work, particularly if the teacher has a list of things to look for, either as a mental or written checklist. This is one example of a simple checklist a teacher might use to assess understanding in younger children who are working on a particular topic or project.

1. Was at least one relevant observation made (indicated by something said or put on paper)?
2. Was something drawn or described clearly enough for it to be identified by someone else?
3. Were differences between things or from one time to another noticed?
4. Were questions asked about what they observed?
5. Were ideas suggested, perhaps in answer to their own questions?
6. Was some interpretation made of findings by associating one factor with another?

7. Were perseverance and patience shown?
8. Were tasks shared cooperatively?

Based on Harlen and Elstgeest, 1992.

A more elaborate checklist, which embodies a description of development within each aspect of inquiry, helps to identify where students are and what their next step might be. Each successive question indicates a further step in development. This example concerns ability in planning and conducting investigations.

1. Do the students start with a useful general approach, even if details are lacking or need further thought?
2. Do they have some idea of the variable that has to be changed, or what different things are to be compared?
3. Do they keep the same the things that should not change for a fair test?
4. Do they have some idea beforehand of what to look for to obtain a result?
5. Do the students choose a realistic way of measuring or comparing things to obtain the results?
6. Do they take steps to ensure that the results obtained are as accurate as they can reasonably be?

This list is based on Harlen and Jelly, 1997, in which similar developmental lists are suggested for other inquiry skills.

Asking Questions

Observation can give a teacher a certain amount of information about a student's thinking process. But even more information can be obtained when observation is combined with asking questions designed to probe this thinking. The most useful kinds of questions for this purpose are ones that are open, as opposed to closed, and person-centered, as opposed to subject-centered. Open questions invite the student to give his or her view of things ("What do you notice about the bubbles?"), rather than respond to what the teacher suggests ("Do you see the colors in the bubbles?").

Person-centered questions ask directly for the students' ideas ("Why *do you think* the bean plant grew more quickly in the closet?"), rather than focusing on the subject of a particular answer ("Why did the bean plant grow more quickly in the closet?"). Asking such questions during activities means that evidence can be gathered about students' understanding, as well as about skills and attitudes.

Looking Closely at Products

The products of students' inquiry, whether they are drawings, constructions, or pieces of writing, give clues to their thinking and are especially useful in assessing understanding of scientific ideas. These products are more useful if the task is set to elicit the students' reasoning about what they have found. The following example is a result of a request that a teacher made for a student to be self-critical about her investigation of how far away the sound could be heard when a coin was dropped:

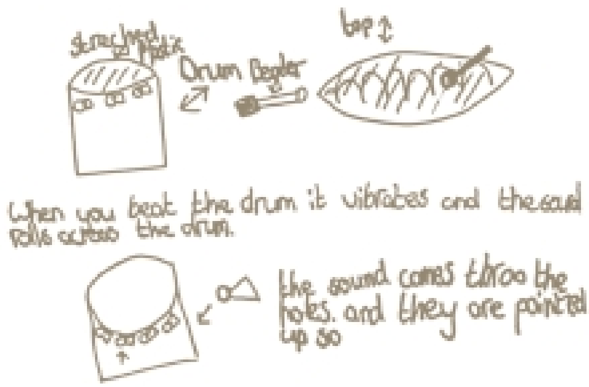
> *"If I did this again I would try to think of a way to test the sound and not just guess and try to think of more surfaces and try with different coins at different heights. On the sound I have got two ideas, one, see how far away you can here [sic] it drop, and two, get a tape recorder with a sound level indicator."*

Students' drawing and writing can also provide evidence of their conceptual development. The two figures show examples of students' work on the subject of sound.

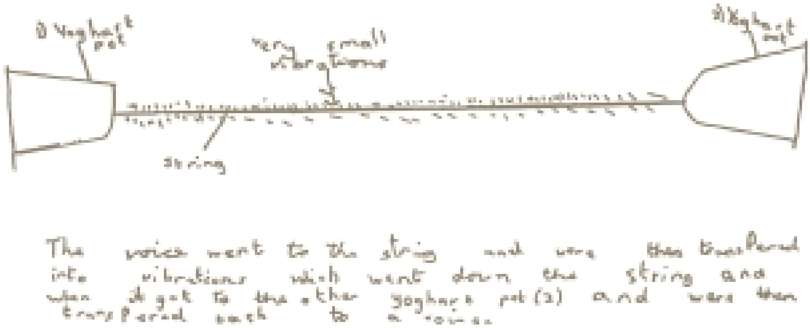
The first figure shows the product of a 10-year-old in response to being asked to write and draw about how the drum makes a noise, and how the sound travels. The idea of sound being associated with vibration is evidently being developed, but this student considered that sound could only travel through air and so had to emerge from the drum through the holes.

