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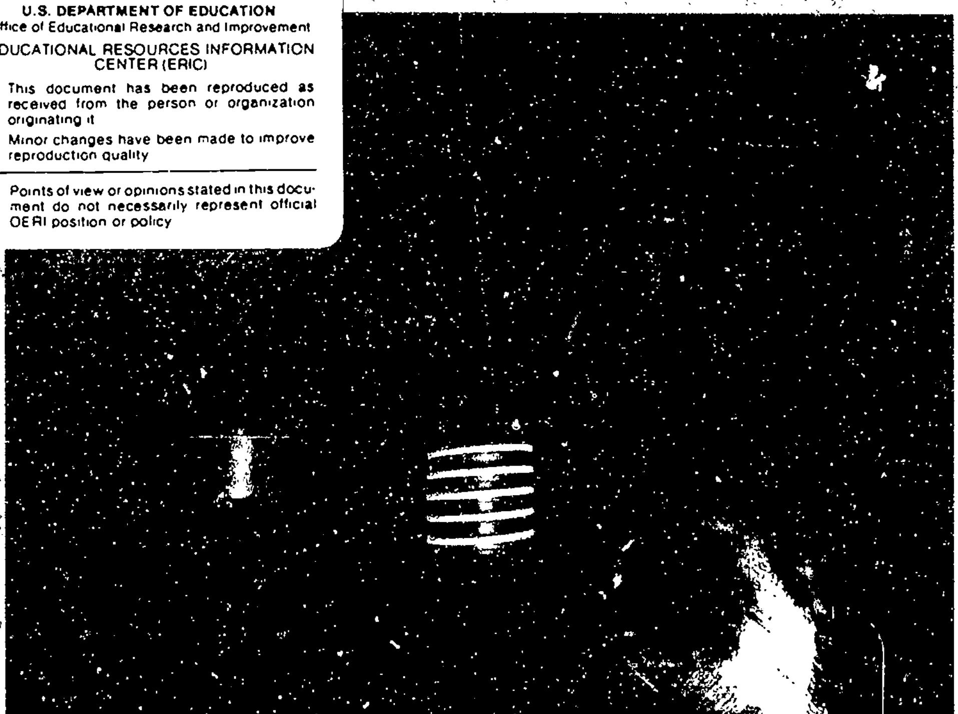
ABSTRACT

This book presents answers to frequently asked questions about hands-on approaches to science teaching and learning. The questions were formulated by speaking with teachers and teacher educators. Variations of the questions are frequently asked by both experienced and novice teachers. A wide range of answers are presented in a triangulated approach. The first perspective for each question is the teacher's response, the second perspective, the responses of hands-on science developers, and the third perspective comes from a review of the literature in science education that incorporates findings, conclusions, assertions, and recommendations that seem to respond in spirit to the questions posed. The chapters in this book include: (1) What is hands-on learning, and is it just a fad? (2) What are the benefits of hands-on learning? How do I justify a hands-on approach? (3) How does a hands-on science approach fit into a textbook-centered science program? (4) How can practicing teachers gain experience with hands-on methods? (5) Where do I find resources to develop hands-on activities? (6) How is hands-on learning evaluated? (7) What are some strategies for helping students work in groups? (8) How does or should the use of hands-on materials vary with age? (9) Hands-on science can be expensive. How do I get materials and equipment? and (10) Where do you keep materials and equipment once you get them? Three appendixes include: (1) a list of acronyms; (2) an annotated bibliography of selected materials that support an activity-based approach to science teaching (curriculum guides, supplementary materials, program frameworks, and planning resources); and (3) an ERIC Digest "Assessing Student Performance in Science." (Contains more than 125 references.) (PR)

Perspectives of Hands-On Science Teaching



David L. Haury and Peter Rillero
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Perspectives of Hands-On Science Teaching

Perspectives of Hands-On Science Teaching

David L. Haury
Peter Rillero

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To the memory of

Patricia E. Blosser

Long-time associate at the ERIC Clearinghouse for Science,
Mathematics, and Environmental Education,
Believer in active learning, and
Friend of science teachers everywhere.

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Preface

This book presents answers to frequently asked questions about hands-on approaches to science teaching and learning. The questions were formulated by speaking with teachers and people who work with teachers on a regular basis to improve classroom practice. Variations of the questions are frequently asked by both experienced and novice teachers.

In an attempt to represent a wide range of perspectives in answering the questions, we have used a "triangulated" approach that incorporates the response of teachers, curriculum developers, and other scholars who have produced the professional literature in science education. Teachers—from their direct experiences and education—have a great deal of practical classroom wisdom, so it seemed natural for experienced teachers to provide the first "angle" to the triangle by writing answers to specific questions about hands-on science. For the second angle, answers to specific questions were also solicited from developers of hands-on materials. The third approach to answering the questions involved reviewing the existing professional literature in science education and selecting findings, conclusions, assertions, and recommendations that seem to respond in spirit to the questions posed.

This compilation of questions and answers is intended as a resource for teachers, supervisors, administrators, parents, educational researchers, and curriculum specialists who are attempting to foster improved science teaching and learning. Think of this as a "briefing document," a summary of information that will help hands-on advocates focus on the key issues and provide sufficient background to get practitioners started down a path of instructional reform. This is not a resource book of activities or instructional guidelines, nor does this document provide a curriculum framework. It is intended as a ready reference for anyone who has to make the case for an activity-based, inquiry-oriented, hands-on approach to teaching and learning in the science classroom.

Please note, the entries identified throughout this book as "Teacher Responses" and "Developer Thoughts" are direct quotes. Because the sections consist entirely of quotations, we have omitted quotation marks. Any modifications we have made to quotations are indicated with square brackets [like this].

The authors view this work as the beginning of a professional dialog that will lead to revised editions of this document and a heightened awareness of the issues associated with hands-on approaches to science teaching. Readers are invited to participate in the dialog by submitting their answers to the questions posed here or by suggesting additional questions that need answering. We will carefully consider each submission for inclusion in the next edition of this publication, to be developed and released as funding becomes available. All contributions will be appropriately acknowledged. *DLH & PR*

Acknowledgments

Many people contributed to the development of this document; some offered written or oral responses to the questions we asked, and others suggested questions to ask, people to contact, and materials to review. We have not included in this document every question or answer that we received, but we read them all and tried to capture the full range of perspectives and ideas submitted. However, we did not consolidate answers. We chose to let contributors present their ideas in their own words, so you will find individuals identified along with their remarks in the pages that follow. Our thanks to each of them for their help, in some cases on very short notice.

Some very helpful individuals are not identified in the pages that follow, so we would like to acknowledge their help here. Dr. Norman Lederman at Oregon State University helped us identify practitioners in the Northwest, Dr. Anita Greenwood at the University of Massachusetts Lowell helped us identify practitioners in the Northeast, Betsy Feldkamp at The Ohio State University helped us identify practitioners in the Midwest, and Dr. Carole Kubota at the University of Washington helped us formulate several of the questions posed in the pages that follow. Each of these individuals is associated with programs that emphasize hands-on approaches to learning, and they have worked with many teachers to promote professional growth in science teaching. Their voices of experience were invaluable to our work, and we thank them for their help. Finally, Linda A. Milbourne at the ERIC Clearinghouse for Science, Mathematics, and Environmental Education provided the final copyediting of the manuscript, saving us from many grammatical embarrassments. Thanks, Linda, for your attention to detail.

Thanks, too, to everyone who contributes to the cause as a result of reading this document. Please notice that this work is not protected by copyright, so you may make as many copies as you wish in your efforts to improve science teaching. Let us know how you do, and remember to share the insights that you gain as you attempt change in your spheres of influence. *DLH & PR.*

Introduction

Just as an artist expands our limits of perceiving, good teachers expand our limits of knowing and understanding. Both artists and teachers inspire us to see more and wonder what other attractions might be lurking just beyond our view. Vivid images of my favorite science teacher of 20 years ago periodically refresh my remembrance of his view-extending ways.

One learning episode that often comes to mind involved a field trip to nearby mud flats along a coastal estuary. Being fond of clams, or eating clams I should say, I knew that a mud flat was not devoid of life, but it was not a place I would choose to go to "look around." What of interest, besides clams, could possibly live in such a place, and why would anyone want to deliberately investigate a place where the odors and the mud seem to have a life of their own, just waiting for unsuspecting victims?

We were studying respiration at the time and had learned several interesting laboratory techniques for determining respiration rates and estimating the volume of oxygen being respired for a given biomass. It all seemed very understandable in the controlled, aseptic conditions of the laboratory.

But as we were standing in the middle of the mud flats, the teacher asked, "How much oxygen is being respired by organisms of these mud flats?" With a dramatic sweep of the hand, he had us all wondering whether he had taken too many walks in that odiferous wasteland. It soon became obvious to us, though, that he was in full charge of his faculties and we were operating on the very edge of our understanding. So, he asked more questions. Less expansive questions near the horizon of our understanding that guided us toward a strategy for answering the larger question. "What organisms might be living in the mud?" "How many of each kind are here?" "How large are they?" "How could we find out?"

Thus began our hands-on lesson on population sampling with hula hoops, application of physiological principles learned in the laboratory, and learning how to learn. From that day on I have enjoyed the sweet aroma of mud flats and the thrill of investigating on my own. The shift in perspective was triggered by a process that any teacher can employ: inquiry-oriented, activity-based, hands-on learning.

As the nation pursues the goal of becoming first in the world in science achievement among students (U.S. Department of Education, 1991), many are advocating an instructional approach that emphasizes activities and learning by doing. Many pushing for reform of science teaching say, "Young people can learn most readily about things that are tangible and directly accessible to their senses....With experience, they grow in their ability to understand abstract concepts, manipulate symbols, reason logically, and generalize" (Rutherford & Ahlgren, 1990, p. 186). Almost all the national reports on the conditions of teaching and learning in schools call for, "More active learning for students and less passivity; more hands-on, direct opportunities to 'make meaning'" (Schmieder & Michael-Dyer, 1991). In classrooms where students are encouraged to *make meaning*, they are generally involved in "developing and restructuring [their] knowledge schemes through experiences with phenomena, through exploratory talk and teacher intervention" (Driver, 1989). Indeed, research findings indicate that, "students are likely to begin to understand the natural world if they work directly with natural phenomena, using their senses to observe and using instruments to extend the power of their senses" (National Science Board, 1991, p. 27).

Instructional approaches that involve activity and direct experiences with natural phenomena have become collectively known as *hands-on science*, which we have defined as any educational experience that actively involves students in manipulating objects. Unfortunately, the use of hands-on activities is far less frequent than lecture and discussion (Weiss, 1987). Most American schools offer traditional instruction in science, with relatively few schools tailoring curricula for a hands-on approach (Howe, Blosser, Helgeson, & Warren, 1990). In a national longitudinal study, 41% of the eighth grade students were reported to be in classrooms where experiments were seldom conducted (National Science Board, 1991, p. 27). The findings perhaps reflect teachers' uncertainty, discomfort, lack of resources, or limited backgrounds with experiential approaches to science teaching, coupled with a cultivated dependency on textbooks (Morey, 1990). According to data from a 1987/88 Schools and Staffing Survey, "fewer than half of all middle school teachers of biological sciences and only about one-fifth of teachers of physical sciences felt they were teaching the subject for which they were best qualified" (National Science Board, 1991, p. 31). In short, teachers have questions and concerns about science teaching and their own teaching assignments, and many seem reluctant to engage students in "hands-on" learning.

In the pages that follow, we present ten questions that teachers frequently ask about hands-on teaching and learning, and we provide three different types of answers to each question, representing the perspectives of classroom teachers, curriculum developers, and educational researchers and theorists. The questions have come directly from teachers themselves and teacher educators, people who work regularly with classroom teachers and know the questions they ask. In an attempt to be direct and clear, we have presented the answers as discrete responses, with no attempt to force consensus or an internally consistent message. Rather, you will hear individual voices representing the broad range of teachers and specialists in science education. Responses from the research literature are necessarily abbreviated, but full citations are provided for each informational *nugget*. Please note that the questions are arranged in what seems like a logical sequence to the authors; they are not arranged according to any ranking or weighting process based on level of concern or priority.

Questions and Answers

1. *What is hands-on learning, and is it just a fad?*

Hands-on learning has become a common phrase in science education. Like many other highly used terms and phrases, there are various interpretations of what is meant by "hands-on learning." Rather than attempt to offer a definitive operational definition, we present in this section a variety of viewpoints on what is meant by hands-on learning in science. Then we address the issues of whether hands-on learning is a new phenomenon and whether hands-on approaches will continue to have a continual impact on science teaching and learning in schools.

Teacher Responses

Hands-on learning is learning by doing. To even imply that it is a fad is to ignore what has been taking place in education, both formal and informal, for years. Vocational education has always understood that if you want someone to learn to repair an automobile, you need an automobile to repair. If you want to teach someone to cook, you put them in a kitchen. Whoever heard of teaching someone to swim in a traditional classroom? Likewise, I do believe we are learning that in order to truly teach science, we must "do" science.
Jeff G. Brodie, fifth and sixth grade teacher, East Side Elementary, Edinburgh, IN

Hands-on learning involves the child in a total learning experience which enhances the child's ability to think critically. The child must plan a process to test a hypothesis, put the process into motion using various hands-on materials, see the process to completion, and then be able to explain the attained results.

Hands-on learning is not just a fad because it enables students to become critical thinkers, able to apply not only *what* they have learned, but more importantly, the *process of learning*, to various life situations.
Sister Judith Mary Frederick, fifth grade teacher, St. Mary's Elementary School, Sandusky, OH

Developer Thoughts

Hands-on learning means many different things to different people. It has become a slogan and is often used to describe any activities in

classrooms that use materials. As a slogan, it can easily become a fad. Hands-on learning, however, is not simply manipulating things. It is engaging in in-depth investigations with objects, materials, phenomena, and ideas and drawing meaning and understanding from those experiences. Other terms for this are inquiry learning, hands-on, and minds-on learning.
Karen Worth, Education Development Center Inc., Newton, MA

The importance of student investigation of basic scientific principles cannot be overstated. Hands-on learning is the only way students can directly observe and understand science. As students develop effective techniques for observing and testing everything around them, they learn the *what*, *how*, *when*, and *why*, of things with which they interact. These experiences are necessary if the youngsters of today are to remain "turned-on" to science and become scientifically literate.
Mathew Bacon, Delta Education (publisher of SCIS 3, Delta Science Modules, ESS, OBIS), Hudson, NH

There is no doubt that there is more emphasis on hands-on materials than in the recent past. That does not mean, however, that the hands-on science activity ever passed away. Furthermore, good science programs cannot exist without hands-on; I do not think it will ever pass away. I do think that we must continue to emphasize the necessity of hands-on in science curriculum, and I truly hope we can keep the hands-on component at a high level.
Jerald A. Tunheim, Project SMILE (Science Manipulatives in the Learning Environment), Dakota State University, Madison, SD

A hands-on approach requires students to become active participants instead of passive learners who listen to lectures or watch films. Laboratory and field activities are traditional methods of giving students hands-on experiences. With the advent of classroom technology, students can now participate in a non-traditional form of hands-on education through the use of computers. This technology extends hands-on learning to include minds-on skills. An example of this hands-on/minds-on learning is the unique MarsLink curriculum project which provides data to students from the Mars Observer spacecraft. This partnership brings near "real-time" science to hands-on learning.
Carol J. Stadum, The Planetary Society (producers of Marslink teaching packets), Pasadena, CA

Programs that are fun and clearly result in developing the curiosity, competency, creativity and caring of learners must, by definition, represent appropriate educational practices. The value of such programs does not change, no matter when or what they are called.
Julie Gantcher, Bronx Zoo Education Department, producers of Pablo Python Looks at Animals, Bronx, NY

Notes from the literature

"*Hands-on activities* mean students have objects (both living and inanimate) directly available for investigation" (Meinhard, 1992, p. 2).

James Rutherford director of the science reform initiative, Project 2061, describes his view of hands-on science. "Hands-on quite literally means having students 'manipulate' the things they are studying—plants, rocks, insects, water, magnetic fields—and 'handle' scientific instruments—rulers, balances, test tubes, thermometers, microscopes, telescopes, cameras, meters, calculators. In a more general sense, it seems to mean learning by experience" (1993, p. 5).

"There are two ways that we find the term hands-on science in common use today. The first, uses hands-on science to refer to a general approach to instruction. Hands-on science can be thought of as a philosophy guiding when and how to use the broad range of teaching strategies needed to address diversity in contemporary classrooms.... The second way hands-on science is commonly used is in terms of a specific instructional strategy where students are actively engaged in manipulating materials, using called a hands-on science activity" (Flick, 1993, pp. 1-2).

Other terms for hands-on activities are materials-centered activities, manipulative activities, and practical activities (Doran, 1990). According to Hein (1987), materials-centered science is synonymous with hands-on science and activity-centered science. The term hands-on is also related to the use of manipulative materials. Elementary school mathematics teachers have long been interested in the use of manipulatives to provide concrete learning experiences (Ross & Kurtz, 1993). The Thesaurus of ERIC Descriptors defines manipulative materials as "instructional materials that are designed to be touched or handled by students and which develop their muscles, perceptual skills, psychomotor skills, etc." (U.S. Department of Education, 1990, p. 249).

"The concept of hands-on science is predicated on the belief that a science program for elementary children should be based on the method children instinctively employ to make sense of the world around them. Science must be experienced to be understood. These experiences should allow students to be actively engaged in the manipulation of everyday objects and materials from the real world. Children are by nature observers and explorers, and the most effective approach to learning should capitalize on these intrinsic abilities" (Shaply & Luttrell, 1993, p. 1).

"Hands-on science is defined as any science lab activity that allows the student to handle, manipulate or observe a scientific process" (Lumpe & Oliver, 1991, p. 345). Hands-on teaching can be differentiated from lectures and demonstrations by the central criterion that students interact with materials to make observations, but the approach involves more than mere activity. The assumption is that direct experiences with natural phenomena will provoke curiosity and thinking, so, "recently, a new twist has been added, and the topic is called Hands-on/Minds-on science" (Lumpe & Oliver, 1991).

"Teachers are now seeking to understand what students are learning as a result of busy hands. This need is being expressed through the introduction of new terms such as *minds-on* and *heads-on* science" (Flick, 1993, p. 1).

"The one metaphor that has become a password for good science teaching is that science teaching should be *hands-on*. In recent years, however, this metaphor has been enriched and expanded with the use of the phrase 'minds on science'" (Hassard, 1992, p. 8). Despite the simplicity and logic of using this approach, research indicates that the recitation (discussion) is the most common method of teaching science (Hassard, 1992).

Inquiry-oriented instruction is related to hands-on learning; however, these terms are not synonymous (Haury, 1993b). Welch would have agreed with this assessment. In the Project Synthesis report Welch states the following: "Instruction in inquiry classrooms reflects a variety of methods—discussions, investigation laboratories, student-initiated inquiries, lectures, debates. . . . Science content and processes are inseparable. 'How do we know?' enters many conversations. Individuals, small groups, or the entire class move easily from discussion to laboratory or other 'hands-on' activities." (Welch, 1981, p. 56).

Karen Worth, chair of the teaching standards committee of the National Science Education Standards Project defines hands-on activities as follows: "Students work directly with materials and manipulate physical objects to physically engage in experiencing science phenomena" (from Bruder, 1993, p. 23). Worth defines inquiry or discovery learning as follows: "Involves the thinking, reading, writing, or research that gives meaning to hands-on. Students probe, collect, and analyze data; draw conclusions; and ask new questions" (Bruder, 1993, p. 23). Worth defines project-based learning as follows: "Provides a real-life context for science learning. Students have hands-on experiences with water, for instance, probing its properties, then do a project (often with peers) to find out how water comes into and leaves the school building."

Hands-on learning can be thought of as comprising three different dimensions: the inquiry dimension, the structure dimension, and the experimental dimension. In inquiry learning, the student uses activities to make discoveries. The structure dimension refers to the amount of guidance given to the student. If each step is detailed, this is known as a cookbook style lab. These types of activities do not increase a student's problem-solving abilities. The third dimension is the experimental dimension which involves the aspect of proving a discovery, usually through the use of a controlled experiment (Lumpe & Oliver, 1991).

Museums devoted to science are increasingly using a hands-on approach. "The Exploratorium is a hands-on museum of science, art, and human perception in San Francisco. It's been called a scientific funhouse, a giant experimental laboratory, even a mad scientist's penny arcade" (Doherty, 1992a, p. 2).

The historical roots of hands-on science teaching

Science education in elementary schools first existed as selections contained in the eighteenth and nineteenth century children's didactic literature (Craig, 1957; Underhill, 1941).

By the middle of the nineteenth century, approximately 20% of the pages of the most popular introductory reading textbooks were devoted to science selections (Rillero & Rudolph, 1992). For many students, this was the only science education they received.