In the second figure, the student has been investigating a string telephone. Although the student used the word "vibration," it is clear that this is applied only to the sound going along the string, and that these vibrations are converted to "sound" in the air.

Both of these examples indicate to the teacher the kinds of further experience and discussion that will help these students' understanding of ideas relating to sound. Of course, the teacher will be gathering similar evidence from other students in the class and will be able to find out to what extent these ideas are generally held. This information will help to decide what issues should be addressed, and whether it applies to all or just some of the students.



A 10-year-old's representation of how a drum makes a sound, and how the sound travels.



A 10-year-old's representation of sound travelling.

How valuable the products of classroom activities are for formative assessment will depend on these factors: the way the request is expressed, and the extent to which the teacher tries to understand the work and to find clues to points of development.

Students are ultimately responsible for their own learning. Thus, if the assessment information is going to be used formatively—for helping learning—then it is the student who is the user, and the student who needs the information.

In making the request, the teacher must ask for the thinking behind the work. The two figures would have been much less informative had the teacher simply asked the students to draw the instruments. Instead, the request was a much more demanding one: to use writing and drawing to express their ideas. The advantage for the teacher in making this request was matched by the advantage for the students, who would see a purpose for their work, as a contribution to sharing ideas. Similarly, the student who wrote the passage quoted above would see that the point of the work was improving the investigation, and not just a matter of writing something as a routine.

As the teacher studies the students' work, all the information gathered is potentially helpful, not just the mistakes children make. It may mean talking with the students to clarify meaning, which is time-consuming. But a few pieces of work, valued by both student and teacher, are of far greater value for learning than are many pieces of work to which both teacher and student may give less attention. Discussing work in this way is also an ideal opportunity for teachers to help students share goals of learning, and for the students to begin making decisions for themselves about improving their work.

Special Tasks

Special tasks designed to give students opportunities to use the skills of inquiry can be both hands-on and written. Hands-on tasks can often be adapted to increase assessment opportunities. For example, activities that challenge students to find out "which x is best for y" could be about soap solutions for blowing bubbles, paper towels for soaking water, types of salt crystals for dissolving quickly, fabrics for muffling sound, and so on. In all cases, investigable questions have to be identified, and decisions must be made about the variable that should be changed, those variables that have to be controlled, and what has to be measured. Students also have to work out how to put these decisions into operation and how to interpret the results.

Good written assessment tasks are less easy to create than are hands-on activities, but can be adapted from published examples.

Giving Feedback to Students

As we have already noted, students are ultimately responsible for their own learning. Thus, if the assessment information is going to be used formatively—for helping learning—then it is the student who is the user, and the student who needs the information.

Giving a student feedback about a teacher's assessment is an important matter to consider, since it can have both positive and negative effects on learning. For feedback to have a positive effect, it should not incorporate comparisons with other students; that is, each student should be given feedback in relation to his or her progress. Further, the teacher should avoid making judgments about the student's ability. Comments should be closely related to the work and how it can be improved. For example, if a teacher finds that a student has some results about how far away different sounds can be heard, and those results clearly indicate that a fair test has not been made, a teacher might comment, "You have some interesting results there. Are you quite sure that you kept things the same for each of the different sounds that you tried? Why don't you check up on that and see if your results are the same?" This would help learning far more than commenting that the results were wrong, or, indeed, just saying "fine" and not using the work to show the student how to improve it.

Negative effects tend to follow when there is an over-reliance on rewards and competition among students. Research shows that this results in students focusing on those aspects of work that are rewarded; those who don't get rewards often settle for just enough to "get by" (Black and Wiliam, 1998). There is also the danger that low marks may be interpreted by students as meaning that they lack ability, and this may lead them to consider that nothing they can do will change this.

In Conclusion

While the information gathered by the teacher in the scenario at the beginning of this essay was used for formative purposes, all the methods of information gathering that were used can also provide evidence that can be used for summative purposes. It is also possible to design summative tests to assess inquiry skills. Thus, the main difference between formative and summative assessment is not in what information is gathered, nor in how it is gathered, but in how it is used. Formative assessment is used for immediate feedback into teaching and learning, while summative assessment is used to give others information about the students' progress.

Another difference between assessment for formative and summative purposes lies in the involvement of students in the assessment process. If assessment is used to help learning, it follows that the students should have a central role in it. Since no learning can take place without the active participation of the students, it follows that they should share the teachers' aims and understand what is expected of them (Sadler, 1989). Feedback, of the positive kind suggested above, is an integral part of formative assessment.

Sometimes gathering information informally, as in the classroom described at the beginning of this chapter, is not sufficient to assess all of the students' skills. In that case, a teacher may introduce special tasks in order to focus on specific aspects of learning that may not have been observed in the regular work. The process might then seem more like assessment for summative purposes. Indeed there is a continuum, rather than a dichotomy, between formative and summative assessment.

Summative assessment summarizes where students have reached in their development at the end of a topic, or at the end of a year. This forms part of the report that ultimately goes out to parents and to other teachers. It also becomes a piece of the ongoing record of each student's progress. Summative assessment often depends on the administration of tests, but this is not always necessary. If ongoing work has been retained in a portfolio, it can be reviewed and a judgment made in relation to criteria or standards. This will reflect a greater range of skills and understanding than can be covered in a short test.

Assessment for both formative and summative purposes is important in education. But too much emphasis on grades, marks, and levels can obscure assessment for formative purposes, which is integral to effective teaching and learning.

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Illustrations taken from *Assessment in the Primary Classroom: Written Tasks,* by Schilling, Hargreaves, Harlen, and Russell (1990) in a book to be published by the National Science Foundation (NSF). Reproduced by permission of Paul Chapman Publishing, Ltd., London.

CHAPTER 12

Assessment of Science Inquiry
by George E. Hein and Sabra Lee

Different types of classroom assessment can give teachers different kinds of evaluation information. This chapter surveys the assessment methods available to teachers, and talks about the challenges inherent in evaluating learning in the inquiry classroom.

All teachers assess what their students know, where they need help, and what they should do next. Teachers do this informally countless times each day, and more formally after completing a topic, or at a fixed time, such as at the end of a marking period or semester, or the end of a unit.

On a larger scale, administrators and policymakers use assessments to determine how well their schools are educating the next generation. Assessment is a more modern and more inclusive term than the traditional "testing." It provides the connection between teaching and learning; it lets us know the result of any educational activity. Until recent years, assessment of science education was not a major concern in K–12 education because very little science was taught, especially in grades K–8. With increased attention to science, and recognition that science instruction is important in preparing students for the modern world, science inquiry and the assessment of science inquiry are now seen as crucial in schools.

Assessing Science Inquiry

It is generally agreed that inquiry science includes some hands-on interaction with the natural world; that is, "problem solving," "investigations," or "inquiries" must involve actively doing as well as thinking and reasoning. But this still leaves room for considerable variation in definitions of inquiry science. In some classrooms, children are given carefully prescribed materials and asked to use them in specific ways—they carry out activities that illustrate known scientific principles. For example, they may all be asked to measure a pendulum's period (the time it takes for one complete swing) as the length of the pendulum is changed. In other inquiry classrooms, children carry out independent investigations, exploring questions for which no one knows the answers. They may be asked to find the acidity of water in a local pond, for instance, and then figure out how that affects nearby plant and animal growth.

In each of these classrooms, the records children keep of their work, as well as other assessments developed by the teacher, can form the basis for determining what children have learned. In the first classroom, the teacher can tell whether the children's data conform to the expected Newtonian results for pendulums. In the second classroom, since the acidity of the local pond may, indeed, be unknown, any result may be correct—or incorrect—and the teacher has to look at assessments that demonstrate the methods children used, rather than the results they obtain. In most science inquiry classrooms, some combination of activities and assessments is appropriate.

In order to develop any assessment, the most important issue to resolve is determining what is going to be assessed. In addition, any discussion of assessment of inquiry must start with a clear statement of how inquiry is defined. As the previous sections of this book have demonstrated, definitions of inquiry vary widely.