Nineteenth century American schools had bleak learning conditions. "Teaching was by rote and drill. Encouragement was by the rod. Obedience (to God, parent and teacher) was the foundation rock for the mansion of learning" (Withers, 1963, p. vii).
Pestalozzi extended Enlightenment ideas into education by having students learn from experiences and observation rather than from the authority of the textbook and the teacher (Elkind, 1987; Rillero, 1993). "After the experts in getting knowledge discovered that it was far more profitable to examine real things and observe how they did work than merely to speculate and argue about them, and that it was unsafe to trust the authority of any man's opinion without testing it by its accordance with facts in nature, the experts in education also began to advocate teaching by direct study of things and experimental verification of opinions" (Thorndike, 1920, p. 176).

Pestalozzi's ideas of using objects for teaching were spread in America in the 1860s. The Object Teaching Revolution occurred as a direct result of teacher education (Rillero, 1993). This movement challenged the dominance of the textbook in education and promoted active learning by students. The evolution of methodologies used in science education including science activities, field trips, and school science collections were influenced by object teaching (Rillero, 1993).

The Committee of Ten (National Education Association, 1893) was instrumental in securing a permanent place for science in the American school curriculum. The science committees repeatedly stressed the importance of object manipulation by students. The Physics, Chemistry and Astronomy Committee recommended "That the study of simple natural phenomena be introduced into the elementary schools and that this study, so far as practicable, be pursued by means of experiments carried on by the pupil" (National Education Association, 1893, p. 118). They added, "The study of books is well enough and undoubtedly important, but the study of things and of phenomena by direct contact must not be neglected" (National Education Association, 1893, p. 119).

The Natural History Committee of the Committee of Ten concurred on the importance of direct concrete experience. They resolved that "the study of natural history in both the elementary school and the high school should be by direct observational study with the specimens in the hands of each pupil, and that in the work below the high school no text-book should be used" (National Education Association, 1893, p. 141).

From object teaching and the stress on student activity, the project method of learning came into existence. McMurray in 1921 wrote "It is a truism of our educational creed that sensory impressions based on object lessons and motor response form the primary basis of thought in dealing with the later materials of knowledge. The project conceived and executed by the child on the ground of his own experience is a still better basis of our educational efforts because it sets up in children self-determination and purposeful activity in a complete, natural and well-rounded unit of effort" (p. 3). McMurray lists 37 student projects that could be done in connection with school and home gardens. Other projects include "concreting a basement floor; papering and decorating a family living room, building a tree house, making a tool chest, supplying the kitchen with running water, building and hanging a gate, constructing a corn crib, planning and laying a tile for drainage" (p. 20). McMurray sums up the use of projects in elementary school science as follows: "It is in these very projects, objective and directly practical in the bearings, that children are best able to see the meaning and value of modern science in its influence upon life. What children in elementary schools need is not abstract scientific principles, not the systematic study of any or all the sciences (an impossible thing), but simple, objective, convincing demonstrations of the main ideas and uses of science in the home and neighborhood and in the larger world beyond. What could be better for children than to allow them to see these tangible projects developing and working out their proper, practical influence upon the conditions of life that surround them? These are preeminently needful and instructive topics that should be given the right of way in the elementary curriculum" (1921, p. 8).

John Dewey "emphasized the same ideas about learning through activity and child-centered instruction advocated during the eighteenth and nineteenth century by Pestalozzi and Froebel.... The most representative feature of Dewey's philosophy of education was his recommendation of the project method of learning described by various followers as a purposive, problem-solving activity carried on in its natural setting" (Smith, 1979, p. 187).

"In more recent times, almost all the major science curriculum developments of the 1960s and early 1970s promoted hands-on practical work as an enjoyable and effective form of learning" (Hodson, 1990). "Since the curricula innovations of the 1960s, the emphasis in laboratory activities has been providing students with hands-on experiences" (Tobin, 1990, p. 407).

"During the late 1950s and the early 1960s considerable interest focused on what should be taught and how it should be taught. During the middle to late 1950s textbooks were used by most teachers as the principal tool for teaching science.... The feeling was that if science for elementary schools was to be improved there should be more care and emphasis on the selection of content (facts, concepts, principles), reduction of the way content was taught (sequence, articulation, examples, etc.), more emphasis on processes of science, more 'hands on' science instead of reading about science, and use of a greater variety of media and materials for teaching science" (Helgeson, Blosser, & Howe, 1977, p. 17).

"Imitating the work of the scientists in investigating the natural world, usually in the laboratory, is found in all the new curricula. Whether it is called inquiry, scientific process, or problem-solving, each curricula group espoused the virtues of "hands-on" experiences to gain greater insights into the basic concepts of science" (Welch, 1979). These curriculum projects were tested and revised and provide a major impetus for current hands-on learning initiatives.

In 1978, McAnarney wrote "during the last 10-15 years there has been an increased emphasis on the development of elementary school science programs which stress a hands-on experience to teaching and learning. The programs, many of the national curriculum project type, made their appearance during the 1960s and the early 1970s. Within the past three or four years so-called 'second-generation' programs, to distinguish from the 'first generation' ones of the 1960s have emerged" (p. 31).

"The term hands-on is so widely used that it is hard to believe that it is something of a newcomer. It first surfaced in the late 1960s meaning to learn how to use a computer by actually using one—hands-on the keyboard, as it were. Although the computer people coined the term, the idea of learning by doing is an ancient one in the arts and crafts, and it has become a mark of good teaching in science and math" (Rutherford, 1993, p. 5).

Hands-on learning is an important aspect of the current constructivist epistemologies that suggest that people construct their own understandings of the world. "Exemplary science learning is promoted by both hands-on and minds-on instructional techniques—the foundations of constructivist learning" (Loucks-Horsley, et al. 1990, p. 48).

"After a quarter of a century, the familiar phrase hands-on science is now a part of the everyday discussion of elementary science. Teachers, administrators, publishers, and trade books all refer to the importance of hands-on activities in science instruction. This is nothing short of a revolution. Descriptions of science education at all precollege levels have shifted from vocabulary and text material to activities, inventions, and even project-based Olympics" (Flick, 1993, p. 1).

Summary

There are a variety of ideas about what constitutes hands-on learning. We have compiled views from teachers, curriculum developers, and other writers to arrive at a general notion of hands-on learning in science which encompasses its use in school classrooms, museums, and other learning environments. From the collected responses and writings, we have come to consider hands-on learning in science to be any educational experience that *actively* involves people in manipulating objects to gain knowledge or understanding.

An emphasis on actively involving students in learning has influenced American schools since the 1860s. However, the term *hands-on* learning seems to have emerged during the 1960s and may eventually fall into disuse. However, the activity-based approach to learning implicit in the phrase has long been important in science education and will likely continue to be held in high esteem by science educators who hold a constructivist view of learning.

2. ***What are the benefits of hands-on learning? How do I justify a hands-on approach?***

Teachers who embrace hands-on learning in science seem to recognize certain desirable outcomes and endorse student-centered instructional approaches. Research has confirmed many of the seemingly intuitive benefits of hands-on learning and has also documented a variety of unanticipated benefits. But what effects of hands-on learning are seen by advocates as most important or valuable?

Teacher Responses

Students in a hands-on science program will remember the material better, feel a sense of accomplishment when the task is completed, and be able to transfer that experience easier to other learning situations. When more than one method of learning is accessed as in hands-on learning, the information has a better chance of being stored in the memory for useful retrieval. Students who have difficulty in the learning arena for reasons of ESL barriers, auditory deficiencies, or behavioral interference can be found to be on task more often because they are *part of* the learning process and not just spectators.

Justifying why I would use hands-on science is based on all the research and methods studies that are current. They support the notion of multi-faceted bombardment of information and experiences so that the retention level is improved. Students who are involved in labs and activities are empowered in their own learning process.
Mary Wieser, French Prairie Middle School, Woodburn, OR

The benefits of hands-on-learning in my school revolves around those children who are either not as academically "talented" or have not shown "interest" in school. This method tends to stimulate these type [of] students into participating and eventually absorbing information that I believe they would not get from "normal" *show-me—tell-me* methods.
Mary Hougland, seventh and eighth grade teacher, Clearview School, Lorain, OH

The single most important benefit to me is that although it requires a great deal of preparation time, once a system is developed, hands-on teaching makes teaching fun. If the kids are learning and having fun doing it, then I am having fun at my job, and I am a happier person overall.
Jeff G. Brodie, fifth and sixth grade teacher, East Side Elementary, Edinburgh, IN

Developer Thoughts

I hear and I forget
I see and I remember
I do and I understand

Chinese Proverb

Although these words may not be the exact translation, they underscore the need for a hands-on approach to science teaching. Without this approach students must rely on memory and abstract thought, two methods which restrict learning in most students. By actually doing and experiencing science, students develop their critical thinking skills as well as discover scientific concepts. This self discovery stays with students throughout their lifetimes while memory fades.
Carol J. Stadum, The Planetary Society (producers of Marslink teaching packets), Pasadena, CA

If students are not doing hands-on science, they are not doing science. Science is a process and if students are not actively engaged in the process, they are not doing science. Most science classes in elementary school teach the vocabulary of science and nothing else.

Study after study has shown the value of hands-on learning. Students are motivated, they learn more, even their reading skills improve. How can you justify not doing hands-on science?
Edwin, J.C. Sobey, National Invention Center, Akron, OH

Learning by well-planned activities and experiences in a well engineered program is a quality instructional approach. It:

- causes students to rely on the evidence instead of upon authority (encyclopedia, minister, doctor, text, teacher, parent). Most students live in an authoritarian world with little or no opportunity to practice decision-making because nearly everyone tells students what to do and when to do it. We continually graduate students who do not yet have the ability to set up a simple experiment with controlled variables, collect and interpret evidence, or make correct interpretations based upon that evidence.
- provides students with a similar set of experiences so everyone can participate in discussions on a level playing field regardless of their socio-economic status. In this way, special benefits are not awarded to those who, by virtue of their wealth or background, have a greater number of experiences under their belts.
- forces student thinking by requiring interpretation of the observed events, rather than memorization of correct responses.
- messages the learner that they, as well as the instructor, can interpret data, and that various interpretations are possible and often probable. When a text or teacher tells students that plants need light to grow (an untruth) students simply memorize this without question and are hampered by the falsehood for a lifetime. However, when a student personally germinates seeds in the dark and finds that they grow taller than seeds grown in the light, it has irrefutable evidence from a personal experience that plants do not need light to grow. Because he now has evidence that light inhibits growth (which it does) he now has a chance of figuring out why plants in a house grow toward the light (cell growth of the lighted side of the stem is repressed while the unlighted side grows more, thus causing the stem to grow in such a manner as to aim the upper part of the plant toward the light which is necessary for growth after the stored food energy is used up.) This information seldom comes from K-6 texts or teachers, yet is a logical interpretation by 10 year old students *if they conduct the experiments*. It:

- encourages questioning of the observed events and the resulting data. When students carry out their own experiments, they become very familiar with the events and the variables involved.
- promotes cause and effect thinking.
- reduces dependence upon authority. Practical experiences in generating hypotheses and planning experiments now, will make the students more independent later when they no longer have authorities standing by at every turn of their lives.

Robert C. Knott, Ed.D. Science Curriculum Improvement Study 3, University of California, Berkeley

The importance of providing children with direct experiences with materials, objects, and phenomena is supported by experience and understanding of how learning takes place. While information can be remembered if taught through books and lectures, true understanding and the ability to use knowledge in new situations requires learning in which children study concepts in-depth, and over time and learning that is founded in direct experience. Therefore, the justification for hands-on learning is that it allows students to build understanding that is functional and to develop the ability to inquire themselves, in other words, to become independent learners.

Karen Worth, Education Development Center, Inc. (Developers of Insights: A 1), Newton, MA

Notes from the literature

"Hands-on and learning by experience are powerful ideas, and we know that engaging students actively and thoughtfully in their studies pays off in better learning (Rutherford, 1993, p. 5).

Recipe for a Science Lesson

Option 1: Find a puddle and photograph it. Show the photograph to a seven-year-old child. Have her read about puddles. Later, ask her to talk about the puddle.

Option 2: Find a puddle. Add one seven-year-old child. Mix thoroughly. Stomp, splash, and swish. Float leaves on it. Drop pebbles into it and count the ripples. Measure the depth, width, and length of it. Test the pH. Look at a drop under a microscope. Measure 250 mL of puddle water and boil it until the water is gone. Examine what is left in the container. Estimate how long it will take for 250 mL of puddle water to evaporate. Time it. Chart it. Now ask the child to talk about the puddle.

If you were a seven-year-old child, what option would stimulate you to talk about the puddle? That's what hands-on science is all about—allowing students to experience science fully" (Donivan, 1993, p. 29).

Piaget stressed the importance of learning by doing, especially in science. According to Piaget, "a sufficient experimental training was believed to have been provided as long as the student had been introduced to the results of past experiments or had been allowed to watch demonstration experiments conducted by his teacher, as though it were possible to sit in rows on a wharf and learn to swim merely by watching grown-up swimmers in the water. It is true that this form of instruction by lecture and demonstration has often been supplemented by laboratory work by the students, but the repetition of past experiments is still a long way from being the best way of exciting the spirit of invention, and even of training students in the necessity for checking for verification" (1986, p. 705).

"Piaget's research clearly mandates that the learning environment should be rich in physical experiences. Involvement, he states, is the key to intellectual development, and for the elementary school child this includes direct physical manipulation of objects" (McAnarney, 1978, p. 33).

Bruner also stressed learning by doing. "The school boy learning physics is a physicist, and it is easier for him to learn physics behaving like a physicist than doing something else" (Bruner, 1960, p. 14). Bruner states, "Of only one thing I am convinced. I have never seen anybody improve in the art and technique of inquiry by any means other than engaging in inquiry" (1961, p. 31). Bruner points out the quick rate of change in our world and says, "the principal emphasis in education should be placed on skills—skills in handling, in seeing, and imaging, and in symbolic operations" (Bruner, 1983, p. 138).

A hands-on approach is also advocated by some people who advocate a constructivist approach to science teaching. "Learning is defined as the construction of knowledge as sensory data are given meaning in terms of prior knowledge. Learning always is an interpretive process and always involves construction of knowledge.... Constructivism implies that students require opportunities to experience what they are to learn in a direct way and time to think and make sense of what they are learning. Laboratory activities appeal as a way of allowing students to learn with understanding and, at the same time, engage in a process of constructing knowledge by doing science" (Tobin, 1990, p. 404-405).

Educational research has shown many advantages of using hands-on science programs. Bredderman (1982) reports the results of a meta-analysis of 15 years of research on activity-based science programs. This synthesis of research was based on approximately 57 studies involving 13, 000 students in 1, 000 classrooms. All of the studies involved comparing activity-based programs (the Elementary Science Study, Science–A Process Approach, or the Science Curriculum Improvement Study) with comparable classrooms using a traditional or textbook approach to science teaching. A variety of student performance measures were analyzed. The most dramatic differences were found in science process skills where the students in activity-based programs performed 20 percentile units higher than the comparison groups. The students in these programs scored higher than the control groups in the following measures (ranked from largest to smallest differences): creativity, attitude, perception, logic development, language development, science content, and mathematics. Students who were disadvantaged economically or academically gained the most from the activity-based programs.

Hands-on learning has been shown to increase learning and achievement in science content (Bredderman, 1982; Brooks, 1988; Mattheis & Nakayama, 1988; Saunders & Shepardson, 1984).

Research indicates that activity-based science can improve students' attitudes toward science (Jaus, 1977; Kyle, Bonnstetter, Gadsden, & Shymansky, 1988; Kyle, Bonnstetter, McCloskey, & Fults, 1985; Rowland, 1990). "There seems to be some evidence from exemplary programs that even poorly taught hands-on science is more interesting to students than the typical textbook based program" (Penick & Yager, 1993, p. 5).

Evidence clearly indicates that hands-on activities increase skill proficiency in processes of science, especially laboratory skills and specific science process skills, such as graphing and interpreting data (Mattheis & Nakayama, 1988).

Hands-on learning in science has been shown to help in the development of language (Bredderman, 1982; Huff, 1971; Quinn & Kessler, 1976) and reading (Bredderman, 1982; Morgan, Rachelson, & Lloyd, 1977; Willman, 1978). Morgan, Rachelson, and Lloyd (1977) concluded from their study that "sciencing activities can make a positive contribution to the acquisition of reading skills of first grade students. These activities can provide the concrete experiences from which many reading skills are derived" (p. 143).

- Participation in science inquiry lessons facilitated development of both classification and oral communication skills of bilingual Mexican-American third grade students (Rodriguez & Bethel, 1983).

- From their analysis of educational research, Barufaldi and Swift (1977) concluded that, "a definite trend emerges that science experience enhances reading readiness skills and oral communication skills among children" (p. 392).

- Activity-centered classrooms encourage student creativity in problem solving, promote student independence, and help low ability students overcome initial handicaps (Shymansky & Penick, 1981).

- "Seen only as a laundry list of theorems in a workbook, science can be a bore. But as a 'hands-on' adventure guided by a knowledgeable teacher, it can sweep children up in the excitement of discovery. Taught by the regular classroom teacher, it can illustrate the point that science is for everyone—not just scientists" (William J. Bennett (as U.S. Secretary of Education), 1986, p. 27).

Summary

There are a plethora of benefits that teachers and curriculum developers adduce to hands-on learning to justify the approach in science. Benefits for students are believed to include increased learning; increased motivation to learn; increased enjoyment of learning; increased skill proficiency, including communication skills; increased independent thinking and decision making based on direct evidence and experiences; and increased perception and creativity. Research supports many of these claims by providing evidence that the learning of various skills, science content, and mathematics are enhanced through hands-on science programs. Students in activity-based programs have exhibited increases in creativity, positive attitudes toward science, perception, logic development, communication skills, and reading readiness. These benefits seem more than sufficient justification for promoting hands-on learning. However, Jeff Brodie provided an important addition—it makes science fun for both the student and teacher. Given the recent concerns about science anxiety and avoidance, enjoyment of science learning seems a worthy goal to be considered in choosing instructional approaches in science.

3. *How does a hands-on science approach fit into a textbook-centered science program?*

Many schools and advocates of hands-on learning seek to do away with textbooks or downplay their value, particularly in the elementary grades. The forces for keeping textbooks are undoubtedly strong; the dominance of the textbook in defining the curriculum has marked American education since its inception. Some schools have decided to keep textbooks and use hands-on science activities to supplement a text-based approach to teaching science. The following responses address the issue of how teachers can use hands-on activities along with a textbook in science teaching and learning.

Teacher Responses

The science textbook serves as a springboard for instruction and learning in my sixth grade classroom. Hands-on learning activities are used to reinforce and extend what my students have read in the text and what they have learned through class discussions. To foster curiosity and create motivation I might introduce a new unit by using a hands-on learning activity. At the completion of a chapter or unit these activities are useful in helping students establish the relationship of concepts and synthesize their knowledge. The teaching of lab skills, problem-solving strategies and group learning skills can be easily incorporated into the learning activity.

Hands-on learning activities offer opportunities for active participation and concrete learning experiences which support the learning styles of early adolescents. The enthusiasm for lab days in my classroom has a positive effect on the attitudes my students have for science. The ability for me to interact with individual students during the hands-on learning activity enhances my effectiveness as a teacher. I feel using the textbook in conjunction with the hands-on learning approach provides a successful learning environment in my classroom.
Lynn Reid, 6th grade science teacher, Sells Middle School, Dublin, OH

Hands-on science may allow a child to network many possibilities, while the text can anchor an experiment in theory or provide a reference for a different strand of thought. At the start of a unit, an activity related to the topic in the text acts as a catalyst setting the mind and the body into the inquiry mode.
Linda Lash, Grade 5 Classroom Teacher, Butler School, Lowell, MA

Science textbooks (including workbooks) are basically worthless unless they are used in conjunction with hands-on activities. Teachers who use only textbooks often wonder why their students lack the motivation to learn, as well as why their students often have difficulty learning facts for chapter tests. Teachers who provide appropriate materials for children to interact within the discovery process find

their students have a much higher level of both motivation and understanding.
Lou Ann Anderson, The Ohio State University Lima branch, Lima,OH

Developer Thoughts

Hands-on science activities should be used in at least three different ways if used in conjunction with a textbook program. Firstly, materials should be supplied to students before they begin a new topic. Students should be given the opportunity to explore freely activities and materials to generate interest and prompt questions related to the topic. Secondly, hands-on activities should be used to enable students to observe directly phenomena that are presented in their textbooks. Finally, students should be given an opportunity to design new experiments based on the knowledge they have acquired. Furthermore, separate hands-on units can be developed, or existing hands-on science programs purchased, to complement a textbook-centered program.
Mathew Bacon, Delta Education (publisher of SCIS 3, Delta Science Modules, ESS, OBIS), Hudson, NH

A major issue here, and perhaps the most important issue, is not about the compatibility of hands-on- and textbook-centered curricula; but the compatibility of resources with teachers' paradigms, especially student- and subject-centered paradigms, which guild the establishment of learning environments. Contemporary education is structured primarily from a history of valuing subject-centered, transmission of knowledge approaches. As a result textbooks are the dominant learning resources and hands-on science curricula have often been used to do textbook science, only with materials. This simply does not produce significant results in learning.