Assessing "Doing" Science

If we accept the notion that inquiry science involves investigations of the natural world, then such inquiry requires both physical and mental activity. To assess both aspects of inquiry requires "performance assessments." Such assessments are likely to include a number of components. First, they should address how well students are able to carry out physical processes, such as measurement, observation, experimental design, problem solving, etc. The level of students' thinking and reasoning skills should also be addressed—that is, whether students draw valid conclusions, choose appropriate methods, recognize regularities in nature, and so on. In addition, it's also important to look at students' knowledge of science concepts, and science content.

Uses of Assessment

Assessment can be used for a variety of purposes. Each presents its own opportunities and challenges. The six most common are as follows:

- Diagnostic assessment (pretests) to help determine what students know when they begin any educational task.
- Formative assessment to help guide day-to-day classroom activities.
- Student outcome or summative assessment to find out what students have learned and mastered in their individual programs.
- Comparative assessment for determining how an individual's or a group's outcome compares to some other group's outcome.
- Assessment to support professional development by using analysis of student work to improve the teacher's performance.
- Student assessment to help determine the effect of a program, curriculum innovation, pedagogic strategy, professional development, or policy initiative.

Let's take a closer look at each form of assessment.

Diagnostic Assessment

Diagnostic assessment is used to determine what knowledge and understanding a student brings to a subject. If teachers were content to have all students doing the same thing—listening to a lecture, for instance, solving problems on a worksheet, or making identical measurements—then diagnostic assessment would be relatively easy. But if teachers want to find out what individual students can do, and how each deals with inquiry, then teachers have to engage their students in inquiry processes. Experienced teachers can use classroom discussions, informal observations of children, examination of children's work products, and short interviews to decide what students can do and what they might be ready for next. Most important for diagnostic assessment is that teachers be clear about what they expect to do in their science teaching and know what qualities they hope to bring out in their students.

Formative Assessment

Assessment used to support day-to-day instruction, called formative assessment, makes use of all the normal activities of a classroom. What turns any instructional activity into an assessment is the explicit intention of a teacher to use it for that purpose, the systematic recording of student results, and the application of some criteria for judging the quality of a child's performance. Many recent NSF-supported science curricula include "embedded assessments," specific activities that can be used to assess students' progress. Thus, students may be asked several times during a unit to draw pictures of a complete circuit, place pictures of plant growth and development in chronological order, draw graphs, or provide a complete description of a scientific term such as "biosystem." Such student products can inform teachers of what ideas have been understood by individual children and what needs to be done next.

Summative Assessment

Traditionally, summative assessment consists of tests at the end of a period of instruction. The term needs to be expanded to include any judgment based on all available evidence of what a student has learned after working on a particular topic.

The most powerful evidence of student growth is provided when teachers combine data from pretests (student work done *before* the topic is studied), embedded assessments (classroom activities recorded *while* a topic is being studied), and post tests (drawings, descriptions, or answers to questions done *after* a topic has been studied). Together, this information provides a summative assessment. For example, if a student does a drawing of a plant, diagrams a functioning motor, gives a specific description of an environment, or carefully draws and correctly labels a graph at the end of a unit, that information can provide powerful evidence of growth in learning, especially when compared to work done just before studying the unit. This form of evidence is particularly valuable in classrooms where traditional paper-and-pencil activities are minimal and time is spent in doing and talking. It often furnishes compelling evidence of student achievement for parents, as well.

Comparative Assessment

Much of the discussion above has stressed individual growth. When assessment is used to compare students with others in a larger arena, however, problems associated with assessing inquiry become more complex. In order to compare students to each other, standards need to be established about what would serve as an appropriate measure of achievement. What is an acceptable experiment for a second grader? How detailed should a fourth grader's plant drawing be? How many variables can a sixth grader be expected to consider in designing an inquiry?

At this level, problems of sampling also come to the fore. Since any one test can ask only a limited number of questions, the results may not accurately reflect what a particular student knows or can do. But a teacher has available a more complete, if informal, knowledge of the student's abilities and skills. Assessment results that are strikingly different from what a student usually does can be modified by including additional information, reassessing, clarifying what is expected, or providing specific instruction.

When tests are used to compare students against district performance or national standards, the tests may not match what actually was taught in individual classrooms. Since the range of what is learned in inquiry science is so large, it is particularly difficult to develop assessments that cover what individual teachers may be doing in their classrooms. In addition, questions about equity—the background children bring to science and the role of inquiry science in various cultures, inside and outside of school—need to be taken into account (Goodwin, 1997).

Teachers who have participated in study groups that look carefully at children's work, or who are engaged in developing performance assessments, frequently comment about how much they have learned from the process and that it has dramatically and immediately influenced their practice as teachers.

Assessment for Professional Development

Engaging teachers in the process of developing performance assessments or interpreting students' responses to them is a powerful form of professional development. Teachers who have participated in study groups that look carefully at children's work, or who are engaged in developing performance assessments, frequently comment about how much they have learned from the process and that it has dramatically and immediately influenced their practice as teachers.

Student Assessment as a Measure of Program Effectiveness

Higher student achievement should be the central goal of all science education activity. Using student assessment for teacher or program evaluation can be problematic.

When teacher professional development is related to student assessment, it assumes that there is a direct relationship between teacher education and student success (Hein, 1996). However, even when professional development is excellent, there may be many other factors affecting student performance. Changes in local administration, for example, may be a primary influence on student test results. Better teaching may not outweigh other factors, such as increased poverty, administrative turnover, shifts in curriculum priorities, or natural disasters that close schools, any one of which can negatively influence assessment results.

Similarly, student assessment used to measure the effectiveness of district programs assumes that the assessments being used are aligned with the programs being implemented. Many current large-scale assessments only require that students respond to prompts that include all of the required information (Madaus et al., 1992). One major change in making assessments more appropriate for inquiry science is to include questions that require that students "supply" information, such as explanations, long answers, drawings, and all performance tests, in contrast to traditional multiple-choice or true-or-false test questions for which students "select" correct answers (Madaus, Raczek, and Clarke, 1997). Forms of assessment that require students to supply information can, at least in principle, assess complex chains of ideas and skills, as well as recall of specific knowledge. Questions that only require the supply of information usually assess specific knowledge in small, discreet units. But although most reform efforts require students to use materials, as well as to think and reason about the natural world, performance assessment is still a minor part of most large-scale testing and is not included in many state efforts.

Assessment Challenges

Because inquiry science places a number of demands on assessment processes, and because there are limited resources available to deal with these demands, there are many challenges to creating satisfactory systems for assessing inquiry science, and especially to modifying existing practices. Usually, however, a reasonable middle ground can be found between conflicting tensions, as described below.

1. Large-scale assessment requires significant standardization, while individual student inquiry must involve some novelty. The practical problems of creating assessments that are appropriate for all students, and yet allow each to fully demonstrate what he or she knows, can be solved given sufficient resources. This is demonstrated by the acceptance of performance assessment in similar situations, such as in group sports, in the performing arts, or in various practical tasks—for example, when a swimmer demonstrates life-saving skills. In these fields, applicants are usually required to complete a standardized task but are allowed some individual variation within a permissible range.

2. Assessing inquiry science requires that teachers document their students' physical skills, such as the ability to observe, measure, and design experiments. Yet, although many science standards refer to the skills that a student needs to do inquiry, there is little empirical evidence about how these skills develop with age. Careful observation is an important skill in science. But, for example, how should we expect a first grader's observations of animal locomotion to differ from a sixth grader's descriptions of the same phenomena? What is a competent measurement for a 6-year-old, and how does this differ from what can be expected from a 9-year-old? We need more research describing the physical and mental capabilities of children of different ages before valid, age-appropriate assessments of science skills can be implemented.

3. Assessment and administrative monitoring usually involves a single test, given at a specific time, and with some ceremony. This process provides a "snapshot" of what a student can do at that time and under those circumstances. Academic test performance, with its attendant test anxiety, may not be the most appropriate measure of student achievement, since society is usually interested in how pupils will perform under "normal" circumstances instead. Some balance between summative judgments made from the accumulation of continuous records, in contrast to judgments from more stressful testing situations, needs to be reached.

4. "Teaching to the test" has a negative connotation among many educators. But when assessment tasks closely mirror what qualified students should be able to do in a particular domain, then instruction and curriculum are closely aligned and teaching to the test is appropriate. In the assessment of inquiry, it is often considered a good idea for the teacher to share criteria for assessment with students, making the whole process open and transparent. To what extent does instruction encourage students to practice what will be assessed? Teachers who have shared assessment criteria with students, or involved students in developing assessment criteria, often report not only increased interest from students, but also improvement in their work.