When we value and incorporate student-centered, constructivist perspectives into our thinking, a larger understanding of what learning should be about emerges; and also a better understanding of the different and unique roles of hand-on materials and textbooks in learning. If a teacher's learning paradigms are constructivist and student-centered, a hands-on curricula will be one important element for learning. Other resources will take on new meanings such as textbooks becoming sources for interesting ideas and reference, rather than words to be memorized. Hands-on curricula will be used to put students more in control of their learning by encouraging individual student inquiry into a thinking about relevant phenomena. This can lead to students more effectively incorporating new ideas into their existing knowledge. Additionally learning resources will be utilized to help remove teachers from transfer of information approaches to becoming effective "learning coaches" for creative and critical thinking. This can reduce the often felt teacher's need to impose specific thoughts and ways of thinking on students. The results should be to better help students' thinking grow in very unique ways, often with very unexpected, yet profound, results.

Thus, since the teacher is the most significant influence for establishing the classroom learning environment, I believe that ultimately, the compatibility of resources for learning will be controlled by the compatibility of resources with the learning paradigms of the individual teacher. To most effectively utilize resources, teachers must continually evaluate and grow their paradigms for learning based on experience as reflective practitioners and review of current learning research. They should recognize that their values enable reform of teaching practice. Are your primary values textbook-centered, subject-centered, material-centered, teacher-centered, student-centered, or what?
Bill Schmitt, Content Director, Galaxy Classroom, Los Angeles, CA

Hands-on science, when defined as inquiry, cannot easily fit into a textbook-centered science program. At best, textbook programs incorporate some activities with materials as supplements to or illustrations of material covered in a particular chapter. These activities tend to be very directed, "cookbook" in nature, and children do them to confirm what they've been told, not inquire into the materials or phenomena. Textbooks also cover a great deal of content, leaving little time for in-depth hands-on experiences.

Fundamentally, textbook programs and hands-on programs represent very different beliefs about how children learn, what is important to learn, and how learning should take place in the classrooms. They are, therefore, incompatible as programs.

There are, however, ways in which texts can be used in a hands-on program. Textbook material, if accurate, can serve as reference for students. Having engaged in a hands-on study, chapters in a textbook may be useful to read as summaries. At times, given time constraints, a hands-on program might include (along with a series of in-depth studies) brief reading on a topic that can't be studied in depth or for which a hands-on approach is not possible.

As students become older—middle and high school level—texts can play a larger role. However, they must be balanced with significant

inquiry, laboratory experience and the use of a wide array of resources must become less encyclopedic and deeper in what they include, and must be written from a conceptual perspective rather than an informational one.
Karen Worth, Education Development Center, Inc. (Developers of Insights: A1), Newton, MA

The text exists to provide background information for use before and after hands-on activities .... The good teacher seeks out activities to complement the text and more fully illustrate the concepts, to give local examples of the big picture, and to keep students interested in the subject. Text teaching is easy, organized, and disciplined, with predictable results (boredom and test anxiety). Teaching with hands-on activities is demanding, hectic, noisy, and sometimes unpredictable, but everyone is involved, eager, and active, and participants remember what they have done. Activities energize, localize, and dramatize science. I never saw a textbook do that.
Rosanne W. Fortner, The Ohio State University School of Natural Resources, producer of Ohio Sea Grant Education materials and Project JASON curriculum activities

The SWOOPE (Students Watching Over Our Planet Earth) Program is based on the discovery and exploration approach to learning. Students take measurements on the environment and send data to a database. Textbooks can be used for reference along with other materials.
Dianne K. Hyer and Roger C. Eckhardt, Students Watching Over Our Planet (SWOOPE), Los Alamos National Laboratory

Notes from the literature

Over 80% of first through sixth grade elementary teachers from a national sample reported using hands-on instruction in their classrooms. Ninety percent of teachers in grades 4, 5, and 6 reported using a textbook for science instruction. For grades 1 to 3 the average approximate percentage of teachers who used a textbook ranged from 45 to 79 (Teters & Gabel, 1984). Clearly there is a large percentage of teachers who use a textbook and a hands-on approach together.

Science instruction in grades 6-8 have been strongly influenced by the high school textbook approach (Padilla, 1981). However, "traditional textbook science programs must not be the only source of classroom learning. For a good balance between structure and flexibility, reading and doing, discussing and experimenting, teachers must identify appropriate activities and integrate them into the textbook"

(Padilla, 1981, p. 38). Teachers should list the objectives of a unit and look for activities that correspond to the content and objectives. If there are no activities or very few for a particular unit, Padilla advises that the teacher should question the appropriateness of the unit for middle/junior high school students.

A textbook-centered program can be augmented with a hands-on component to integrate *right brain* and *left brain* functioning in improving achievement and attitude (Hider & Rice, 1986).

Lack of time to teach hands-on science is a frequently mentioned obstacle (Morey, 1990; Tilgner, 1990). This is compounded by the tendency for teachers to want to "cover the textbook." According to a district science supervisor, "In all elementary schools, once you buy a text, it doesn't matter what the state or the district says" about what is actually required; teachers try to cover the entire book (Martens, 1992, p. 154). To create time for hands-on instruction it is important for teachers to decide the major concepts to be taught and use hands-on activities to help achieve these goals.

Penick and Yager (1993) observed that exemplary elementary school science programs, almost without exception, "have developed their own curricula, usually based on ESS materials or the Science Curriculum Improvement Study (SCIS). In almost all instances, textbooks were not in a central position. Teachers saw the locally developed curriculum as more appropriate cognitively, relevant, responsive, and reliable. In fact, many teachers spoke of textbooks as 'supplementing the curriculum.' When asked, 'What would cause your program to fail?', the most common answer was, 'adopting a textbook for science.' This doesn't mean they use no printed materials. Instead, they either wrote their own or used carefully selected portions of commercial materials" (p. 4-5).

Stefanich (1992) sees a trend to increase the use of textbooks. "There is a growing concern on the part of some educators and citizens that knowledge objectives have been deemphasized too much. As a result, the trend is toward more content through utilization of textbook-based materials. Elementary teachers appreciate the clarity of content and convenience for yearly planning afforded by the scope and sequence outlines offered in the textbook series. They feel greater confidence that students are acquiring a core of essential knowledge and appreciate the clarity of content and convenience for yearly planning afforded by the scope and sequence outlines offered in the textbook series" (p. 14).

In order to adopt more of a hands-on approach, teachers need to be free of influences that promote the exclusive use of the textbook. "If a school district is promoting hands-on science but has always required the use of a textbook, textbook use must become optional so that participants do not face contradictions between what they are being asked to do and school district policies. In addition, teachers must not be held accountable for test score results during the change from traditional to hands-on science. Scores are likely to fall during the transition period" (Foster & Dirks, 1993, p. 15).

"Most school districts simply adopt a textbook series, provide three and a half hours of inservice education, and call the result a science program. Needless to say, this strategy does not serve the best interests of our nation or provide the best education for our children. Science educators should not assume that a textbook series or a packaged program will be the solution to their school district's needs. Rather, textbooks and other programs must serve as points at which to begin the process of developing science programs" (Orlich, 1983, p. 10).

Textbooks may be improving their incorporation of hands-on science learning. During the 1970s several publishers produced "hybrid" materials which combined textbooks with aspects of hands-on learning. These hybrid materials were closer in emphasis to the NSF project materials than to textbooks of the 1950s (Helgeson, Blosser, & Howe, 1977). The emphasis on process skill objectives and the resultant materials-centered activities (also called manipulative, practical, or hands-on) were extended with many textbook series and textbook/kit programs. Pratt (1981) prepared the elementary school report in Project Synthesis. He analyzed three groups of textbooks: four popular textbooks that were used by an estimated 22% of elementary classrooms; three texts associated with ESS, SCIS, and SAPA (8% of classrooms); and four "new generation" textbooks. The frequently used textbooks were rated poorly for "First Hand Experience" and "Involved in Data Gathering." The NSF and new generation texts were rated high to good for these categories. From responses to a survey asking how much hands-on materials or models influence their textbook selection, 69% of grades K-2 teachers and 72% of grades 3-5 teachers indicated that this was considered often, considered extensively, or it was the main factor in their textbook selection (Harty, Kloosterman, & Matkin, 1989).

"No other subject area has a set of programs for which student performance is so demonstrably superior to traditional programs. Textbook publishers have borrowed many of the ideas from these investigative curricula [ESS, SAPA, and SCIS], but have not adopted the instructional philosophy that is key to their success" (Atwood & Howard, 1990, p. 858).

In an analysis of science textbooks for junior high/middle school students, Shepardson (1993) found the activities tended to stress lower level skills such as information gathering, remembering, and organizing rather than higher level skills such as classifying, inferring, theorizing, generalizing, hypothesizing, and predicting.

"A hands-on methodology elicits a 'minds-on' response from students. The relevance of the topics, the students' understanding of and interest in science, and reading skills can all be increased with the introduction of tradebooks. Tradebooks are commercially available publications that can be uses as supplements to your classroom text" (Kralina, 1993).

Charron and De Onis (1993) describe the approach of two elementary school teachers, Tess and Maria, in combining reading and science. Tess used a reading strategy with her students that consisted of four steps.

Step One: Students brainstorm and record what the already know about a topic.
Step Two: Students list what they want to learn.
Step Three: Students investigate the topic by reading about it.
Step Four: Students summarize what was learned.

Tess and Maria then decided to adapt the approach for science instruction by adding hands-on activities to the reading activity in step three" (Charron & De Onis, 1993, p. 15). After reviewing the district science framework, they found activities from sourcebooks and Maria's files. The entire unit, incorporating textbook, tradebooks, and hands-on science activities, took two weeks. "The teaching of science in the elementary classroom is sometimes characterized as either 'reading about science' or 'doing science.' Elementary students may benefit most, however, when curricular areas are combined. By gauging what their third graders already know about plant growth and what they would like to explore further, then developing a lesson series that combined reading, discussion, and laboratory activities, Tess and Maria provided their students with an understanding of both plant growth and scientific process that is superior to that acquired from either a textbook or a hands-on activity alone" (Charron & De Onis, 1993, p. 17).

Summary

The cry to "throw the textbooks away" is in part a backlash against the dominating influence of textbooks on science curricula and instruction. However, the textbook has withstood the test of time in conveying basic information, outlasting even the use of chalk and chalkboards. A large percentage of teachers are able to combine hands-on learning and text-based instruction. The responses of teachers presented in this section indicate that hands-on learning and science textbooks need not be incompatible. Textbooks can provide springboards to discussion or instruction, serve as references for students, provide background information, or supply examples and applications of key ideas in science.

It seems critical, however, that the goals of instruction be clear and that learning be based squarely on direct experiences when inquiry is the focus. We hope that textbook publishers and curriculum specialists will consider the importance of providing quality hands-on activities to enrich textbook programs. Even better would be an orientation that views textbooks as useful supplements to hands-on learning, providing information and resources to extend learning beyond what has been constructed from direct experience.

4. *How can practicing teachers gain experience with hands-on methods?*

While the majority of teachers may be supportive of hands-on learning, many are concerned with their limited backgrounds in science (Tilgner, 1990; Symington & Osborne, 1983). A lack of adequate preparation becomes an obstacle to teachers attempting to implement science programs (Morey, 1990). Most teachers report a need for help in learning new teaching methods and obtaining information about instructional materials (Finan, 1990; Koker, 1992). How can the needed knowledge and experience be obtained?

Teacher Responses

Gaining experience with the hands-on approach is critical to feeling comfortable with this teaching strategy. Ideally, this experience would be obtained before exposing students to hands-on lessons. One way I continue to be introduced to hands-on ideas is by annually attending both our statewide science conference and the regional NSTA conference. Having funding provided is great, but even if that can't be secured, it is well worth the expense. A wealth of ideas in the form of workshops and presentations are included and are often presented in such a way that you participate in the activities, thereby gaining that valuable experience. Additional avenues for this experience include summer workshops or classes, peer coaching, and just diving in with your students using the multitude of resources available focusing on hands-on activities.

Jeff Gunn, Cheldelin Middle School, Corvallis, OR

There are several ways teachers can gain experience with the hands-on approach. 1) Watch other teachers in your building who use this method. 2) Talk to teachers who use activities or teach hands-on science. Many times you can get ideas on activities, materials, classroom management and resources that can ease your way into this approach. 3) Find activities that correlate with a concept you are currently teaching. Try the activity and observe the students' reactions and their knowledge of the concept after the activity. 4) Go to workshops and inservice activities that promote the use of hands-on. Cooperative learning workshops would also encourage implementation.
Elizabeth A. Henline, Mt. Orab Elementary, Mt. Orab, OH

Developer Thoughts

It would seem that the answer to this questions is simple: Practicing teachers gain experience with hands-on methods by using hands-on science in their classrooms with their students. A more difficult question is how teachers are prepared to enter into the experience. Their are several answers.

Teachers can prepare themselves to teach hands-on science as individuals—without guidance. Many resources are within the financial reach of teachers and they can gather their own materials and plunge in. This avenue is not the most productive, but can work.

Teachers can prepare themselves to teach hands-on science by participating in courses, institutes, workshops, and projects with other teachers under the guidance of experts in the area of science methods, curriculum, and resources. Such preparation, accompanied by some practical experience teaching science is often the most effective way to gain proficiency with hands-on science in the shortest time.

The most effective way to revolutionize the teaching of science is to involve a complete school staff in the process of curriculum reform so that they have investment in the course of study and support from the other teachers in the school. The staff should make a commitment to hands-on methods and seek the resources and guidance needed to bring the curriculum objectives to reality. The school should provide the teaching materials and the inservice training necessary to implement the program. Periodic staff meetings to share successes and troubleshoot problems should be a regular part of the business of education. A recognition of the fact that a vital science program will require continual inservice and updating is essential. The job is never done — science education is dynamic.
Larry Malone, FOSS Project, Lawrence Hall of Science, Berkeley, CA

You become a quality hands-on, material based, inquiry approach, student-centered teacher by becoming that kind of learner! Roll up your sleeves, dig in, get your hands-on, and allow your childlike curiosity to support your wonder and investigations into things that truly interest you; especially the most common events and things in everyday life. Do *not* let habituation set in! Push yourself to always be searching, testing, open-minded, and a critical thinker. Do not be afraid to invent ideas based on real evidence and have your own unique ways of seeing things. Treat knowledge as tools to continue to grow ever more profound ideas and not as a final answer or as a weapon to squash other's equally profound ideas.

As a teacher, you should strive to value the serious thinking of your students and encourage dialogue to discuss different ways of explaining things. Encourage the growth of ideas by focusing on new learning opportunities presented by each new idea. Finally, invite your students to join you in your learning adventures as active and confident colleagues in learning.
Bill Schmitt, Content Director, Galaxy Classroom, Los Angeles, CA

There are several ways that teachers gain experience with hands-on methods. One way is to attend a short workshop at a convention, such as NSTA, or participate in a summer institution sponsored by a publisher of a hands-on curriculum or by a professional association. Often you can use state Eisenhower funds to support this type of education.

Another method for gaining experience is to identify a variety of hands-on activities. You can gather these activities piecemeal in journal and activity books, or by finding coherent units in published curricula, or soliciting suggestions from other teachers. After identifying some activities that interest you, try them out by yourself and then with students.

A third option is to look for intern or summer job possibilities in hospitals or industrial laboratories. Working side by side with bench scientists provides a very real experience with hands-on methods. Fourth, consider employing a consultant to work with the teachers. This consultant could be a lead teacher in a building or district, a local curriculum developer, a science education professor, or a nationally recognized expert.
Janet Carlson Powell, Senior Staff Associate, BSCS, Colorado Springs, CO

States frequently offer a wide variety of ways for teachers to gain experience in the hands-on approach. Though the following response pertains specifically to Indiana, similar programs are offered in other states.

Regional workshops are conducted throughout Indiana. The majority of higher education institutions conduct inservice training programs. Projects WILD and LEARNING TREE have reached over 20,000 teachers with hands-on workshops. Hoosier Association of Science Teachers, Inc. (HASTI) designs a special block of environmental education each year during their annual conference. The Environmental Education Association of Indiana (EEAI) reaches 200 teachers each year during the annual conference. Regional education service centers also conduct workshops.
Joe Wright, Environmental Science Consultant, Indiana Department of Education

Notes from the literature

In a survey of the members of the National Middle Level Science Teachers Association, the major need identified was the need to develop science teaching techniques (Koker, 1992).

"Hands-on science teaching has been widely promoted through textbooks, activities manuals, methods courses and workshops for inservice teachers; and it is a key component of student-centered instruction. However, this mode of teaching is far from universally employed by teachers; perhaps because it is so different from the type of instruction they experiences in their own school and college science studies" (Prather, 1993, p. 61).

Elementary teachers in the National Science Teachers Association (NSTA) who reported in a survey that packaged science kits and teacher guides would be the most useful approach to improving science instruction (Teters & Gabel, 1984).

The experience that teachers gain from hands-on learning opportunities has important benefits. A hands-on activities course which promoted social interaction lessened student-teachers' science anxiety and increased content knowledge (Hall & McCurdy, 1989).

Videotapes can be an effective way to show teachers appropriate methods for using science kits (Winnett, 1988).

Universities frequently hold preservice and inservice workshops. For example, the University of Miami held summer workshops entitled "Teaching Science With Toys" (Taylor, Williams, Sarquis, & Poth; 1990).

"How does one keep up with new developments in the profession of teaching? Taking college coursework, being active in professional organizations, participating in inservice activities and workshops, serving on committees considering the adoption of new textbooks or developing new curricula, are several of the possible means for maintaining an awareness of new scientific and methodological advances" (Rillero & Roempler, 1993, p. 10). However, one of the most effective methods of continuous growth as a teacher is regular reading of professional journals.

Hands-on science museums may be an effective way for teachers to get experience with hands-on learning (Ault & Herrick, 1991). Doherty (1992a) describes the experiences of the Exploratorium which has been open since 1969. "From the very beginning, these teachers asked us to help them learn the science behind the exhibits. In response, the Exploratorium created two teacher-training programs: the School in the Exploratorium, for elementary school teachers, and the Teacher Institute, for middle and high school teachers. These programs teach science using hands-on discovery—the same method we encourage them to use in teaching science to their students" (p. 2). Ault and Herrick (1991) present another reason to use hands-on science museums to aid in teacher preparation. "The role of informal learning is not just to accomplish objectives of attitude and conceptual change through thoughtful exhibitry, but also to foster practice and success in science teaching and learning within families and social groups. After all, family, museum, and school together share responsibility for the science environment of each child. All parties in this shared responsibility have much to learn, yet only the teacher is pivotal to all three. For this reason we encourage other teacher education programs to explore the integration of exhibit evaluation and teacher preparation in science" (p. 105).

Summary

There are many existing avenues for teachers to learn about and gain experience with hands-on teaching, including workshops, visits to science museums, and other teachers. State, regional and national conferences provide exposure to methods, materials, and a wider community of peers. We agree with Larry Malone that the best way to obtain experience in using hands-on materials is for teachers to start using them in their classrooms with his or her students. The responses of students to hands-on experiences will be infectious, and concerns about materials and instructional strategies will diminish over time. Like everyone else, teachers learn best by getting involved, trying things out, starting out with what is simple and interesting, and continually searching for new ideas, experiences, and resources.

However, paths for teachers to gain experience in specific programs need to be better developed. Administrators need to give teachers time, resources, and encouragement to participate in some of the available programs and prepare classroom activities. Just as an activity-based approach to instruction requires materials, activity-oriented teachers require direct experiences from which to build a personal repertoire of activities and techniques. If we endorse learning through activity for school students, we must also recognize the value of learning through activity among teachers. We all construct meaning from the experiences we have.

5. Where do I find resources to develop hands-on activities?

In terms of time investment, it is often most efficient for teachers to find, tailor, and use existing activities developed by others. In this section we provide perspectives on where teachers can find activities and related resource materials. Every classroom is different, and every teacher has his or her own instructional style, so it is critical to the success of hands-on approaches to learning that each teacher be a *developer* of activities and instructional strategies. A natural feature of hands-on teaching and learning is that no two teaching situations are exactly alike, nor will a given instructional activity often be implemented in exactly the same way in different classrooms.

Teacher Responses

In my own experience, I generate lab activities based upon ideas obtained by four different means. A primary resource for developing hand- on activities has to be textbooks. I have a tendency to stockpile old physical science textbooks and peruse them for ideas on labwork. In a similar vein, the reading of science periodicals and NSTA publications [*Science and Children*, *Science Scope*, and *The Science Teacher*] will also lead to generation of hands-on activities.

A second resource I use to develop hands-on activities is other teachers. Almost all teachers have some original ideas or have read some resource you have not. Failure to tap into the minds of your peers would have to be considered one of the original sins of teaching.

A third means of developing lab activities is the use of currently used activities. I have found far too many lab activities where students only superficially analyze what they have investigated. In rewriting interpretations to include more critical thinking skills, students end up hypothesizing on related questions and topics. Many of these types of questions have led me to design related labs to an original lab.