Conclusion

Assessing inquiry science at the national level is still in its infancy, but over time, teachers have developed a large body of practical experience that can form the basis for good classroom assessments. While school reform efforts are improving education for all children, continuing attention to assessment will help us better understand what children have or have not mastered during their education. As more schools implement inquiry science, we will build a firmer experience base of what it means to do science in classrooms, contributing to the national effort to develop valid, appropriate tests. A growing body of methods is available to assess inquiry science, primarily based on performance assessments. Classroom teachers can develop ways to understand what their students know and can do, and they can utilize this growing body of materials to document student growth.

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CHAPTER 13

End Paper: The Value of Knowing What You Do Not Know

by Mark St. John
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How does inquiry affect us every day? Asking questions, and then pursuing our interests to extend our awareness of the world around us, is the essence of lifelong learning. This essay challenges us to examine the limits of our knowledge, and step beyond the boundaries of the known.

The word inquiry comes from the Latin words *in*, or "inward," and *quirer*, which is the verb "to question." So inquiry is not just asking questions, it is questioning *into* something. Inquiry entails the perception of depth. It has the quality of penetrating into something, going deeper, so you can see what you haven't been able to see before.

When you begin an inquiry, you are deliberately setting out to search for what you don't know. You have to have the confidence—perhaps even the arrogance—to say that you might be able to figure it out for yourself. And in that process, you get a sense of real excitement and energy. That energy is both part of, and contributes to, what we often call "engagement." But in order to use inquiry to answer your question, you have to become good at knowing what you don't know. I would argue that that's exactly the opposite of what happens in schools. Classrooms focus on what you do know (or are supposed to know) and leave you unprepared to deal with the things you don't know.

In some ways, we are all surrounded by a bubble of the known. When you "know" something, you identify how your model of the world fits with, and explains, what you see. Living in the bubble of the known is comfortable and comforting. You see what you know, and you know what you see. But to do inquiry, you have to get good at always looking for the boundaries of your knowledge, and at the limitations and contradictions within what is known. That is what scientists do. They are always looking for the limits, the boundaries, the points at which their theories fail to explain the world. Scientists, in essence, are always looking for that "door" from the known to the unknown, where they can press forth and push and, in a sense, expand the bubble of the known. Inquiry is the action you take when you deliberately challenge the limits of your knowledge.

To do an inquiry well, you have to know what to focus on, and how to address what you don't understand. You have to be able to continually discern what the next step should be as you push into the limits of what you know. You have to know what is likely to be productive inquiry, and what is not. That's the real art, and it is an art we almost never teach to children. How do you learn to expand your knowledge? You have to be able to recognize what you don't know, and become fearless in going beyond that boundary.

In his book *The Year of the Greylag Goose*, for example, zoologist Konrad Lorenz says:

> *Whenever I sit for a couple of hours on the gravel bank… with my flock of geese, or in front of my aquarium with tropical fish at home… the time rarely goes by without my observing something unexpected. I never have an explanation at hand for these novel observations. Rather, they lead me on to new questions which require further observations and, very frequently also, experimental investigation….*

Lorenz is looking for that moment of incongruity, the moment when what he sees and what he knows don't match up. Primatologist Jane Goodall once talked about a similar experience. After closely watching the same family of chimps over several days she complains, "I see nothing." What she means is: "I see what I understand, and what I understand is what I see. They are doing things that make sense to me." But unlike a good student in school, she is not satisfied by this experience. She says, "I am not here to see what I know; I am here to see what I don't know."

The process of science is very much one in which you put your thinking on the line, watch an event or phenomenon, and then match the two—pressing and probing until you find the place where there's a contradiction, or where you encounter something you cannot understand or explain. This process of "looking for trouble" is not something we often value in the classroom. Children are rarely taught that there is anything useful to be gained in examining what you do not know. Yet, for children, this is the essence of how they might learn to find things out for themselves, and thereby become authors of their own knowledge.

Excerpted from the Catherine Moloney Memorial Lecture given April 25, 1998, at New York's City College Workshop Center.

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APPENDIX

Major Contributors
Recommended Resources

Major Contributors

Doris Ash is a science educator at the Exploratorium, a museum of science, art, and perception in San Francisco, California. Dr. Ash has a background in biology, teaching, and research in learning and learning environments. She has done research with the Fostering a Community of Learners (FCL) project at the University of California, Berkeley, gender research in Oakland, California, and worked on teacher professional development at the Institute for Inquiry. She has an M.S. and B.S. in Biology from Cornell University and a Ph.D. in Science Education from U.C. Berkeley.