A fourth resource I use to develop hands-on activities is the students themselves. No matter how long you teach, students will continue to ask questions that you have never been asked before. Since all labwork is based upon finding answers to questions, students may design labs themselves based upon these questions. In many instances we have designed labs in class by collecting data and manipulating variables.
Larry Dutcher, Hixson Middle School, Webster Groves, MO

First I decide a topic I want to teach students. Then I develop an outline and look for activities that will make it interesting to students. I look to NSF curricula such as AIMS, GEMS, TOPS, OBIS, CHEM, CEPUP etc. Books and magazines I have found useful include CESI sour. books, *Science for Children* (a topical index put out by the Smithsonian), and Ranger Rick's *Nature Scope* magazine.

I attend every state and national science convention I can to help [stay] abreast of new developments and curricula. I have many binders of activities collected from CESI make and takes, SEPA Share-A-Thons (Society for Elementary Presidents Awards) and sessions I have attended. The exhibit area also has good ideas to be gotten.

Each summer I have taken part in some NSF institute in our state and out of state. I see these offered in NSF reports or journals. I have attended institutes on Bottle Biology-Fast Plants, Operation Physics, Particles and Prairies at Fermi Lab, Astronomy and Fermi to name a few. NSTA's journal *Science and Children* is an excellent resource. I also use a laser disk program (Windows on Science) for technology purposes. I also inquire into units developed by exampling school districts such as Mesa, AZ and Schaumbery and Henidel IL. It doesn't happen overnight, but gradually you will find your resources adequate to meet your needs to teach exciting science.
Bob Burtch (Presidential Award Nominee, grade 5 teacher), J B Nelson Elementary School, Batavia, IL

Developer Thoughts

Say you want to teach a life science unit organized around the half dozen microscopes purchased from last year's special funding. You consult your TOPS *Ideas* catalog and find a few related lessons on *Light*, but otherwise come up dry. What should you do next?

Because all hands-on activity involves materials, your next step is to pull together anything related to microscopes (even remotely) and place it on a designated table. Go on a nature scavenger hunt with your class. Ask your students to bring small things of interest from home. Add everything that turns up to your table collection. Then ask each student to focus on one particular object. Examine it through a microscope, of course. Write about it. Draw it. Design an activity to teach someone else something new. Swap activities.

This sort of unstructured messing about is not for the uninitiated. It will generate confusion and noise to be sure. But for you veteran teachers skilled at pulling order out of chaos, the results are rewarding. Not only will you foster creativity and problem solving skills, [but] you will also generate a wealth of microscope activities using materials you already have!

You can, of course, mess about with your own table full of materials at home, then bring a collection of more organized activities to school. (As a curriculum developer, this is what I do all the time.) Either way, the same important principle holds: assemble materials first. Creative, inexpensive ideas will follow, more wonderful than you ever thought possible.
Ron Marson, TOPS Learning Systems, Canby, OR

A hands-on approach requires students to become active participants instead of passive learners who listen to lectures or watch films. Laboratory and field activities are traditional methods of giving students hands-on experiences. With the advent of classroom technology students can now participate in a non-traditional form of hands-on education through the use of computers. This technology extends hands-on learning to include minds-on skills. An example of this hands-on/minds-on learning is the unique MarsLink curriculum project which provides data to students from the Mars Observer spacecraft. This program is developed and disseminated by The Planetary Society and Washington University, St. Louis. Monthly packets and daily electronic bulletin board activities are designed for students to interpret and analyze data arriving from the exploration of Mars. Students become partners with Mars Observer scientists as they work with data and images from a new world. This partnership brings near "real-time" science to hands-on learning. With this data students can compare images, features, and interactive systems on the Red Planet with those on Earth. This aspect of real space exploration and comparison brings a powerful hands-on opportunity for students to discover and to understand the formation and evolution of planetary systems.
Carol J. Stadum, The Planetary Society (producers of Marslink teaching packets), Pasadena, CA

Notes from the literature

Identify the four to eight major science topics that you teach at a grade level. Start a filing system of activities based on these major topics (Kotar,1988).

Conferences can be a great source of teacher tested activities. Donivan (1993) describes coming back from a National Science Teachers Association convention: "The six of us returned to school 'bursting' with ideas, enthusiasm, and lesson plans and resources for hands-on science activities. The experience was too good to keep to ourselves, so the principal set a time for us to present a half-day inservice to the rest of the staff" (p. 30).

NASA frequently publishes educational materials that contain ideas for developing hands-on activities. In *Rockets: A teaching guide for an elementary unit on rocketry* (Vogt, 1991), there is factual information on rockets followed by ten hands-on activities utilizing inexpensive materials. Earth's Mysterious Atmosphere. Atlas 1 Teacher's Guide with Activities. For Use with Middle-School Students (NASA, 1992) is designed as a detective story to help the reader appreciate some of the many questions currently studied by scientists around the world regarding changes in the Earth's atmosphere. The science activities and concepts are designed to complement middle school curricula. Space Station Freedom. An Activity Book for Elementary School Students (NASA, 1993) contains activities and illustrations that are meant to be presented to elementary-level school children by a teacher or a parent. The activities subject matter include: the space shuttle, communications, weightlessness, solar energy, hatches and airlocks, and living and working in outer space. These and other NASA publications are available free to educators. Contact: (1) NASA Teacher Resource Center; Mail Stop 8-1; NASA Lewis Research Center; 2100 Brookpark Road; Cleveland, OH 44135; (2) NASA Teacher Resource Laboratory; Mail Code 130-3; NASA Goddard Space Flight Center; Greenbelt, MD 20771; or (3) your nearest regional NASA Teacher Resource Center.

ERIC can also be a great source for activities and ideas. ERIC is short for Educational Resources Information Center, a federally funded system that has developed and maintains the world's largest education-related, bibliographic database. You can search the database for materials in a variety of ways, and most of the materials in the database can be obtained in printed form. For more information, contact a reference librarian or call 1-800-LETERIC. If you have access to the Internet, you can also send an electronic request for assistant directly to the Clearinghouse for Science, Mathematics, and Environmental Education. The electronic mail address is ericse@osu.edu.

Activities can also be developed from studying proven programs. *Promising and Exemplary Programs and Materials in Elementary and Secondary Schools-Science* lists many activity centered programs (Helgeson, Howe, & Blosser; 1990). *Science Education Programs that Work* has compiled a collection of exemplary hands-on programs. These programs include: "Hands-On Elementary Science"; "Life Lab Science Program"; "Starwalk"; "Stones and Bones: A Laboratory Approach to the Study of Biology, Modern Science, and Anthropology"; "Wildlife Inquiry Through Zoo Education (WIZE)"; and "Jeffco Life Science Program" (Sivertsen, 1990). Teachers can read the descriptions of programs and materials and evaluate their appropriateness for their classes. Activities can be modified to meet their students' needs.

Journals for teachers can be an excellent source for ideas and resources in the development of science activities. For example, from an analysis of a sanple of ERIC abstracts Rillero and Roempler (1993) found that in the NSTA publication *Science and Children* 76.5% of its abstracted feature articles discussed science activities.

J. Peter O'Neil, a Wisconsin science teacher, has created a Macintosh-based collection of science activities on *Microsoft Works* and *MacPaint* files that are accessed with *Hypercard* (Bruder, 1993). A CD-ROM version with over 1,000 files of science activities will be released this year.

"A resource book of activities that have been tried and found successful, perhaps modified many times from experience, can be a wonderful thing to have on hand. Good sourcebooks do, in fact, enable most of us in teaching to pinpoint relevant exercises quickly, to challenge individuals or groups of students more engagingly, and offer us useful primary or supplementary learning experiences. Often they provide relief from the constant drain of inner resources, and at other times, good sourcebooks stir our own creative powers to invent, with a particular idea or child in mind" (Pines & Pines, 1981). Pines and Pines go on to say, however, that there are dangers inherent in over-reliance and improper use of sourcebooks. Many valuable sourcebooks and activity guides are available from the National Science Teachers Association and the ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

A particularly useful sourcebook for identifying human resources is the *Sourcebook for Science, Mathematics & Technology Education*, which is revised annually and published by the American Association for the Advancement of Science. The authors say, "We want the

Sourcebook ... to be the first place you look when you need information about science, mathematics, and technology education" (Calinger & Walthall, 1990). The book includes over 2,000 entries regarding specific programs, publications, and organizations, including the coordinators for the Dwight D. Eisenhower Science and Mathematics Education Program.

Guidelines can be used to help new teachers select appropriate activities and to tailor activities to their curricula, students, and situations. Rillero, Brownstein, and Feldkamp-Kemp (1994) provide guidelines for choosing effective activities in their Science Activity Filter (see figure 1). When problems with activities are found they can be modified for a particular group of students or situation.

Martinez and Haertel (1991) researched features of science experiments that made them interesting to seventh grade students. Their sample of students first generated lists of features they thought made science experiments interesting. Then the students sorted the combined class lists into three groups. The factors that create interest grouped into three groups or clusters: cognitive, mastery, and social. In the cognitive cluster were the following factors: you learn more, you discover new things, you do something different, you don't know how it will turn out, you feel challenged, and you see changes in what you are doing. In the mastery cluster are the following items: you get to make things, you can take things apart, you can put things together, and you get to use equipment. In the social cluster were the factors: you can work with a friend and you get to talk about your ideas. Martinez and Haertel advise teachers and curriculum developers to arrange instructional materials and procedures to enhance the components of interest.

Summary

There are many sources of science activities and countless resources that can be used for developing activities. Textbooks do provide activity ideas, but teachers should also see each other as sources of ideas for activities. Many teachers participate in conferences, workshops, institutes, and other events where ideas can be gained and exchanged. The periodicals and publications of the National Science Teachers Association (NSTA) are other places to search for ideas; schools may want to consider subsidizing memberships in NSTA for lead teachers, curriculum specialists, and department chairs in science.

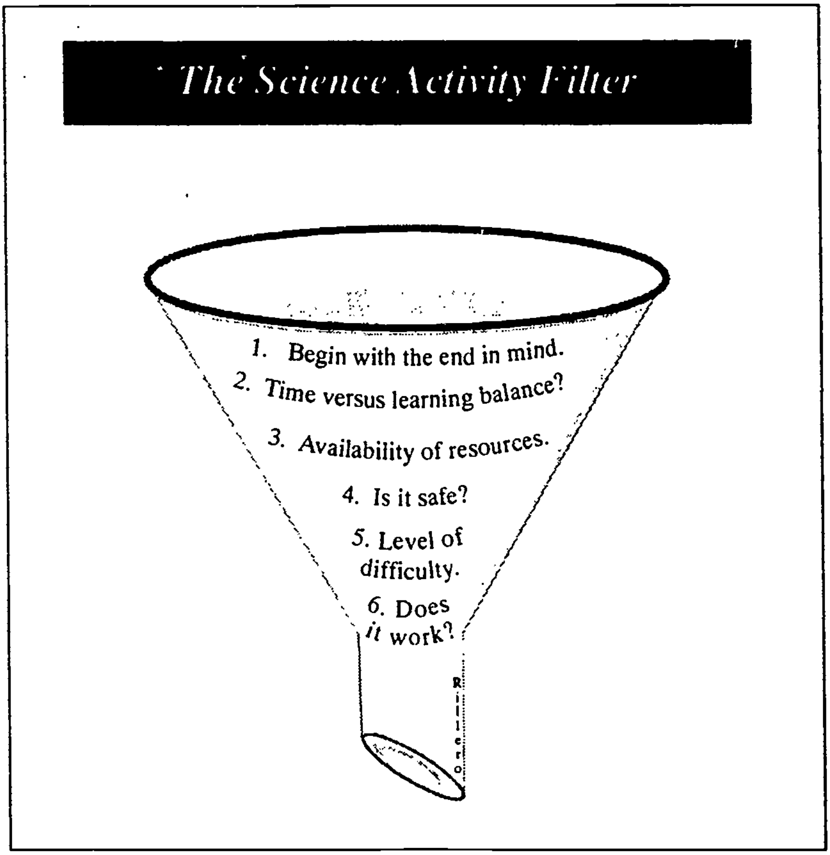


Figure 1. The guidelines of the Science Activity Filter. The order of the guidelines presents a useful protocol for evaluating science activities for potential use in a classroom.

Many sources of activities and resource materials are listed in Appendix B of this guide. Resources such as the ERIC database and other CD-ROM products also greatly facilitate access to information about activities for a wide variety of instructional situations and student populations. Here are four specific places to seek help in locating activities and materials: (a) send an electronic request for help to *askeric@ericir.syr.edu*, (b) send an electronic mail message to *ericse@osu.edu*, (c) connect to the Internet Gopher server at *gopher.ericse.ohio-state.edu*, or (d) dial 1-800-LET-ERIC and have them direct you to additional resources.

In choosing or developing activities, however, the focus should be on specific learning outcomes for specific students. The value of hands-on learning is greatly diminished if there is no sense of purpose in doing a particular activity. In every classroom where hands-on learning occurs, the vital connection is the one between the desired student understanding or set of skills and the experiential base from which meaning is being constructed.

6. *How is hands-on learning evaluated?*

Teachers understand the importance of evaluation and are expressing concerns regarding appropriate practices (Symington & Osborne, 1983). In all modes of instruction evaluation has important roles in efforts to assess student learning, to discover misconceptions among students, and to determine the effectiveness of programs (Doran & Hejaily, 1992). "As classroom teachers, we can praise hands-on experiential science, but until we can demonstrate that students are learning significantly more of the fundamental thinking skills of science, we cannot say that they have truly achieved science literacy" (Tetenbaum, 1992, p.12). Here we offer a variety of views on evaluation and assessment of hands-on learning and teaching.

Teacher Responses

Hands-on learning in my classroom is evaluated by having the students tell me why certain events or situations occurred. If the proper answers are not given, I continue to ask more questions about the experiment and I give them clues as we go to help them figure out the answer .... Then I ask for volunteers to restate in their own words the concepts that we discovered. Finally, I ask questions at random to check one more time if they learned the objectives of the class.
Bertha Vargas, fourth grade teacher, Gertrude M. Bailey International School, Lowell, MA

Hands-on learning in science can be evaluated in two ways. One way is to have the student explain to you or to the whole class the process or experiment they experienced and why it works the way it does. If he or she can explain clearly and confidently what was to be learned, then the teacher can be confident they understand the concept. The other way to evaluate is to give short quizzes or tests to see if they can explain things in a written form.

I feel both oral and written expression are important for evaluating science. They need to be able to orally explain and write what they have learned.
Laura Beyer, third and fourth grade teacher, Cassady Alternative School, Columbus, OH

Developer Thoughts

To determine if a student is able to do science, he or she must engage in performance-based assessments. In this context the student works with materials to answer questions. The assessment must be designed so that the answers cannot be obtained by any other means. The materials used should be familiar to the student, but the context should be fresh. If one is assessing the ability to measure length, the student should be asked to discover the length of an object that he or she has not seen before. A good response on the part of the student would be to select a familiar meter tape and use it properly to measure the length accurately.... To determine if a student is able to communicate adequately a series of questions are asked that require the use of the vocabulary and discussion of the concepts developed in the science activities.

Larry Malone, Full Option Science Program (FOSS) Co-director, Lawrence Hall of Science, Berkeley, CA

Notes from the Literature

"There is considerable evidence to suggest that assessment can focus learning activities in science classrooms. How teachers assess students and what they assess has a major impact on the implemented curriculum. In most instances, test-driven systems result in classroom activities which emphasize rote learning of science facts and rote learning of algorithms to solve exercises similar to those which are included on the test.... In ideal circumstances, an assessment scheme should provide students with opportunities to represent what they know about identified aspects of science. At the classroom level, teachers are encouraged to use a variety of methods to assess student knowledge acquisition. These methods include traditional pencil and paper methods, personal oral interviews, and performance tests. The desirability of using a range of techniques is based on an assumption that much of the knowledge acquired in a hands-on and minds-on science program is tacit and has not been verbalized. Accordingly, although students can apply certain knowledge when they do science, they cannot necessarily reproduce that knowledge in verbal form on a pencil and paper test or in a discussion with the teacher" (Tobin, 1990, p. 411).

The evaluation measures of SAPA, ESS, and SCIS lagged behind the curriculum development and implementation stage. Funds for the completion of the SAPA Science Process Instrument were not available, SCIS primarily focused on conceptual objectives, and ESS made no apparent effort to evaluate specific skills (Doran, 1990).

"The problem of assessment also constrains the spread of 'hands-on' science. It is relatively easy to test children's knowledge when they have been asked to memorize lists of data from a text. It is much harder to design tests that measure learning derived from direct experience.... The challenge before science educators is to develop better means of measuring both factual knowledge and the kinds of understanding students acquire through activities. When that task is accomplished, a major roadblock to science achievement will have been removed" (William J. Bennett (as U.S. Secretary of Education), 1986, p. 28).

"The most widely used method of collecting information on classroom learning is the written, or paper and pencil test. These tests are extremely useful for assessing student achievement on content objectives" (Meng & Doran, 1993, p. 7). Meng and Doran (1993) also present many examples (see figure 2 and figure 3) of standardized exam multiple choice items used to assess science process skills.

"Just as reading about scientific phenomena is not the best or only way to learn science, most educators agree that filling in bubbles on a standardized test is probably not the most effective way to measure a student's potential understanding of science" (Bruder, 1993, p. 23).

"Among the new labels being used toady is performance-based assessment. Though there are a variety of definitions, it is clear that performance-based assessment does not include multiple-choice testing or related paper-and-pencil approaches" (Haury, 1993a, p. 1).

Example of Measurement Item with Diagram

How long is the block of wood shown in the diagram?

A. 10 cm
B. 20 cm
C. 25 cm
D. 30 cm
E. 35 cm

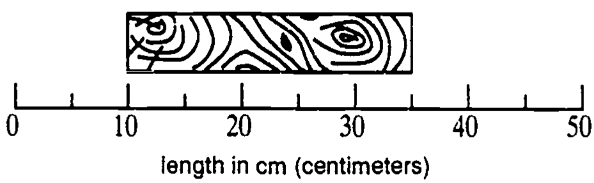
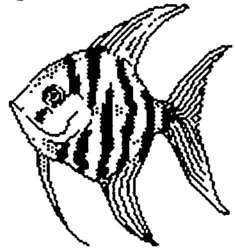


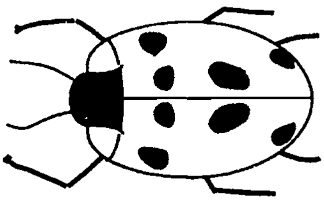
Figure 2. Example of Measurement Item (Item 1)

Identifying Properties of an Object

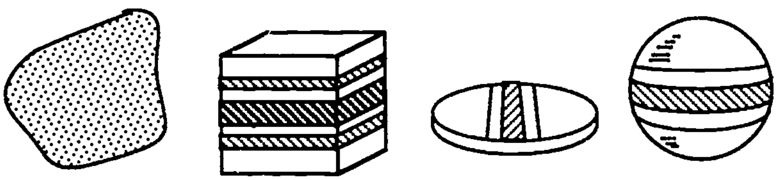
1. Find three properties of this fish.
   A. soft, curvy, spotted
   B. rough, red, hard
   C. soft, slippery, square
   D. soft, curvy, striped



2. Find three properties of this ladybug.
   A. spotted, round, black head
   B. spotted, square, black body
   C. spotted, smooth, has four legs
   D. round, striped, has six legs



3. Find the object that is <u>flat</u>, <u>round</u>, and <u>striped</u>.



A B C D

Figure 3. Identifying Properties of an Object.

"Instructional activities that use concrete manipulatives help teachers address a broad range of conceptual knowledge, scientific and organizing skills, and scientific and personal attitudes. Assessing learning goals across this broad spectrum requires a repertoire of assessment strategies that promote the fit between the dominant intelligences and desired educational outcomes" (Flick, 1993, p. 6).

"At the elementary school level especially, but continuing throughout school and beyond, informal investigation is an important part of 'hands-on' science.... The teacher's evaluation of such activities is also likely to be informal, relying mostly on unobtrusive observations. Teachers may find it useful to observe systematically individual students, small groups, or even the class as a whole. The teacher's observations should be recorded in writing, either immediately or at the end of the day, noting the time, date, and activity. These remarks may be quite brief, even cryptic, but should specify in some way what was seen, not just the teacher's judgment of its quality. If the comments are recorded on index cards, say, they can be filed easily by student name, can serve as a record of progress and attainment to be used in planning further instruction, shared with parents, used in grading, and perhaps even shared with the students themselves" (Haertel, 1991, p. 241).

The majority of teachers (Grades K-2) responding to a survey on the use of New York State's Comprehensive Instructional Management System Science Program report that the observational approach was useful for assessing students' strengths and weaknesses (Guerrero, Eisler, & Wilcken, 1990).

Observational checklists are easy and flexible assessment tools. For instance, to measure a student's ability to draw conclusions the following scoring rubric could be used:

Points	Characteristics
0	Fails to reach a conclusion
1	Draws a conclusion that is not supported by data
2	Draws a conclusion that is supported by data, but fails to show any evidence for the conclusion
3	Draws a conclusion that is supported by data and gives supporting evidence for the conclusion (Nott, Reeve, & Reeve, 1992, p. 45).

Livingston (1992) describes the use of the Science Activity Evaluation Form to measure activity-based science process skills. The Form is derived in part from an analysis of Benjamin Bloom's *Taxonomy of Educational Objectives* and an analysis of middle school science activities. The following potential student behaviors are listed from low-level skills to high-level skills: draw, identify, list, locate, observe, compare, describe, distinguish, outline, state, apply, build, test, analyze, classify, computer, graph, design, infer, interpret, conclude, explain, and hypothesize. Teachers are instructed to write a student name by a skill when they observe it in class. The Science Activity Evaluation Form can be used to evaluate the work of students. It can also be used to identify activities or curricula that only engage students in predominantly low-level skills.

Laboratory practical exams have been used to assess student attainment of science process skills. For individual assessment, each student should perform all the manipulation of equipment and materials to answer questions (Stensvold & Wilson, 1993). "Questions can be administered in a rotation pattern so that one-third of the class does one question while the others do a second and third question. This practice increases the likelihood of individual testing and minimizes the equipment necessary for any one exam activity. Questions need to be planned so that equivalent amount of time is needed for each" (Stensvold & Wilson, 1993, p. 250). An example of an activity station is based on experiences with the ESS unit, Batteries and Bulbs. A sealed box has six metal knobs on top connected by hidden circuits. "From their testing of the box, students collect and interpret their data and hypothesize all likely patterns of the unknown circuit (more than one was possible). They are also required to provide a rationale for their hypothesized circuit(s)" (Stensvold & Wilson, 1993, p. 251).

"A behavioral objective for a task helps focus the specific skills and materials and helps to establish scoring parameters" (Doran & Hejaily, 1992). Performance tasks for skills should not be paper-and-pencil items, but should involve students in doing activities. The directions must be clear and concise; diagrams can help with clarity. Questions should be based on the process skills identified. For example, "Write your observations for ..." or "Predict what will occur when ...." In developing a scoring system, performance and not content should be stressed as the most important aspect contributing towards a grade (Doran & Hejaily, 1992).

Keep the performance items direct and simple, and not too long. Provide diagrams and clear instructions. Use materials which are familiar to the students. Remember to consider the manageability of the item with a classroom full of students. Develop a scoring rubric before having students complete the assessment. Discuss the scoring system with other teachers and try for consensus on how to award points (Finson & Beaver, 1992).

Kanis, Doran, and Jacobson (1990) developed a Science Process Laboratory Skills (SPLS) test as an important part of the Second IEA Science Study. This test was given to a representative sample of American fifth grade students (n=2,392) and ninth grade students (n=2,248). The following three main skill areas are assessed with this instrument: performing, investigating, and reasoning. Performing skills on the test include observing, measuring, and manipulating. The investigating skill includes planning and designing of experiments, and the reasoning skill includes interpreting data, formulating generalizations, building and revising models. There are two forms of the fifth grade instrument, Set A and Set B, both are meant to be used simultaneously. Set A contains five performing skill items, two reasoning skill items, and no investigation skill items. Set B contains five performing skill items, five reasoning skill items, and one investigation skill item.

The specific tasks for the instrument are as follows:

- Describe and explain color change of bromothymol blue solution after blowing through a straw.
- Cite at least three similarities and differences of two plastic animal specimens.
- Determine if four objects are electrical conductors by testing in a battery-bulb circuit.
- Predict and measure the temperature of the mixture of equal amounts of hot and cold water.
- Observe and explain the dissolving of coffee crystals in water.
- Determine which seeds contain oil by rubbing them on paper.

(Doran, 1990, p. 26)

States are beginning to play a role in authentic science process skills assessment. Wisconsin will use task-oriented assessment for mathematics, science, language arts, and social studies (Project prepares task-oriented assessments, 1993). According to Darwin Kauffman, the director of Wisconsin's Department of Public Instruction "Hands-on performance assessment tasks are on the cutting edge of what is going on in schools as far as assessment" (Project prepares task-oriented assessments, 1993, p. 2). New York State developed a mandated test called the Elementary Science Program Evaluation Test (ESPET), which was first administered to 211,000 fourth grade students. The manipulative skills section of this test has attracted national and international attention. According to Susan Agruso (1993), the Project Director, the ESPET manipulative skills section "consists of five hands-on stations with a total of 15 questions designed to evaluate student ability to measure physical properties, predict an event, create a classification system, make generalizations, and draw an inference. This assessment program has had a profound effect on science education in our elementary schools. Students are especially excited about the manipulative portion, enjoying the opportunity to engage in problem-solving activities that require their handling equipment and taking data" (p. 1).

Technology may help in overcoming obstacles to performance-based assessment in science. The Scope, Sequence, and Coordination project of the NSTA has plans to test a compact-disc interactive (CD-I) system in assessment. The system "is designed to alleviate labor intensive tasks—such as recording and analyzing student responses.... The assessment would go like this: A student works alone, using the CD-I program as a guide to carry out tasks—at various levels of complexity—with real objects and phenomena. The CD-I tracks their responses to identify patterns of preconceptions, knowledge, and problem-solving techniques" (Bruder, 1993, p. 24).

"As educators move toward more performance-based assessment, the potential advantages offered by portfolios must be considered. Growing out of authentic classroom practices, portfolios provide a holistic view of student performance. They allow for the alignment of instruction and assessment and provide the opportunity for students to be more closely involved in reflecting upon and assessing their own growth. They also offer a vehicle for increased communication among teachers and between home and school. Although the implementation of portfolios is labor-intensive and time consuming, the gains in terms of improved education seem to warrant their consideration as part of the assessment process" (Newman & Smolen, 1991, p.32).

"At the elementary school level especially, but continuing throughout school and beyond, informal investigation is an important part of 'hands-on' science.... The teacher's evaluation of such activities is also likely to be informal, relying mostly on unobtrusive observations. Teachers may find it useful to observe systematically individual students, small groups, or even the class as a whole. The teacher's observations should be recorded in writing, either immediately or at the end of the day, noting the time, date, and activity. These remarks may be quite brief, even cryptic, but should specify in some way what was seen, not just the teacher's judgment of its quality. If the comments are recorded on index cards, say, they can be filed easily by student name, can serve as a record of progress and attainment to be used in planning further instruction, shared with parents, used in grading, and perhaps even shared with the students themselves" (Haertel, 1991, p. 241).

Portfolios are increasingly becoming an important tool in science teaching and learning. A portfolio is a collection of documents that contain evidence of achievement. Evidence presented in the portfolio may be worksheets, laboratory reports, raw data, first drafts, or diagrams of laboratory equipment. It is very important that the evidence is meaningful to the students and it is recommended that students attach captions to each entry and state what the evidence is and why it is evidence (Collins, 1992).

"Assessment through student writing and portfolios provides a means for teachers to help students take a longer view of their learning in science. Portfolios are not just collections of student writing but depend upon written products by students to interpret, explain, and generally give the student's perspective of the collected works.. These works may be represented as by photographs, diagrams, drawings, and even hi-tech records such as computer documents or video and audio tapes...The portfolio itself is not the assessment. Assessment comes from teacher judgment of the materials with respect to a set of criteria" (Flick, 1993, p. 5).

"The development of portfolios allows teachers and students to work and learn together; provides opportunities for reflection and self-assessment; helps redefining [of] traditional student and teacher roles in relation to the science curriculum; emphasizes the culture in which teaching and learning occurs; and empowers both students and teachers with respect to science learning" (Tippins & Dana, 1992).

Swang (1993) has his sixth grade science students keep two types of portfolios—work portfolios and exhibit portfolios. Students maintain items for both portfolios in printed form and on computer disks. Swang uses the work portfolio to assess student work in progress. This includes rough drafts of steps in scientific research, class notes and research notes, data tables, notes from scientific literature on a topic of study, and notes of encouragement from the teacher. Swang uses the work portfolio to monitor student work and understanding. However, no grade is given to this portfolio. By working with the student the quality of work is improved so that it can be placed in an exhibit portfolio. The student prepares a more formalized report for this portfolio. The quality of work has already been established so the grade for the exhibit portfolio is an "A."

Concept maps my be an effective way to assess learning from hands-on science. Markham, Mintzes, and Jones (1994) conclude from a study of college biology students that concept maps are a powerful and psychometrically sound tool for evaluation in science education.

Hein (1987) recommends a variety of approaches be used in assessing hands-on learning, including observing students at work, examining the things they manipulate, and evaluating science-related drawing and writing. Other assessment techniques include group discussion, journaling, and student interviews (Gaffney, 1992; Tippins & Dana, 1992). Some assessment task should be done by student teams to help build group skills (Small & Petrek, 1992). It is often beneficial to have students score their peers' group work (Culp & Malone, 1992).

Summary

It is clear that the traditional paper-and-pencil, multiple-choice approach to testing cannot be used alone to adequately assess the full range of learning outcomes typically associated with hands-on learning in science. Just as hands-on learning involves activity, demonstration of experientially based learning requires some degree of active expression beyond responding to a small set of standardized test items. Recommendations include more frequent use of verbal explanations, using assessment strategies that incorporate performance tasks, developing observational checklists and scoring schemes, and compiling portfolios of student work. It is acknowledged that these enriched forms of assessment require a greater investment of time to develop, administer, and interpret, but there is also a great need to more carefully align student assessment with curricular aims, instructional practices, and performance standards. For more help in locating resources and ideas, see Appendix C.

7. *What are some strategies for helping students work in groups?*

"The teacher, acting as the director of research, with students working as science-research teams always has been a great way to teach science" (Small & Petrek, 1992, p. 30). Some see group work as particularly important in science classrooms. In addition to developing social skills and facilitating classroom management, working in teams reflects the way science is practiced. Science itself is a collaborative, cooperative enterprise. As Johnson and Johnson (1991) observe, just scan the list of articles in any issue of *Science* or other scientific journal and count the number of authors associated with each article. Scientists work in teams. As Rutherford and Ahlgren (1990, p. 189) point out, "the collaborative nature of scientific and technological work should be strongly reinforced by frequent group activity in the classroom." So, how do you facilitate group work in the science classroom?

Teacher Responses

In order to involve all members of a group in a hands-on learning activity, one should assign roles for the children. For example, one student may be the recorder, another could be in charge of materials, and another may actually perform the activity. The roles should be rotated or reassigned so that each child can be involved in every part of the process and so that each child may have a chance to play their favorite role.
Kathleen Costello, 3rd grade teacher, Holy Spirit School, Columbus, OH

The challenge in education today is to effectively teach students of diverse ability and differing rates of learning. In my experience with a multi-age, racially mixed, elementary classroom, this can be achieved through cooperative learning and cross-age tutoring. In cooperative learning, all contribute to the group effort because students receive group rewards as well as individual grades. High achievers deepen their understanding and lower achievers gain a sense of accomplishment through contributions to the group problem. Cross-age tutoring allows tutees to receive individualized instruction and work with positive role models. Grouping students in this way eliminates dull, repetitive programs which, by nature, lead at best to minimum competencies. In a day raining of reinforced racial and social-economic isolation and racial prejudice in our schools and the alienation toward school among lower achieving students, group learning may be the only proven effective port in the storm.

Strategies for implementing a group learning environment are many. Those which I have used successfully are:

1. Decide the size of the group. I typically use from two to six students, depending on the nature of the task and the time available.
2. Assign students to groups, preferably by your heterogeneous grouping rather than by student ability or student self-selection. Do not change group assignments with each new task, rather allow time for each group to get to know each other through the work of several tasks. I may change grouping as little as once a month.
3. Arrange the room so that groups can work together without disrupting other groups.
4. Plan instructional materials to promote interdependence. Give only one copy of the materials to the group.
5. Assign roles to assure interdependence. I give job titles such as summarizer, researcher, recorder, encourager, and observer.
6. Structure individual accountability as well as a group assessment in which individuals' rewards are based both on their own scores and on the average for the groups as a whole.
7. Discuss desired behaviors. Request that students take turns, use personal names, listen carefully to one another, and encourage everyone to participate.
8. Monitor student behavior. Circulate around the room to listen and observe groups in action. Note problems in completing assignments and working cooperatively.
9. Allow opportunities for groups to orally report their findings to the whole class.

10. Give feedback to each group about how well the members worked with one another and accomplished tasks and how they could improve.

Sally Parker, The Montessori House, Tampa, FL

Developer Thoughts

First of all, the room environment can be constructed so that it fosters the cooperative learning approach. Instead of putting desks in rows, put them together to make laboratory tables. Or better yet, get rid of most of the desks and put in tables. Also, there are many group-learning activities that can be done in a "different" academic setting that will enable students to learn how to work together.... Doing science experiments is more fun in a group, even in a twosome, because you can share equipment and knowledge, learn how to make charts and graphs together, discuss the outcomes of the experiments, and come to conclusions together. The teacher can also suggest roles each member of a group can play such as one person reading the instrument, another recording the data, another physically starting the experiment, etc.

Dianne K. Hyer and Roger C. Eckhardt, Students Watching Over Our Planet Earth (SWOOPE), Los Alamos National Laboratory

Teachers should organize small groups to do the science activities. Our research and feedback from teachers in over one thousand classrooms have found very little problem getting students in small groups to cooperate. The problem has been associated with larger groups with limited equipment. The teacher may assign specific tasks to the students such as data keeping and various aspects of carrying out the experiment.

Jerald A. Tunheim, Project SMILE (Science Manipulatives in the Learning Environment), Dakota State University, Madison, SD

In a hands-on approach to teaching science, some basic factors contribute to the success of students working in groups. Review the checklist to assess whether you attend to these factors.

Team Task

- Do you evaluate a task to determine if it actually lends itself to a team approach? (If students can do the task just as well on their own, why should they work in a group?)
- Do you provide enough structure and support for teams to complete the task independently and successfully? (Is the structure and support in the form of clearly stated, written, and illustrated, or tape-recorded instructions, rather than in the form of your constant intervention?)

Team Interdependence

- Do you structure the task so that all members of a team must be involved to successfully complete the task? (You can provide such structure by limiting supplies so that teammates must share them, requiring one product from each team, providing different information to each member of the team, and requiring that all members share the information to complete the task.)
- Do you require teammates to assume some level of responsibility for the understanding and performance of others on their team?
- Do you allow for teams to assess their effectiveness at working together as a team?

Time Jobs

- Do you select jobs that are appropriate for the age of the student?
- Do you select jobs that will promote team interdependence? (If you assign a team reporter rather than randomly calling on members of a team, why should the other members of the team be attentive and involved?)
- Do you clearly describe the responsibilities of each job and review the descriptions as necessary?
- Do you monitor whether students are effectively performing their assigned jobs?

Team Memberships

- Is the size of the team appropriate to the age of the students? (Students are able to work effectively in teams of two in kindergarten and first grade, and in teams of three in grades two through six. The larger the team, the less each student can interact with the other students and the more it takes for each student to contribute to the work of the team.)
- Do you thoughtfully assign teams rather than allow students to select their teammates?
- Do you vary the composition of each team?
- Do students remain in the same team long enough to develop interdependence and the ability to resolve conflicts, but not long enough to become bored with one another?

Gail Foster, BSCS (Producers of Science for Life and Living: Integrating Science, Technology, and Health), Colorado Springs, CO

Notes from the literature

"If we expect students to work together, we must teach them social skills just as purposefully and precisely as we teach them academic skills" (Ostlund, 1992, p. 32).

Toh and Woolnough (1993) investigated the effect of giving explicit knowledge on student acquisition of the following process skills: planning, performing, communicating, and interpreting. They found that giving instruction in planning and communicating were indispensable for helping students work on open-ended investigations.

The following three categories of social skills can help students work together: cluster skills which help students form groups, task skills which help students accomplish their goals, and camaraderie skills which help group members like each other. In developing social skills stress one at a time. The teacher should model, explain, and elicit examples of appropriate behavior for the skill. For example, in promoting the skill of involving all group members in an activity, students in a group can be given different color chips. When they encourage another student to participate they can place their chip in a pile. At the end of the activity, the number of chips contributed by each person can be counted to determine how effective they were in using this behavior (Ostlund, 1992).

"Hands-on laboratory work is the classic cooperative learning activity. A group of students working together on an experiment or activity, following instructions with a variety of duties and tasks requiring students to cooperate, is the prototype of cooperative learning" (Ossont, 1993, p. 30).

Cooperative learning is a model of teaching where students work together to achieve a goal or complete a task. The goal or task can be reviewing for a quiz, solving a problem, or doing a laboratory activity. The importance of working together is stressed, and this is the challenge for the students and the teacher (Hassard, 1992).

Ossont (1993) found cooperative learning was very useful in a middle school class—made up of students with severe social problems—where any effective learning seemed impossible. He explains that cooperative learning is beneficial to this age group because "students at the height of adolescent fervor are required to sit quietly in rows for many hours a day.... Cooperative learning offers the chance to combine academics and socialization—elements that are equally important in our student's eyes" (Ossont, 1993, p. 28).

"An effective way to manage a classroom of active students when teaching indoor gardening tasks is to organize a cooperative learning 'jigsaw' in which each cooperative group becomes 'expert' at a particular technique or gardening skill. Each expert can later teach his or her skill to another group of students or work with other expert group members to present a short demonstration to teach the skill to the whole class" (National Gardening Association, 1993a, p. 5). Examples of tasks that could be performed are planting seeds, planting bulbs, thinning seedlings, transplanting seedlings, making cuttings, and planting different fruit and vegetable parts (ex. potato eyes, carrot tops). The teacher needs to make sure materials are present, give the experts questions they should answer, and have a folder at each station giving the task definition, instructions, and cooperative group roles (captain, materials monitor, checker, recorder, and presenter).

"Ideally, although it is not always possible, each cooperative group should include students with a complete range of ability, learning style, personality, and gender. Arranging students in diverse groups is especially difficult at the beginning of the year, when students' relative strengths and weaknesses are not yet apparent. For the first ten weeks, I randomly set up groups of three to five students. Then, once I have more insight about individual students, I can use it to set up more balanced groups. For convenience and to minimize time spent moving desks around, I try to assign seats so that group members are near each other" (Ossont, 1993, p. 28-29).

When teachers intervene to assist working groups, even when requested by students, the intervention usually ends with the teacher giving directions. The intervention produces far more teacher talk than student talk (Oakley & Crocker, 1977).

It is important to not give too much guidance and to not over help the students. In a case study of a teacher attempting to implement a hands-on, problem solving approach, Martens (1992) found that the teacher's desire for students "to get the right answer" produced teacher behaviors which eliminated opportunities for problem solving.

Summary

Helping students work in groups facilitates hands-on learning and directly engages students in the processes of science. "Doing science" requires learning skills associated with communication and cooperation as well as procedures associated with inquiry. In some cases it is beneficial to assign roles (with "job titles") to members of groups and to consciously establish heterogeneous groupings. It also seems important to communicate explicit expectations for both individuals and groups and to structure activities so interdependence is essential to successfully completing the assigned tasks. It is also important, however, to not provide too much direct guidance to groups; collaborative problem solving is to be encouraged over "getting the right answers."

Various cooperative learning strategies seem particularly useful in science classrooms. Variants of the "Jigsaw" approach, for instance, give all students the opportunity to be "experts" and contribute to group learning. For more background on cooperative learning and its many forms, refer to *Using Cooperative Learning in Science Education* by Patricia Blosser (1992).

In general, once students learned how to work productively in groups, one should resist the temptation to jump in too early and put the students on the right path. An essential part of the learning is finding out how to identify a path of inquiry and negotiate the path in collaboration with others.

8. *How does or should the use of hands-on materials vary with age?*

Too often we assume that good teaching is good teaching. What works well with one group of students will probably work well with others. But we all differ in a lot of ways, and many of the differences we progress through are age related. What are the implications for actively engaging students with materials? What are the age-related factors that must be considered?

Teacher Responses

In the early childhood (ages 4-7) years, the *process* of exploring, experimenting, and inquiring should be the major emphasis. The language association should be primarily oral. In the middle years, the process of inquiry should be followed, rather than preceded, by writing/ reading experiences.
Ruthanne McCarthy, kindergarten teacher, Gertrude M. Bailey International School, Lowell, MA

All students of any age should have hands-on experiences. As they become older then they may use written materials to further the knowledge base. The important thing is to be sure a student is cognitively ready for an experience—without this the activity may be fun but no real learning or understanding takes place.
Bonita-Talbot -Wylie, Presidential Awardee 1990, President of SEPA, third grade teacher, Minnetonka Schools, Excelsior, MN

I strongly believe that hands-on learning is for everyone. As an early childhood educator, hands-on learning has always been a vital element of developmentally appropriate learning. However, as an adult I look back on the learning that I remember most and without fail it involved active participation. Since when is fun only for children!
Barbara Axene-Kidwell, Disabilities Coordinator, Head Start Program, Columbus, OH

Developer Thoughts

There is no student too old for hands-on activities. Teachers, senior citizens, etc., still enjoy learning and participating through activities. The type of activity will vary with age, from observing, exploring, and manipulating tangible objects and places at young ages, to thinking about and trying out planned events at upper elementary, to manipulation of data, maps, and remote images in high school. There is a period in which activities are not cool (grades 8-9, 12, and middle age...), but seniors who go to elder hostels and nature summits, etc., love to get involved in their own learning. Isn't it sad how some people don't let themselves participate because they don't want to seem unsophisticated or they think they can learn just as much by watching others?
Rosanne W. Fortner, The Ohio State University School of Natural Resources, producer of Ohio Sea Grant Education materials and Project JASON curriculum activities

Notes from the literature

"Hands-on activities have a clear place within instructional models that are built upon a constructivist view of learning. They can be used at any point during inquiry-based instruction that strikes a developmentally appropriate balance between the use of physical materials and verbal, reflective interactions with other students and teacher. Hands-on activities are necessary for developing concrete, experiential background especially for students who have little exposure to experiences important for learning about the natural world" (Flick, 1993, p. 6).