Dennis Bartels is director of the Center for Teaching and Learning at the Exploratorium in San Francisco, California. Before joining the Exploratorium, Dr. Bartels was principal investigator and project director of the NSF South Carolina Statewide Systemic Initiative and directed the development of the State Curriculum Frameworks there. He is a graduate of the University of North Carolina and received his Ph.D. in Education Administration and Policy Analysis from Stanford University. He was recently appointed chair to the State Advisory Committee of the California Science Project and serves on several committees, advisory boards, and review panels for the National Science Foundation.

Peter Dow has a background in teaching, business, curriculum design, and teacher professional development. He currently serves as principal investigator of TEAM 2000, an NSF Local Systemic Change (LSC) project that is a collaboration between the Buffalo Public Schools and Buffalo State College. He is employed by the Research Foundation of the College and is President of First Hand Learning, Inc., a nonprofit corporation he co-founded in 1998 to develop materials and programs that support inquiry-based learning and to foster partnerships between cultural institutions and schools. Dr. Dow recently served on the Committee on Science Education K–12 of the National Research Council, where he chaired the subcommittee that developed the Inquiry Addendum to the National Science Education Standards. He is the author of *Schoolhouse Politics: Lessons from the Sputnik Era* and holds A.B., A.M.T., and Ed.D. degrees from Harvard University.

Hubert M. Dyasi is professor of Science Education and director of New York's City College Workshop Center, a science teacher development institution. Dr. Dyasi has been a co-principal investigator in the New York State Systemic Initiative on K–8th grade mathematics, science, and technology education. He served as a member of the working group on teaching standards for the *National Science Education Standards,* and is now helping to develop an addendum to the Science as Inquiry Standard. In 1995, the NSF National Institute for Science Education at the University of Wisconsin-Madison selected Professor Dyasi as one of its first fellows.

Wynne Harlen has been director of the Scottish Council for Research in Education since 1990 and was previously professor of Science Education at the University of Liverpool. She began her professional life as a teacher and college lecturer in science and has been engaged in curriculum development, research, and assessment in science for over 30 years. She worked on the Assessment of Performance Unit's monitoring of science for 7 years. Her research into students' learning has given her particular interest in using assessment to improve teaching and learning. She has published 19 books and contributed to 30 others.

George E. Hein, professor emeritus, taught and worked at Lesley College in Cambridge, Massachusetts, for over 20 years, where he was founding director of the college's Ph.D. program. He has developed comprehensive, qualitative evaluation systems for mathematics and science education programs. He founded the Program Evaluation Research Group (PERG) at Lesley College in 1976 to evaluate the educational work of Boston-area museums and arts organizations. He served as both secretary and chair of ICOM/CECA, the international association for museum educators. In 1999, he was an Osher Fellow at the Exploratorium.

Barry Kluger-Bell has worked as a physicist, college-level physics teacher, science teacher educator, and program director. He earned a Ph.D. in physics from the University of Colorado, Boulder. He has worked as teacher/physicist at the Exploratorium since 1988. In this position, Dr. Kluger-Bell has served as science resource teacher, planned and led workshops, and developed curriculum and professional development materials. He has also worked in classrooms with elementary teachers and children. Dr. Kluger-Bell currently serves as assistant director for science at the Exploratorium Institute for Inquiry.

Sabra Lee has an undergraduate degree in biology and a master's degree from Tufts University in education with a strong background in mathematics and the arts. She has worked in mathematics and science education at TERC and Lesley College for more than 20 years. Her experience includes educational program evaluation, curriculum and resource development, documentation, and workshops for educators, teachers, and parents. She currently works primarily in elementary school mathematics and science education, designing and carrying out program evaluations and creating professional development and curriculum materials. She is lead evaluator for two NSF Local Systemic Change (LSC) projects, as well as for other mathematics and science projects. She has written about active science assessment as well as mathematics professional development.

Lynn Rankin is director of the NSF Exploratorium Institute for Inquiry, a professional development program for elementary educators that develops partnerships with school districts and serves as advisors to local and national science education reform efforts. With a degree in education from the University of Arizona and a background as a classroom teacher and curriculum developer, she is currently serving on a committee of specialists developing the addendum to the *National Science Education Standards* on scientific inquiry, and a committee sponsored by the NSF National Institute for Science Education at the University of Wisconsin-Madison to examine effective professional development strategies for science education.