Several research studies have been conducted to try to determine how teachers are using hands-on science. Harty, Kloosterman, and Matkin (1989) surveyed elementary school principals and concluded that teachers in the upper elementary grades have more science manipulatives than teachers in the lower grades. Teachers at the lower elementary grades spend 70 minutes per week on hands-on science teaching as opposed to the upper elementary teachers who spend 90 minutes per week.

Manipulatives are used to teach science more frequently in grades 3-5 than in grades K-2, and problem-solving was given greater emphasis in grades 3-5 than in grades K-2 (Kloosterman & Harty, 1987).

At higher grades, teachers report more time spent on teaching science. In the NAEP report (Mullis & Jenkins, 1988) 70% of grade three teachers reported spending two hours or less on science. For grade seven and grade eleven, the percentage of science teachers that reported spending two or less hours per week for a class was 17 and 10, respectively. It appears as though elementary science teachers are spending a greater proportion of their time using hands-on science activities. For example, in the NAEP report card 44% of seventh grade students and 40% of third grade students reported not having done any experiments in the previous month (Mullis & Jenkins, 1988).

From a sample of ERIC abstracts analyzed (n=782) during the years from 1970 to 1990, Rillero and Roempler (1993) determined the NSTA publication for elementary school teachers, *Science and Children*, consistently devoted more attention to science activities than did the NSTA publications for high school teachers (*The Science Teacher*) and college teachers (*Journal of College Science Teaching*). For example, the percentage of abstracted articles mentioning science activities in 1990 for *Science and Children*, *The Science Teacher*, and the *Journal of College Science Teaching* were 93.0, 57.7, and 10.0, respectively.

The importance of the early use of hands-on learning has been long recognized. "The study of both plants and animals should begin in the lowest grades, or even in kindergarten. One object of such work is to train the children to get knowledge first hand. Experience shows that if these studies begin later in the course, after the habit of depending on authority—teachers and books—has been formed, the results are much less satisfactory (National Education Association, 1893, p. 139).

"Hands-on activities are critical for [elementary school] science learning, particularly because elementary students are at the concrete stage of their cognitive development" (Loucks-Horsley, et al. 1990, p. 48). "Elementary school experiences are important for establishing understanding of science concepts and developing needed skills for further learning" (Howe, Blosser, Helgeson, & Warren, 1990, p. 33).

In Britain, it has been proposed that the National Curriculum for elementary school science be composed of 50 percent inquiry activities and 25 percent for the secondary school curriculum (Tinker, 1993).

Hands-on elementary science curricula can assist children in making transitions from one Piagetian level of thought to the next (Kren,1979).

The earlier teachers emphasize the concrete, sensual aspects of science, the firmer the foundation will be for science learning. However, no matter what the age of the student, "experiences form the basis of real learning. Early in any science lesson, your students should begin their hands-on experiences. Save the vocabulary words and textbook reading activities for later as reinforcements of the lessons the students have already learned firsthand" (Kotar, 1988, p. 40).

Arons (1979) observed that college students doing the ESS Battery and Bulb activity went through exactly the same sequence and pace as elementary students doing the activity. "When these students are given a dry cell, a length of wire, and a flashlight bulb and are asked to get the bulb lighted, they almost invariably start by connecting the wire across the terminals of the battery and holding the bottom of the bulb to one battery terminal. They have no sense of the two-endedness of either the battery or the bulb; few of them notice that the wire gets hot when connected across the battery terminals and almost none infer anything from the observation (Arons, 1973, p. 771).

Hein (1987) argues that science educators need to do a better job of determining when specific process skills should be learned. "In many other fields — reading, music, mathematics, or sports, for example— a sequence of progressively complex steps to help children achieve mastery in a systematic way has been devised. In these fields, students learn new fields while integrating them with earlier ones and practice using them. But in science, we speak of observational skills, problem-solving skills, and other skills, such as measuring, but we have not defined a progressive development" (Hein, 1987, p. 10). Hein points out that observational skills are one of the most important science skills; however, state and local guidelines do not differentiate between the observations of a first grader and those of an eighth grader.

Summary

It is interesting to note that the age-appropriateness of hands-on learning strategies is less than clear cut. Though there is some agreement that activities for younger students are developmentally more appropriate when the emphasis is on skills associated with the concrete world, such as observing and measuring, activity-based learning is appropriate at all ages. A theme expressed repeatedly is that learners of all ages benefit from hands-on learning. This is congruent with constructivist views of learning. When coming to understand a new domain of knowledge, we all progress through similar sequences of exploring, interpreting, and gaining meaning from experiences. So, hands-on learning is not just for young learners; we all construct our knowledge on an experiential base that must be developed, sooner or later.

9. *Hands-on science can be expensive. How do I get materials and equipment?*

Inadequate science equipment is an obstacle to hands-on science teaching that has existed since the 1970s (Tilgner, 1990). Lack of supplies is the most reported major barrier in elementary science education (Morey, 1990; Teters & Gabel, 1984). Numerous studies have found the lack of hands-on materials to be a major problem for teachers (Finan, 1990; Glass, 1984; Guerrero, Eisler, & Wilcken, 1990). This section looks at ways teachers can overcome the hurdle of expensive equipment and materials.

Teacher Responses

To teach hands-on science to middle school sixth-graders in a rural school district, where lab equipment is scarce to nonexistent, requires dedication and innovation on the part of the classroom teacher. It can be done. To teach body systems to my sixth-graders I have a very understanding butcher who supplies me with all of the hearts, lungs, kidneys, brains, eyes, and other organs that we are studying free of charge. The students are able to handle, dissect, and examine tissue from these organs to get a much better understanding of living body tissue and its function. These labs fuel a fire that no textbook or black and white film from the 1950s could even spark.

In physical science I can make 15 sets of gram weights from nuts, bolts, and other items from my local hardware store. I can make graduated beakers from empty jelly jars and mark them with a permanent marker. I can make a balance from pegboard, a nail, a piece of soda straw, and scraps of wood. The materials and equipment you can design for this age group to foster an early interest in the sciences is only limited by the teacher's imagination and dedication to their subject area.

Saundra K. Elsea, Sixth Grade Science/Health, Kingston, OH

If my school has monies I just ask my principal and if he has funds I have no problem. If money is not to be found I ask the children to bring in materials from home. As a last resort I simply buy the materials with my own funds. At times we have done fund raisers for field trips and that could be another source for materials.
Dave Kelly, Sixth Grade Teacher, Daley School, Lowell, MA

It seems to me that when you begin to study the "hands-on" approach, one pictures a science lab with microscopes, Jacob's Ladder, etc. But, looking at and reading books such as *Mudpies to Magnets* you realize that 98% of the materials you need are in your home. Such materials are easy to collect. Plus, they're replaceable.
Mike Thorn, Kindergarten teacher, Eakin Elementary School, OH.

The best way is to pool the money [at the] ... district or building level and buy in quantity. Your dollar goes a lot further because you can get discounts. It also works best if one person [is] ... given responsibility because then he [or] she can become knowledgeable, have time to do comparison shopping, etc.
Bonita Talbot-Wylie, Presidential Awardee 1990, President of SEPA, third grade teacher, Minnetonka Schools, Excelsior, MN

As the budget ax falls on local school districts, funding continues to be a major concern across the country. Science teachers, notoriously known for being beggars, scavengers, and packrats, can turn their resourcefulness into grant dollars with creative ideas and innovative classroom programs.

Start simple! For my first grant, I used a project which had been successful in my classroom for several years. I knew the project inside and out, the intended audience, the expected outcomes as well as the limitations. As the students and I discovered "new twists" in the project, funding became a problem. I needed a plan to finance the project and its possible spin-off ideas.

Start small! Each year, small grants are awarded to groups, individuals, and organizations dealing with some sort of science education. Look to local or state agencies and organizations for your first proposal. For example, the Ohio Wildlife Diversity Project Grants for 1993, funded by the Ohio Division of Wildlife, awarded a total of $9,108 to three Ohio schools. It is interesting to note that the largest award, of the twelve contracts awarded, went to an elementary school teacher. A good source for larger more competitive awards is the "Earn & Win" section in each issue of *NSTA Reports*. Amid the nationally recognized awards are a handful of state and regional awards as well. Be sure to consider the full gamut of types of funding sources that might be interested in science education—private foundations, state agencies, federal agencies, private businesses, and professional associations. Doing the homework to match your need, project, or program with the interests of donors is extremely important and will increase your chances of success.

Start now! I submitted my first grant proposal in 1991 and have been awarded three grants. My projects were not exceptional but rather they addressed the needs of my students and school with elements of creativity and innovation. With a carefully selected funding source, clear and concise writing technique, and quality objectives, you're well on your way to being funded.
Sally A. Parker, The Montessori House, Tampa, FL

Developer Thoughts

In some cases you can get materials and equipment from people who have them—research people. Contact corporations in your area to ask them to consider you when they are discarding materials. You can acquire some very nice, albeit used, equipment.

However in many cases you need 25 of the same object, and you cannot expect to have it donated in that quantity. You must raise the money. Find out whose father or mother is an engineer, scientist, or medical doctor. Impress them with your need and ask them to call a few other parents to make a contribution. I did that last year and raised over $400 with a dozen phone calls (and only one turndown).

For bigger projects, local companies and foundations may contribute. They are out there; you need to find them. See if your community has a volunteer center or a community foundation. They can help you find the sources. The library may also have the information.
Edwin J.C. Sobey, National Invention Center, Akron, OH

Hands-on science programs that start with what you already have (or can easily obtain) are naturally cheap—perhaps $10 to $15 per student per year [see question 10 for a list of materials Marson recommends]. If your school doesn't budget for science materials, you can order many items out of general supplies. Here at TOPS we occasionally get orders paid by the PTA.
Ron Marson, TOPS Learning Systems, Canby, OR

Many effective science activities can be done with readily available materials. However, buying materials for large numbers of students can be expensive. The SPLASH (Student-Parent Laboratories Achieving Science at Home) program originated to get parents more involved with their children's science education and to give students more hands-on science activities in order to improve their attitudes toward science and achievement in science. A weekly activity is assigned to the students that utilizes commonly available materials in the home. Flour and balls are used to simulate crater formation, paper to construct whirly-birds and paper airplanes for flight investigations, and popcorn to design controlled experiments. Teachers can have students bring materials from home for class activities, or assign extension activities to utilize materials in the home environment.
Peter Rillero, SPLASH (Student-Parent Laboratories Achieving Science at Home), The Ohio State University, Columbus, OH

Notes from the literature

Over three quarters of the teachers (grades K-2) responding to a survey on the Comprehensive Instructional Management System Science program (New York State) reported that the materials required were not readily available in their school (Guerrero, Eisler, & Wilcken, 1990).

Kahle, Anderson, and Damnjanovic (1991) in a survey of United States elementary school teachers, found that teachers who stated they had inadequate resources in science rated the availability of materials and equipment in physical science the lowest.

Elementary school classrooms are a little more likely to have commercially available science manipulatives than they are to have teacher-assembled materials (Harty, Kloosterman, & Matkin; 1989). However, there are many sources of information for teacher-assembled materials.

Fox (1994), a fourth grade teacher, describes the solution at her elementary mathematics/science magnet school that utilized site-based management and community-wide support to gather and store science materials. In a collaborative effort teachers visited other schools and evaluated curriculum guides and textbooks to create priority lists of equipment and materials. This lists was shared with school administrators, and then parent groups, school partners, various local business (including pet and hardware stores and a zoo), and supportive intermediate-level science teachers. An amazing collection of material was collected. Then available funds were used to purchase equipment that was not collected, which included lab tables, microscopes, beakers, test tubes, and flasks. "The communal project has resulted in an enormous sense of ownership and pride in the school science program, as well as continued funding for the laboratory" (Fox, 1994, p. 22).

Doherty (1992b) describes how an electroscope can be made from inexpensive materials, and explains the advantage of having students build the instrument. "All of the teams have successfully built electroscopes by draping charged strips of Scotch Brand Magic Tape® over bent straws stuck into film cans full of clay. Judith [the classroom teacher] found the tape in administrative supplies; the straws were donated by a local fast-food restaurant; the film cans came from a neighborhood camera store; and the clay came from Judith's own collection supplies. The resulting electroscopes are not black boxes made by some science supply house; there are no hidden or mysterious parts. The students have built them, and so 'own' them. If an electroscope breaks, the students fix it or build a new one. Each group checks the electroscope it has built. One girl combs her hair and brings the plastic comb towards the strips of tape dangling from the soda straws. One piece of tape is repelled by the comb, but the other is attracted. The electroscope works! The team cheers and brags to the surrounding tables" (p. 15).

Graduated cylinders can be created from quart size plastic oil containers that have a volume sight tube calibrated in ounces or parts per quart (Schlenker & Yoshida, 1992). Students or the teacher can use scissors to remove the pouring spout of the bottle so it looks more like a beaker. To measure in the metric unit of milliliters, 100 ml of colored water is poured into the container and the level marked. This is repeated so that 100-ml increments are marked on the volume sight tube. Now the graduated cylinder can be used.

Bait shops can be an inexpensive source of living vertebrates that can be used for classroom activities (Texley, 1993).

The outdoors can be an important source for materials for science teaching (Tredway, 1982). Tredway advises teachers to choose a site that is within a 15-minute walk from school. Possible activities in the local environment include collecting trash and sorting it into categories and weighing it to make a graph, collecting leaves for identification, and describing the type and number of insects in the study area.

Stangle (1993) explains that teachers can integrate language arts with science by going out and finding critters that are characters in the books the children are reading. Critters such as ants, butterflies, crickets, and worms can be observed in their natural habitats. Large jars with a rubber band securing a fine net to the top enclosing sticks and rocks and moistened leaves can be convenient temporary homes for the organisms. Questions—such as What do the critters eat? and How do they move?—can guide the students in making observations. After an hour or two the critters should be returned to the outdoors.

Many low cost, educationally sound hands-on activities can be found in magazines for teachers. For example in *Science Activities*, Philips (1992) described how readily available equipment can be used to teach principles of the controlled experiment. The National Science Teacher's Association produces *Science and Children* (elementary grades) and *Science Scope* (middle grades) which contain an abundance of inexpensive, creative science activities. For example, in "Can-Do Science" in *Science and Children*, Scott (1992) describes different hands-on activities that can be done with ordinary cans.

As the problem of materials is increasingly recognized, many science educators are designing activities to use very simple materials. The introductory paragraph of "Electrifying Science" by Duane Inman (1993) illustrates this approach to low or no budget science. "Elementary science teachers increasingly are being encouraged to teach more science and to use a hands-on approach. But they are usually then constrained by budgetary limitations that, to many, seem to preclude the effective use of activity science in the classroom. Following are several activities, grouped by the process skills involved, that I have found to be of high interest and relatively low budget and that are effective in stimulating interest in science and in teaching science concepts to elementary students" (Inman, 1993, p. 15).

Activities from journals, teacher magazines, conference presentations, curricula, and books can be found using the ERIC database. The most efficient search utilizes a computer with a CD-ROM. The ERIC descriptor "science-activities" will identify thousands of documents containing hands-on science articles. It is recommended that you narrow your search to a topic of interest by using descriptors or identifiers. For example, if you want hands-on activities related to electricity your search terms would be "science-activities" and "electricity." To get activities that may not be strictly limited to science it is advisable to use the descriptor "learning-activities." For example, to find activities related to evolution the following search could be used: "science-activities" or "learning-activities" and "evolution." See page 131 for more information on the ERIC system.

- The ERIC Clearinghouse for Science, Mathematics, and Science Education produces publications for hands-on activities in science mathematics, and environmental education. A free list of publications can be obtained by writing the Clearinghouse.

- Grants from Eisenhower math and science funds, corporations, and school districts may be used to purchase science equipment and materials. Bruder (1993) lists the following corporations willing to fund K-12 science programs: ARCO Foundation, 515 South Flower Street, Los Angeles, CA 90071; The Lukens Foundation, 50 South First Street, Coatesville, PA 19320; America Honda Foundation, P.O. Box 2205, Torrance, CA 90509; Sterling Winthrop Inc., 90 Park Avenue, New York, NY 10016; and National Semiconductor Corporation, 2900 Semiconductor Drive, Mailstop 16-179, Santa Clara, CA 95052. Bruder advises writing for information and an application and not sending grant proposals.

- The National Gardening Association (1993b) has collected excerpts from successful grant applications for funding the GrowLab program. They make the following offer: "To request 'How to Fund a Classroom GrowLab,' send a stamped self-addressed envelope to Growlab Grants, National Gardening Association, 180 Flynn Ave., Burlington, VT 05401."

- "There will always be problems with doing investigative science, especially with living materials and simple apparatus. Some teachers will always be able to cite reasons why they cannot teach investigative science, even when their colleagues are overcoming the barriers and doing an outstanding job. It is the contention of the authors that the large numbers of teachers who fall between these two extremes would be willing to give investigative science a try, and would persist in doing so, if some of the obvious barriers could be reduced" (Atwood & Howard, 1990, p. 858).

- Among the recommendations for the Comprehensive Instructional Management System Science Program was the following: "Given the importance of manipulative materials to the program's hands-on approach, program staff in collaboration with district and school administration, need to explore alternative ways of making these more readily available; this might include establishing networks among teachers for sharing materials and modifying lessons in ways that take the paucity of supplies into account" (Guerrero, Eisler, & Wilcken, 1990, p. 28).

Thorndike, the famous educational psychologist recognized the value of using simple, inexpensive materials in science education. In 1920 he wrote the following: "Laboratory or experimental methods of teaching depend less upon extensive equipment of [sic]instruments and complicated arrangements for controlling nature in experiments, than upon the attitude of open-mindedness and sincere curiosity. A teacher may be as prejudiced, dogmatic and pedantic with a thousand dollars' worth of brass instruments as with a text-book; and a scientific teacher can make a pail of water, a hot-air stove and a school yard the means of first-rate experiments. *Indeed, the instructiveness of an experiment is commonly in a rough proportion to the simplicity of the apparatus used*" [emphasis added] (Thorndike, 1920, p. 178).

Summary

There is no denying the fact that hands-on teaching and learning requires materials, and some materials can become expensive or difficult to obtain. But the greatest challenge, it seems, is to first focus on what experiences are desired, then consider the alternatives in terms of materials. Often the materials can be quite simple or readily available from nontraditional sources. For instance, some have suggested using nuts and bolts from the hardware store for weights, or obtaining from the local butcher organs, bones, and assorted joints to dissect. Many teachers also report that most of what is needed for simple hands-on activities are readily available in the homes of teachers and students.

A materials-based, hands-on approach should not be totally dependent, however, on the scavenging abilities of teachers. Many local businesses, agencies, and parent organizations will award small grants to purchase essential equipment and supplies. Many corporations seek needy recipients for used equipment when updating their own resources. Also, all American public schools receive Federal monies to support improved teaching and learning, particularly among historically underserved and underrepresented groups in mathematics and science. Find out who in the district knows about the sources of funding, and submit proposals.

No matter what approach is taken to science teaching, there is a cost factor: costs for books, materials, or a person's time. The quest for materials must not take place in a vacuum; efforts to obtain materials must be considered in the context of the time and expense being committed to the full array of textbooks and services being managed in the service of instruction. When all is said and done, however, the real key to hands-on learning is to use whatever is available to spark curiosity and promote active inquiry.

10. Where do you keep materials and equipment once you get them?

Extensive hands-on science programs generally require lots of materials, and therefore, storage and organization must become key issues. "BATTERIES AND BONES, magnets and mealworms. The gathering and storage of models and materials for science teaching can be a daunting task" (Fox, 1994, p. 20). Appropriately, teachers are concerned with their ability to organize and maintain materials (Finan, 1990; Symington & Osborne, 1983). In this section we provide perspectives on how others have coped with organizational and management issues once materials have been obtained.

Teacher Responses

My classroom has standard kitchen base cabinets around half the room and seven large (7' by 4') cabinets which are 18 inches deep. The large cabinets are equipped with hasps and padlocks. There is no chemical storage cabinet but I have only household chemicals which are kept in the locked cabinet. All materials are in the science room. There is only one 7th and 8th grade science room in the building.
Phyllis Frysinger, Miami View Elementary, S. Charleston, OH

Going hand in hand with having districts pool money to buy equipment [see Talbot-Wylie, question 9] is [having] ... a district or building [centrally located] ... for storage and [having] ... a check out system where the materials are rotated so nothing is sitting idle during the year. A district science center has been part of our system since 1976 and we have [saved] anywhere from [one to two thirds of] ... the total budget by buying in bulk and rotating the units throughout the district. They get used three to eight times per year depending upon the unit and grade level. It works.
Bonita Talbot-Wylie, Presidential Awardee 1990, President of SEPA, third grade teacher, Minnetonka Schools, Excelsior, MN

Developer Thoughts

You may think that materials lists are boring. But they are the bedrock. Materials define the content, economy and ultimate success of any hands-on science program. Here's my list; color it basic.

CONSUMABLES

paper clips
masking tape
wooden spring clothespins
steel straight pins
aluminum foil
rubber bands (all sizes)
straws
index cards
thread and string
plastic wrap
sandwich bags
paper towels
drinking cups —
(paper, plastic, styrofoam)
clear tape
heat source — candles
matches
ice source
pie tins
paper plates
waxed paper
toilet tissue
adding machine tape
size D Dry cells
flashlight bulbs
insulated copper wire
(about 24 and 32 gauge)
beakers (50, 100 ml)

CONSUMABLES (continued)

bare iron wire
(about 24 and 32 gauge)
steel wool
refrigerator magnets
balloons
black felt tip pens
food coloring
table salt
rice
popcorn
pinto beans
dish washing detergent
petroleum jelly

NONCONSUMABLES

Scissors
test tubes (large and small)
wall clock or wristwatches
meter sticks
oil-based modeling clay
eye droppers/ with bottles
graduates (10, 100 ml)
lab balance (improvised
with TOPS)
tubs or buckets
hand calculators
stop watches
syringes (needles removed)

NONCONSUM. (continued)

thermometers
microscopes and sides
staplers
pliers
paper punches
hand lenses
pennies
nails
marbles
washers

RECYCLABLES

gallon plastic milk jugs
cardboard boxes
jars with lids
medium cans
Styrofoam egg
cartons
plastic produce
bags
soda bottles
soda cans
butter tubs w/ lids
waxed milk cartons
clean gravel
clean sand

I use these materials over and over again to teach the 700 or so hands-on science lessons that I have developed at TOPS Learning Systems. I organize these simple things on open shelves in labeled boxes, jars and cans. When I teach about animals, or plants, or light, or sound, or rocks and minerals, 80-90% of what I need is already right at hand.

The remaining 10-20% of unlisted materials are specialty items I store in the closet. My *Animal Survival* box contains tempera paint for camouflage. My *Green Thumbs: Radishes* box contains radish seeds and potting soil left over from last year's unit. Mirrors and colored cellophane are in my *Light* box, tuning forks in my *Sound* box, and egg-carton rock collection in my *Rocks and Minerals* box.
Ron Marson, TOPS Learning Systems, Canby, OR

Notes from the literature

Commercial science kits are attractive and can be convenient resources. Storage problems are solved by the manufacturer's attention to detail—durable boxes, materials carefully sorted, and written instructions (Hickey, 1992). The disadvantage of the kits are they tend to be more expensive than purchasing items separately. Because of their expense, teachers may feel compelled to use the kits even if they are not appropriate for the students and curriculum. The solution is for teachers to create their own kits using shoeboxes. A good science shoebox contains a statement of the task, a list of materials, a worksheet or list of instructions, materials needed, and an assessment question. Examples of science shoeboxes include: Why Does Bread Rise? Balloon in a Bottle, and Magnetic Attraction (Hickey, 1992).

Materials can be kept in bags. Combining a book with hands-on material in a bag creates interesting activities. The large sealable food bag should contain all of the necessary materials and a card with step-by-step instructions. A hole in the corner of the bag can be used to hang the bag on a peg or bulletin board (Carlile, 1992).

Cans can be used both for conducting science activities and storing activities. The activity cans can be stored in a large metal trash can (Scott, 1992).

Neirro (1992) describes her solution to storing materials for student science exhibit work. "Since storage space is practically nonexistent at Presido Hill, I asked each child to get a sturdy shopping bag with handles, so they could easily carry their 'in process' exhibit from school to home and back. Of course, this presented its own problems. Some of my students ended up misplacing their half-built exhibits;

some left their projects on the bus. Other projects and materials 'disappeared.' None of the materials were expensive or irreplaceable, but it was no fun for those unfortunate students to start over again (Neirro, 1992, p. 23).

From an analysis of school districts with elementary school science programs labeled exemplary, Penick and Yager (1993) concluded that many of these districts "developed a central science kit distribution system sending complete science kits to schools on a scheduled basis. While the ready availability of kits ... does not guarantee excellent science teaching, it does eliminate a lot of the excuses for not teaching science. Teacher efficiency improves when the amount of preparation time required to teach science is reduced" (p. 5).

Fox (1994) describes a solution at her elementary school that utilized site-based management and community-wide support to gather and store laboratory materials. "To organize the materials we collected for our laboratory, school administrators approved a campus inservice day. Working together, faculty members placed consumables in white plastic dishpans labeled alphabetically, to which we attached detailed lists of each pan's contents. Once the materials were organized, we set up the materials in a classroom that school administrators designated as our laboratory. We stored the dishpans of supplies in cubby holes beneath a wall-length counter. Two small closets held high-cost or easily broken science equipment, such as microscopes, microslide viewers, graduated cylinders, and compasses, and a larger walk-in closet was a pack rat's delight, storing such items as paper plates, wooden blocks, baby-food jars, empty film canisters, and string. On shelves, we displayed the natural items we collected, such as birds' nests, fish skeletons, seashells, and various cones and seeds, as well as an array of equipment, including newly obtained triple-beam balances. Finally we hung light spectrum and safety charts on the wall for reference" (Fox, 1994, pp. 21-22).

Summary

While the storage and management of materials is of widespread concern among teachers, there are common solutions. There need to be physical spaces–cabinets and shelves–where materials can be readily stored and labeled in boxes, jars, cans, or other suitable containers. Dishpans, tote trays, and plastic bags can be used. Since some items will be used together in specific activities, they can be stored together in kits; other basic materials are used regularly in many activities, so they can be stored separately in supply areas. Teacher-produced kits can be assembled in shoe boxes or the boxes in which paper for the photocopier is delivered. Whatever containers are used, schools should consider having a central location for kits and supplies that must be shared among several teachers. The guiding principle in managing materials is to invest a little creativity and teamwork in creating safe storage areas with convenient access where items are easily found and replaced at a moment's notice.

Final Comments

The information presented in this document was gathered by contacting teachers and consultants who promote hands-on approaches to science teaching, by talking with curriculum specialists and developers who design programs and materials for active learning, and by reviewing the professional literature related to hands-on teaching and learning. Broad support for hands-on methods clearly exists, but there are also crucial questions to be answered by anyone or any group planning to enrich their classrooms with a more activity-based, inquiry-oriented approach to teaching. As the responses to questions presented here indicate, none of the crucial questions are as simple as they first appear, and different educators have different concerns and priorities relating to each question. Perhaps the crucial first step in developing a hands-on teaching style is to acknowledge the open questions and begin a process of finding personally satisfying answers.

The questions and answers offered here will help start the process of self-improvement or school-based reform, but they will soon have to be supplemented by questions and answers of more immediate concern related to local conditions, priorities. and concerns. Hands-on advocates should consider doing what we have done to develop this document; survey stakeholders to generate a list of their questions, then speak with colleagues and specialists about possible answers, and study the professional literature. There are many resources that facilitate access to the reservoir of professional knowledge, so reformers should make a serious attempt to find out what others already know before investing too much time in formulating personal answers to questions. In addition to the ERIC system mentioned on page 131 and the several sourcebooks cited, there are many on-line databases and electronic bulletin boards waiting to be used. The authors, in fact, used electronic bulletin boards and mail services to communicate with several of the contributors to this document. For a comprehensive listing of available resources, refer to the *Directory of Online Databases* (Marcaccio, 1992).

Most important, keep asking questions, and consider the full range of answers that colleagues offer.

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Appendix A

Acronyms of interest to science educators.

AAAS	American Association for the Advancement of Science
ACS	American Chemical Society
AIMS	An Integrated Mathematics and Science or Activities
BSCS	Biological Sciences Curriculum Study
CEPUP	Chemical Education for Public Understanding
CHEM	Chemistry Education Materials Study
CESI	Council for Elementary Science International
COMETS	Career Oriented Modules to Explore Topics in Science
COPES	Conceptually Orientated Project in Elementary Science
DASH	Developmental Approaches in Science and Health
ED	U.S. Department of Education
EPA	Environmental Protection Agency
ERIC	Educational Resources Information Center
ERIC/CSMEE	ERIC Clearinghouse for Science, Mathematics, and Environmental Education.
ESE	Earth Systems Education
ESL	English as a Second Language
ESS	Elementary Science Study
FOSS	Full Option Science Program
GEMS	Great Explorations in Mathematics and Science
ISCS	Intermediate Science Curriculum Study
ISIS	Individualized Science Instructional System
NAEP	National Assessement of Educational Progress
NARST	National Association of Research on Science Teaching.
NASA	National Aeronautics and Space Administration
NDN	National Diffusion Network
NSF	National Science Foundation
NSTA	National Science Teachers Association
OBIS	Outdoor Biological Instructional Strategies
SAPA or S—APA	Science—A Process Approach
SCIS	Science Curriculum Improvement Study
SPLASH	Student-Parent Laboratories Achieving Science at Home
SMILE	Science Manipulatives in the Learning Environment.
SWOOPE	Students Watching Over Our Planet Earth
USMES	Unified Science and Mathematics Education Study

Appendix B

Selected Materials That Support an Activity-Based Approach to Science Teaching

In selecting material resources to recommend, we have assumed that readers are primarily interested in emerging trends and practices, so most materials presented here have been produced or updated within the past few years and reflect current thinking about hands-on science. Some older materials are included, however, because they offer enduring ideas. Guidelines used in selecting materials reflect current concerns about science teaching and learning, including the desire to: (a) foster scientific literacy among all students, (b) develop skills and habits of mind associated with inquiry, (c) promote understanding of science and technology in a societal context, and (d) focus attention on environmental and global conditions in need of responsible human action. The use of newer forms of media and information technologies is also emphasized.

Types of Materials Listed

Curriculum Guides typically present detailed content and procedural specifications for individual grades, units, or courses. Guides generally include goals, content outlines, concepts, central ideas, activities, evaluation guidelines, and resources for implementing a discrete portion of an overall program.

Supplementary Materials are used to enrich an existing or evolving program, course, or unit. Supplementary materials include sets of activities that can be embedded within more comprehensive plans, non-print media that serve to enhance instruction, or discrete modules designed to extend learning into new domains, often focusing on current issues or problems relating to standard units of study.

Program Frameworks bring direction and coherence to multi-level strands or courses of study that span a series of grades or discrete courses. They generally provide the conceptual structure for a program rather than detailed specifications for particular units, activities, or lessons. A framework is often used to guide development or the search for individual units, modules, or courses that eventually make up a program or course of study.

Planning Resources provide or point to additional sources of information that will aid individuals and groups in developing classroom materials, locating additional materials, or formulating school-based plans. Some resources provide guidelines for developing programs and frameworks, while others provide reviews of materials not listed here.

Ways to Use These Materials

This listing of resources is intended to facilitate ongoing, incremental change as school-based programs are designed in response to local needs and visions. There has been no attempt to rank the materials or to rate them for purposes of adoption. Rather, the hope is that individuals or school-based teams will treat this list as a reservoir of good ideas, good ideas for both design and content.

In terms of design, the materials presented here provide a spectrum of alternatives for packaging the curriculum, from plans for enriching the standard curriculum to thematic frameworks that organize the content in new ways, in ways that reflect how people actually use knowledge and skills to negotiate life experiences. Many new curriculum designs incorporate the use of microcomputers and various forms of non-print media. Seeing how others have designed curricula to incorporate various types of media helps us generate ideas for exploiting the new technologies in our own planning.

As an aid to capitalizing on new ideas for organizing the content, we suggest that individuals and school-based groups consider developing a planning matrix to guide their deliberations about the materials presented here or elsewhere. A matrix for the elementary years might look like the following:

Strand	K	1	2	3	4	5
Personal Biology						
Plants & Animals						
Earth & Space						
Physical Science						
Environments						
Technology						
Issues & Decisions						

The columns designate grade levels, and the rows represent the themes around which the content will be organized at each grade level. The themes used here are offered as examples; one of the early challenges of a planning team will be to identify themes that reflect local priorities and perspectives. Once themes have been identified, the next step is to determine what specific units or modules will be inserted into each cell of the matrix to bring substance to the vision. A three-phase process is recommended: (a) complete a strengths assessment of the existing program, (b) seek additional sources to complete the matrix, and (c) initiate a process of continuous development.

A strengths assessment would include surveying teachers to determine which cells of the matrix could be filled with existing units that have been successful and match the local vision. To fill the remaining empty cells, a process of unit development and piloting may include tailoring existing plans, such as those listed here, to local conditions, or it may involve curriculum writing workshops where teachers incorporate ideas gleaned from a variety of sources into their own designs. In either case, the main goal is to avoid starting with a blank page whenever possible.

Once the matrix has been filled in, curriculum development should be viewed as a continuous process of ongoing refinement. Avoid periodic surges of curriculum reform by creating a feedback process so all units become regularly updated in an incremental fashion on the basis of comments by teachers. Implement school or district routines for collecting teacher feedback and incorporating ideas into updated guides.

The matrix facilitates an evolutionary model of curriculum development by combining flexibility with stability. Once adopted, the thematic strands are rarely altered, and only after deliberation that involves all stakeholders; this is the stabilizing structure of the curriculum. Cell contents can be changed quickly and repeatedly, however, in response to the success or failure of specific units in terms of the local vision and evaluative criteria. As matrix cell contents are adjusted in response to feedback, the overall curriculum becomes increasingly well adapted to local conditions. In short, the overall structure of the matrix embodies the vision, and program development becomes a matter of finding, testing, and refining suitable plans for each cell of the matrix. This approach avoids the pitfalls of two common pathways of curricular change: wholesale adoption of someone else's program and comprehensive curriculum writing by local teachers. This approach utilizes existing resources such as those listed here, and it allows local teachers and curriculum specialists to more quickly focus on student performance and incremental program adjustments.

Selected Materials

The list is divided into sections corresponding to the four types of documents described: curriculum guides, supplementary materials, program frameworks, and planning resources. Within the first two sections, materials are separated by grade level and the science content focus is indicted for each item. Materials in the final two sections are presented in standard bibliographic form, with annotations providing descriptive information. Materials are listed alphabetically, but in some cases several titles by the same author or publisher are listed as a group. Unless otherwise indicated, materials are available from the indicated developer or publisher.

Curriculum Guides

Elementary grades (K-6)

An Activity Guide for Teachers: Everglades National Park

Grades: 4-6
Science Content: Biology, Environmental Education

The Everglades was the first national park set aside specifically to protect its unique diversity of plants and animals. This guide has been derived from the myriad of educational activities used int he park's Environmental Education program over the last 20 years. Many were created by classroom teachers, while others were developed by park staff. The units in the guide are on the park, the environment, plants, wildlife, and fresh and salt water ecology. Appendix A contains information to duplicate and Appendix B contains supplementary activities and drawings.

Contact: Florida Advisory Council on Environmental Education
Room 237, Holland Building
Tallahassee, Florida 32399-1400

Bio Sci II Elementary

Grades: 3-6
Science Content: Biology

This visual database for elementary students offers 64 hands-on activities and includes barcoded lessons and teacher plans. It covers essential themes and concepts of the life sciences. the videodisc (which is narrated in English and Spanish) includes hundreds of still images, film sequences, computer graphics, animation and diagrams.

Contact: Videodiscovery
1700 Westlake Ave. N, Suite 600
Seattle, WA 98109-3012

Completing the Cycle–Its Up to Me

Grades: K-3
Science Content: All

This book addresses the problem of vanishing or depleting resources. It has been prepared to enlighten the school children of Indiana to the need for all Americans to become cognizant of environmental issues.

Contact: Indiana Department of Education
Center for School Improvement and Performance
Room 229, State House
Indianapolis, IN 46204-2798

Conservation for Children

Grades: 1-6
Science Content: Biology

This program teaches students about the interdependence of plants and animals, requirements of life, energy sources and use, pollution probiems, recycling, and other conservation concepts based on scientific principles. Teachers can use the materials as a primary resource for teaching basic skills, as supplementary materials to a core program, as enrichment activities, skill review, or as independent units of study. Evaluation data confirms that students using the materials for a minimum of 30 minutes per week master 80% of the learning objectives. In addition, 75% of the parents of 2,000 students in the evaluation study responded that they observed their children implementing conservation practices at home which they had never seen before the children used the program materials.

Contact: Sopris West, Inc., 1140 Boston
Longmont, CO 80501

DASH (Developmental Approaches in Science and Health)

Grades: K-6
Science Content: Biology, Chemistry, Earth Science, Physics

This is a comprehensive K-6 program under development that integrates content from the sciences, health, and technology. Draft versions of modules for kindergarten through grade 2 are completed, but materials for the upper grade levels are in various stages of design and field testing. The project is innovative in facilitating the use of the skills and knowledge of science, health, and technology in both personal and social contexts. DASH connects school studies to daily life, commerce, communications, transportation, medicine, and ongoing research.

Contact: Dr. Donald B. Young, University of Hawaii–CRDG
1776 University Avenue
Honolulu, HI 96822

FOSS (Full Option Science System)

Grades: 3-6
Science Content: All

FOSS provides a fresh approach to science instruction and assessment for students in grades three through six. As the name implies, FOSS is more than a collection of activities; FOSS is a carefully planned and coordinated science curriculum. Its modular design provides versatility so that FOSS can be used in many different ways in many different schools settings. FOSS springs from a philosophy at the Lawrence Hall of Science that has guided science curriculum for more that 25 years. FOSS provides flexibility for teachers and curriculum planners, making FOSS adaptable to just about every science framework, guide, and program.

Contact: Meg Boffey, 310 S. Michigan Avenue
Chicago, IL 60604
(800) 554-9862

GrowLab: Activities for Growing Minds [curriculum guide] and ***GrowLab: a Complete Guide to Gardening in the Classroom*** [companion horticultural guide]

Grades: K-8
Science Content: Biology

Funded in part by the National Science Foundation, GrowLab is an indoor, inquiry-based science program using "living garden laboratories." The curriculum guide and horticultural guide help teachers implement creative student-centered investigations with classroom plants and gardens. The GrowLab Program also includes instructional posters, teacher training videos, and national "partner" networks. All GrowLab resource users receive free (three times each year) the *Growing Ideas* newsletter which provides classroom-tested project ideas, instructional features, and a forum for exchange of ideas among teachers using plants to stimulate learning.

Contact: National Gardening Association, 180 Flynn Avenue. Burlington, Vermont 05401.

Hands-On Nature.

Grades: K-6
Science Content: Biology

The goals of this book are to spark a child's curiosity about the natural world, to increase their awareness of the many interrelationships within it, and to foster a positive attitude towards it.

Contact: Vermont Institute of Natural Science, P.O. Box 86 Woodstock, VT. 05091

Insights: An Elementary Hands-On Inquiry Science Curriculum

Grades: K-6
Science Content: Biology, Earth Science, Physical Science

This curriculum consists of 17 modules, each designed to be used at one of two grade levels (K-1, 2-3, 4-5, 6). The modules represent a balance of science areas and a continuous growth experience and understanding of 6 major science themes: systems, change, structure and function, diversity, cause and effect, and energy. Each is made up of a carefully sequenced set of hands-on experiences of developmentally appropriate content which is directily relevant to the child.

Contact: Education Development Center, Inc
55 Chapel Street
Newton, MA 02160
(800) 225-4276 x430

Life Lab Science

Grades: K-3
Science Content: Biology, Earth Science, Physical Science

This is a complete garden-based 4-year curriculum for the elementary level. It includes a videodisc, comprehensive lessons, teacher materials, experiments, and everything needed for elementary science education. The multimedia videodisc includes still images, movies, computer graphics, music, story-telling and animation. It is narrated in both Spanish and English. Broad topics include plants, animals, life cycles, habitats, climate, water, food chains, and others.

Contact: Videodiscovery
1700 Westlake Ave. N, Suite 600
Seattle, WA 98109-3012

Living in water. An aquatic science curriculum for grades 4-6, 2nd ed.

Grades: 4-6
Science Content: Biology, Environmental Education

Developed by the National Aquarium in Baltimore, this curriculum treats life and conditions in both marine and freshwater habitats. Each of the five sections addresses a question about water which is then answered through inquiry. Each section includes background information for teachers, and extension activities provide students the opportunity to pursue related topics according to interests. Procedural information is provided for teachers, with worksheets and informational sheets being provided for students.