Mark St. John is the founder and president of Inverness Research Associates, a small firm specializing in evaluation, policy analysis, and technical assistance. For the past decade, Dr. St. John and his associates have studied a wide variety of investments in educational reform, including major professional development efforts, curriculum development projects, assessment reforms, and larger systemic change initiatives. Over the past 5 years, he has been involved in national studies of NSF's science education projects and the national Eisenhower program. He is currently involved as an evaluator and provider of technical assistance to the NSF's Statewide Systemic Initiatives.

Karen Worth has been a member of the Wheelock College faculty for over 25 years, where she teaches early childhood and elementary education at the graduate level, directs grant programs in science education, and works as advisor and technical assistant with the Boston Public Schools. She served as chair of the working group on teaching standards for the *National Science Education Standards*. She also is a senior scientist at Education Development Center, Inc., in Newton, Massachusetts, where she was principal investigator for the development of the NSF-supported Insights Elementary Science Curriculum and currently serves as co-director of the NSF Center for Urban Science Education Reform, which provides technical assistance and resources to 22 urban school districts. She works as a consultant and advisor to many urban systemic reform efforts and science education programs nationwide.

RECOMMENDED RESOURCES

Books

Doris, E. (1991). *Doing what scientists do: Children learn to investigate their world.* Portsmouth, NH: Heinemann.

Driver, R. (1983). *The pupil as scientist?* Buckingham, England: Open University Press.

Driver, R., Guesne, E., and Tiberghien, A. (eds.) (1985). *Children's ideas in science.* Buckingham, England: Open University Press.

Drummond, M.J. (1994). *Learning to see: Assessment through observation.* Ontario: Pembroke Publishers.

Duckworth, E. (1987). *"The having of wonderful ideas" and other essays on teaching and learning.* New York: Teachers College Press.

Gallas, K. (1995). *Talking their way into science: Hearing children's questions and theories, responding with curricula.* New York: Teachers College Press.

Harlen, W. (1996). *The teaching of science in primary schools,* 2d ed. London: David Fulton Publishers Ltd.

Harlen, W., and Jelly, S. (1989). *Developing science in the primary classroom*. Essex, England: Addison Wesley Longman Ltd.

Hein, G.E., and Price, S. (1994). *Active assessment for active science: A guide for elementary school teachers.* Portsmouth, NH: Heinemann.

James, M. (1998). *Using assessment for school improvement.* Oxford: Heinemann.

Layman, J.W., Ochoa, G., and Heikkinen, H. (1996). *Inquiry and learning: Realizing science standards in the classroom*. New York: College Entrance Examination Board.

National Research Council. (1999). *Inquiry and the national science education standards: A guide for teaching and learning.* Washington, DC: National Academy Press.

National Research Council. (1996). *National science education standards.* Washington, DC: National Academy Press.

Osborne, R., and Freyberg, P. (1985). *Learning in science: The implications of children's science.* Auckland, NZ: Heinemann.

Saul, W., and Reardon, J. (eds.) (1996). *Beyond the science kit: Inquiry in action*. Portsmouth, NH: Heinemann.

Shapiro, B.L. (1994). *What children bring to light: A constructivist perspective on children's learning in science.* New York: Teachers College Press.

Short, K.G., et al. (1996). *Learning together through inquiry: From Columbus to integrated curriculum*. York, ME: Stenhouse Publishers.

Whitin, P., and Whitin, D.J. (1997). *Inquiry at the window.* Portsmouth, NH: Heinemann.

Videos

National Gardening Association. *Windows on the classroom*. Four-part series. Burlington, VT.

Rosebery, A., and Warren, B. (1996). *Sense making in science.* Three-part series. Westport, CT: Heinemann.

WGBH Educational Programming. (1999). *Science K–6: Investigating classrooms*. Twelve-part video with supporting print publications. Boston, MA.

WNET. (1997). *Just think: Problem solving through inquiry*. Six-part series. Albany, NY: Office of Educational Television and Public Broadcasting.

Zubrowski, B., and Education Development Center, Inc. *Learning to see: Observing children's inquiry in science.* Westport, CT: Heinemann.

Web Sites

American Association for the Advancement of Science/Benchmarks for Science Literacy:
http://project2061.aaas.org/tools/benchol/bolframe.html

Exploratorium Institute for Inquiry:
http://www.exploratorium.edu/IFI/index.html

National Science Education Standards:
http://www.nap.edu/readingroom/books/nses

National Science Foundation:
http://www.nsf.gov