Contact: National Aquarium in Baltimore Education Department, Pier 3
501 E. Pratt Street
Baltimore, MD 21202
ERIC Document Reproduction Service (refer to number ED 309 071)

Living with insects in the big city. Urban insect ecology and safe pest management

Grades: K-3
Science Content: Biology

This program has ten units, each to be taught in 40-50 minute periods. Each unit includes a statement of purpose, concepts to be taught, a listing of necessary materials, preparation requirements, and graphics. Recommendations for follow up activities are also included. A general introduction to insects can be found at the beginning of the curriculum. Detailed information on non-toxic pest control for some common pests has been included in the appendices. Topics include: urban insects; live insects; chain of life; pesticides; media and insects; biting insects; kitchen insects; and pest management. Although the units have been developed to follow a sequence of concepts dealing primarily with non-toxic pest control, they can also be used separately as parts of any environmental or natural science curriculum.

Contact: ERIC Document Reproduction Service (refer to number ED 306 121)

OEAGLets - Oceanic Education Activities for Great Lakes Schools for younger students

Grades: 1-3
Science Content: Biology, Earth Science

The package includes three activities related to Lake Erie that may be applied to all primary subject areas. Included are "Lake Erie–Take a Bow," a 69-page unit on the geography of the Great Lakes and their importance to people; "Build a Fish to Scale," a unit on the external characteristics of fish; and "A Day in Life of a Fish," a unit on fish behaviors, functions of body parts, and adaptations for survival.

Contact: Ohio Sea Grant,
1541 Research Center
1314 Kinnear Road
Columbus, OH 43212

Pablo Python Looks at Animals

Grades: K-3
Science Content: Biology, Life Science

Pablo Python is an introductory life science curriculum for children of all ability levels in grades K-3 combining hands-on multi-disciplinary classroom activities and the scientific resources of zoos to teach fundamental science concepts and observation skills. This program utilizes multi-media approach that encourages young children to explore the world, using all their senses. It is organized around basic concepts such as size, shape, texture, pattern, color, sounds, locomotion, feeding, and animal survival. **Pablo Python** can be used as a whole life science curriculum or as a flexible, instructional supplement.

Contact: New York Zoological Society, Bronx Zoo; Education
185th Street & Southern Blvd.
Bronx, NY 10460

The Pillbug Project

Grades: 3-7
Science Content: Biology

Pillbugs, also known as sowbugs and isopods, are an ideal classroom pet to introduce students to what science is really all about, learning directly from the world around them. Woven through the days of exploration is the delightful adventures of Patricia Pillbug. Her adventures spawn creative activities and exercise the imagination. Concepts of cooperative learning, a variety of assessment techniques, and reproducible pages to from individual student logbooks give this volume a solid pedagogical framework.

Contact: National Science Teachers Association
3140 N. Washington Blvd.
Arlington, VA. 22201

Project SMILE

Grades: K-5
Science Content: Chemistry, Physics

Project SMILE (Science Manipulatives in the Learning Environment) is a national project supported by the U.S. Department of Education. It is based on research identifying a critical need to improve educational content in the elementary grade (K-5) in the areas of chemistry and physics. Project SMILE utilizes video-assisted packets facilitated by elementary teachers or other personnel with classroom experience. The video-assisted materials have been effective in test workshops held during the summer of 1991.

Contact: Dakota State University, c/o Project SMILE
Madison, South Dakota 57042-1799

Project STARWALK

Grades: 2–5
Science Content: Earth Science

Project STARWALK is an elementary Earth/Space Science program for grades two through five. Using a process approach in observing, graphing, and predicting, students receive a series of classroom lessons structured around a planetarium laboratory lesson. These classroom lessons are designed to prepare students for their planetarium laboratory activities and to consolidate concepts in class through a specific laboratory activity, as well as to teach students how to use a seasonal star map or a star finder.

Contact: Project STARWALK, Southwest
Math/Science Magnet, H.S.
6512 Wornall Road
Kansas City, MO 64113

Rockets: A teaching guide for an elementary science unit on rocketry

Grades: 5-6
Science Content: Physical and Space Sciences

This resource guide provides background information and activities for teachers to use in preparing a unit on basic concepts and principles associated with rocketry. It is suggested that this unit be used as an introduction to building and launching commercial model rockets. The activities make use of simple and inexpensive materials, and do not require the use of solid propellant model rockets. The guide includes informative diagrams, complete instructions for activities, and sources of additional information.

Contact: NASA Educational Affairs Division
NASA Headquarters
400 Maryland Avenue, SW
Washington, DC 20277-2028

Science curriculum guide: Kendall Demonstration Elementary School, 2nd edition

Grades: K-8
Science Content: Earth Science, Life Science, Physical Science

The curriculum guide was developed to serve hearing impaired children and is based on learning objectives which are organized by school year as well as by content area. The instructional plan for each objective and sub-objective includes teaching strategies, student activities, and suggested resources in a variety of educational media. The curriculum is organized around seven major concepts: space, time, change, adaptation, variety, interrelationships, and equilibrium. Knowledge objectives are divided into three major content categories (physical science, earth science, and life science) and 10 subcategories (e.g. energy, geology, sound and hearing). In addition, the curriculum develops the following eight skills: observing, communicating, experimenting, formulating and testing hypotheses, classifying, measuring, inferring, and predicting.

Contact: Outreach, Pre-College Programs, KDES 3400,
Gallaudet College,
Washington, DC 20002.

Science For Life and Living: Integrating Science, Technology and Health (BSCS)

Grades: K-6
Science Content: Biology, Earth Science, Health

Science for Life and Living is a comprehensive, year-long program at each grade level K-6. The curriculum is designed around major concepts and skills that integrate the disciplines of science, technology, and health. Concepts such as order, change, patterns, systems, energy, and balance broadly define the content at each grade level. Each unit of the program develops those concepts in a science, technology, or health context using topics that relate to students' life and living.

Contact: Jill McDermott, Kendall/Hunt Publishing
2460 Kerper Blvd.
Dubuque, IA 52001

Science For Life and Living: Integrating Science, Technology and Health (BSCS)

Grades: K-6
Science Content: Biology, Earth Science, Health

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Contact: Jill McDermott, Kendall/Hunt Publishing
2460 Kerper Blvd.
Dubuque, IA 52001

Turn on units: English as a Second Language content area curriculum in math, science, and computer science for grades K–6

Grades: K-6
Science Content: General

This guide was prepared for use Limited English-Proficient (LEP) children. It is intended to serve as both a ready-to-use guide and a model for developing units for LEP students. The thematic units of this guide address topics of high interest to students: robots, using computers. plants, building terrariums, architecture, and cooking. The units are designed to engage students through games, role playing, movement activities, constructions, creative arts, and field trips. The guide includes objectives, key concepts, outlines of activities, lists of materials, detailed procedures, and suggestions for evaluations and extensions.

Contact: ERIC Document Reproduction Service (refer to number ED 347 090)

Programs With Components For Middle School Grades.

Activities for the Changing Earth System

Grades: 6-12
Science Content: Earth Science; Biology; Physical Science

This book presents curriculum activities for teaching about global environmental changes. Activities are designed around the goals stated in the *Framework for Earth Systems Education* that was developed from the Program for Leadership in Earth Systems Education (PLESE) supported by the National Science Foundation. Many of the activities illustrate historical approaches of scientific inquiry that are so frequently ignored in standard science teaching materials. Each activity demonstrates the linkages between the Earth's subsystems.

Contact: ERIC/CSMEE
1929 Kenny Road
Columbus, OH 43210-1080

Bags, Beakers, and Barrels. An action curriculum toward resolving hazardous materials issues

Grades: 7-12
Science Content: Biology, Chemistry, Environmental Science

This interdisciplinary curriculum is organized around hazardous materials issues at the local, state, national, and global levels. The aim of the curriculum is to promote awareness of issues, develop life-long learning skills, and foster awareness of attitudes, values, and behaviors. Units focus on connections; hazardous materials in the home, school and community; and community action projects. Each unit includes activities, listings of objectives, preparation suggestions, follow-up activities, and handouts. For more information, refer to ERIC document number ED 313 216.

Contact: Industrial States Policy Center, 1406 W. 6th Street, Cleveland, OH 44113

CEPUP (Chemical Education for Public Understanding Program)

Grades: 5-12
Science Content: Chemistry, Environmental Science

This modular program is being developed at the Lawrence Hall of Science with funding provided by the National Science Foundation and private foundations. CEPUP presents chemistry in a societal context, engaging students in chemical surveys, risk assessment, water testing, examination of plastics, study of food additives, and experiments with household chemicals. Teacher guides provide conceptual overviews, guidelines for activities, test banks, and technical instructions. Kits of materials are available from various suppliers.

Contact: Addison-Wesley Publishing Company,
Order Processing Department
Route 128
Reading, Mass. 01867

CHEM - Chemicals, Health, Environment, and Me

Grades: 5-6
Science Content: Chemistry, Biology

CHEM is a series of ten units designed to provide experiences for fifth graders that help them to accomplish an understanding of: (a) the nature of chemicals and how they interact with the environment, (b) how to collect, process, and analyze data, (c) how to use scientific evidence as a basis for life-style oriented decisions, and (d) how studying science and mathematics can be a productive and relevant part of their lives.

Contact: CEPUP, Lawrence Hall of Science
University of California
Berkeley, CA 94720

Earth's Mysterious Atmosphere

Grades: 5-8
Science Content: Chemistry, Physics, Earth Science, and Biology

A teacher's guide with activities that focus on changes occurring in the environment. The guide is organized around issues related to global warming and the thinning ozone layer, treating them as mysteries to be investigated and explained. The guide provides background and procedural information, as well as questions to discuss, suggestions for integration with other subjects, and home activities.

Contact: NASA Educational Affairs Division
NASA Headquarters
400 Maryland Avenue, SW
Washington, DC 20277-2028

Earth: The Water Planet, Revised Edition

Grades: 5-9
Science Content: Earth Science

This book explains how to use readily available materials and a variety of instructional methods to investigate how water shapes our planet and daily lives. Included are hands-on experiments challenging students to purify swamp water, conservation-oriented activities showing how much water is wasted by a dripping faucet, and a role-playing activity in which students present opposing views at a town meeting.

Contact: National Science Teachers Association
3140 N. Washington Blvd.
Arlington, VA. 22201

Evolution: Inquiries into Biology and Earth Science

Grades: 8-12
Science Content: Biology, Earth Science

This curriculum-based program for grades 8-12 integrates biology and earth science using evolution as a unifying theme. It includes lessons, hands-on activities, teacher materials and a CAV videodisc. This program was developed in cooperation with BSCS.

Contact: Videodiscovery, 1700 Westlake Ave. N, Suite 600, Seattle, WA 98109-3012

FAST (Foundational Approaches in Science Teaching)

Grades: 6-9
Science Content: Biology, Chemistry, Earth Science, Physics, Environmental Education

This is a full-year course that involves students in laboratory and field-oriented investigations in the context of three curricular strands: physical science, ecology, and relational study. The physical science and ecology strands introduce a typical array of concepts, but the relational study strand introduces students to matters such as resource management, environmental use, world food production, and conservation. The curricular package includes teacher guides, a student text, a student record book, a classroom library of reference booklets, and an evaluation guide. FAST has been recognized as an exemplary science program by the Search for Excellence in Science Education project of the National Science Teachers Association, and by the National Diffusion Network.

Contact: Dr. Donald B. Young, University of Hawaii–CRDG
1776 University Avenue
Honolulu, HI 96822

Informal Science Study

Grades: 5-12
Science Content: Physics

The Informal Science Study is a supplementary and complementary physical science curriculum package with components for grades 5 through 12. The materials capitalize on experiences that learners have in non-classroom settings, such as amusement parks, athletic events, and playgrounds. They are designed to assist students in the acquisition and application of science concepts in real-world situations.

Contact: Howard Jones, 112 Farish Hall
The University of Houston
Houston, TX 77004

Jeffco Life Science Program

Grades: 7-8
Science Content: Biology

This program is a year-long life sciences course which replaces the curriculum currently being used in general science or life science. It can also be used in an integrated science-health course. Learner materials consist of a text that integrates laboratory activities and readings. Topics fall in the categories of body structure, foods and digestion, body basics, body changes, cells and genetics, body controls, and ecosystems and ecology. Students apply these concepts in an application activity or discussion.

Contact: Middle School Life Science Office, Jefferson County Public Schools
1829 Denver West Dr. #27
Golden, CO 80401

Methods of Motion, Revised Edition

Grades: 5-9
Science Content: Physics

This manual is designed to help introduce Newtonian mechanics to students in the middle grades. The 27 teacher-created activities–including marble races, a tractor-pull using toy cars, fettucini carpentry, film container cannons, and others–use readily available materials to give students visual, aural, and tactile evidence to combat their misconceptions.

Contact: National Science Teachers Association
3140 N. Washington Blvd.
Arlington, VA. 22201

National Geographic Society Kids Network

Grades: 4-6
Science Content: Biology, Earth Science

With NGS Kids Network, kids don't just *study* science, they *do* science! This innovative program–available now for Apple IIGS and IBM computers, and soon for Macintosh–will motivate the most reluctant students. Kids conduct original research in acid rain, water pollution, weather, solar energy, and trash. Also, they collect data and share their findings via a modem with their "research teammates." NGS Kids Network is guaranteed to infuse your science classes with enthusiasm for learning. A *free* preview is available upon request.

Contact: National Geographic Society
Education Services, Box 98018
Washington, D.C. 20090
For further information, refer to number ERIC document number ED 403 017

Physics at the Indy 500

Grades: 6-9
Science Content: Physics

Basic physics principles are taught using examples drawn from Indy 500 auto racing. The package includes a videodisc, teacher manual and student lessons, and covers the following 5 major principles: Bernoulli Effect, Centripetal Force, Conservation of Energy, Doppler Effect, and Newton's Third Law. Interactive computer software for Macintosh or IBM/DOS is also available.

Contact: Videodiscovery
1700 Westlake Ave. N, Suite 600
Seattle, WA 98109-3012

Preparing for Tomorrow's World

Grades: 7-12
Science Content: Physics

Each module contains all the materials necessary to implement the program. Contained in a 3-ring binder format the teacher's guide presents objectives, activities, discussion questions, and other instructional aids. Where appropriate, the modules have student guides which contain all necessary background information. The student guides are reproducible. Some of the units include a film strip with audio tapes to present additional background information. The modules are: Coastal Decisions, Space Encounters, Beacon City: An Urban Land-Use Simulation, and Decisions.

Contact: Sopris West, Inc.
1140 Boston
Longmont, CO 80501

Project Earth Science: Astronomy

Grades: 5-9
Science Content: Physics, Earth Science

Hands-on, teacher-tested activities bring the concepts of astronomy down to Earth. The guiding theme of this book is Earth's uniqueness among the planets of the Solar System.

Contact: National Science Teachers Association
3140 N. Washington Blvd.
Arlington, VA. 22201

PROJECT W.I.Z.E. (Wildlife Inquiry Though Zoo Education): Survival Strategies

Grades: 7-10
Science Content: Biology, Physics, Environmental Studies

Project WIZE, a comprehensive environmental science curriculum project, geared for grades 7-10 enables teachers to combine hands-on and traditional classroom activities with those conducted in the field. The field components can utilize local zoos, aquariums, nature centers, or parks.

Contact: Bronx Zoo, Education Department
Bronx, NY 10460

Science CAP

Grades: 5-8
Science Content: All

Science CAP™ for Macintosh computers helps prepare great classroom science activities and can save hundreds of hours of preparation time. It is specially designed to help science teachers grades five through eight prepare exciting classroom science activities. Science CAP™ is a collection of more than 500 files containing science-related activities, diagrams, worksheets, overheads, teaching forms, tests and answer sheets. It covers topics ranging from astronomy to consumer product testing to science fairs. Every file is easy to use, modify and customize. It provides an excellent resource database and a framework for cataloging, enhancing and refining lessons. It comes with a 100% satisfaction guaranteed.

Contact: DEMCO, P.O. Box 7488
Madison, WI 5379i-9955

Science Discovery: Science Sleuths and the Image & Activity Bank

Grades: 6-9
Science Content: Biology, Earth Science

Image & Activity Bank (Disc 1) is a visual database of photographs, movies, computer graphics, animation, diagrams–all integrating major concepts in earth, life, and physical science. The multimedia videodisc is narrated in English and Spanish and includes 24 student lessons. *Science Sleuths* (Disc 2) consists of 24 science-oriented mysteries, plus all the clues, data, and resources needed to solve the "problems." It is very interactive and student-centered. The disc contains everything needed. The science mysteries are cross-disciplinary, integrating the major science disciplines. They include printed teacher and student materials.

Contact: Videodiscovery
1700 Westlake Ave. N, Suite 600
Seattle, WA 98109-3012

Science Essentials

Grades: 4-8
Science Content: A variety of topic areas

The SCIENCE ESSENTIALS video program is intended to stimulate viewers to actively explore the phenomena, to learn by doing. SCIENCE ESSENTIALS consists of 12 series, each of which contains four episodes (on four VHS videocassettes or one CAV videodisc). Each series focuses on a single topic: Animals, Ecosystems, Electricity and Magnetism, Geology, Heat, Human Body, Light, Matter, Plants, Simple Machines and Motion, Sound, and Weather.

Contact: Meg Boffey
310 S. Michigan Avenue
Chicago, IL 60604
(800) 554-9862

Science Plus

Grades: 6-8
Science Content: All

This Canadian textbook series was developed by the Atlantic Science Curriculum Project and is designed to develop students' understandings of significant ideas and their scientific process skills. This is achieved by using a directed discovery, or inquiry-approach that challenges students. It is an activity-based program, yet, for reasons of convenient manageability, only 30% of the activities are "hands-on" ones.

Contact: Project Director
Altantic Science Curriculum Project
University of New Brunswick

Science-Technology-Society: Preparing for Tomorrow's World

Grades: 7-12
Science Content: All

A multi-disciplinary approach to problem-solving and critical thinking designed to promote decision-making and problem-solving skills needed to deal with issued at the interface of science, technology, and society. A sound instructional model is utilized to develop the skills necessary for students to move to higher levels of cognitive reasoning and citizenship.

Contact: Sopris West, Inc.
1140 Boston
Longmont, CO 80501

Stones and Bones

Grades: 5-12
Science Content: Biology, Earth Science

A biological approach to the study of humankind provides activity-based, interdisciplinary laboratory investigations for grades 7 through 12. The instructional format is designed to meet the needs of students at all ability levels, from unmotivated and non-college oriented students to highly academic, college-oriented students. Each instructional pathway includes student laboratory explorations, student data worksheets, teacher's guide, and other supplementary instructional printed materials, as well as accurately replicated casts of fossil specimens used in the instructional program.

Contact: Physical Anthropology Center, 6625 Physical Anthropology Center, Van Nuys, California, 91406.

SWOOPE Radiation and Radon Unit

Grades: K-1
Science Content: Biology, Chemistry, Physics, Earth Science

SWOOPE, Students Watching Over Our Planet Earth, engages students (K-12) in the study of environmental science problems important to society. Using hands-on classroom activities written by teachers, students learn about certain aspects of environmental science, taking measurements on those aspects using real instruments. Some of the data are sent to a national database, where they can be analyzed and used by interested scientists. The students, then, receive discussions of what the regional, state, or national data reveal. In the SWOOPE *Radiation and Radon Unit,* students examine background ionizing radiation using hand-held Geiger counters and measure radon levels in their homes and schools.

Contact: Dianne Hyer/Roger Eckhardt
Los Alamos National Laboratory
MS D447
Los Alamos, NM 87545

SWOOPE Water Quality Unit

Grades:	K-12
Science Content:	Biology, Chemistry, Earth Science

SWOOPE, Students Watching Over Our Planet Earth, engages students (K-12) in the study of environmental science problems important to society. Using hands-on classroom activities written by teachers, students learn about certain aspects of environmental science, taking measurements on those aspects using real instruments. Some of the data are sent to a national database, where they can be analyzed and used by interested scientists. The students, then, receive discussions of what the regional, state, or national data reveal In the SWOOPE *Water Quality Unit,* students examine surface, ground, and city water for temperature, pH, turbidity, hardness, and the concentration of nitrates, coliform bacteria, and chlorine.

Contact: Dianne Hyer/Roger Eckhardt
Los Alamos National Laboratory
MS D447
Los Alamos, NM 87545

TOPS Modules: Open-Ended Task Cards and Structured Worksheets from TOPS Learning Systems

Grades:	4-12
Science Content:	All major topic areas

Tops offers 32 modules in science and mathematics covering a wide array of topics including: heat, light, sound, electricity, magnetism, machines, plants, animals, rocks and minerals, probability, metrics, solutions and oxidation. Each TOPS module contains comprehensive teaching notes in the front of the book, plus reproducible student task cards or worksheets in the back. Teachers gather their own simple materials and the module is ready to teach. Clear directions and quality illustrations lead students into independent hands-on explorations that are educational and fun. Learning becomes focused on student activity rather than discussion or lecture.

Contact: TOPS Learning Systems, 10970 S. Mulino Rd.
Canby, Oregon 97013

Wet and Wild Water

Grades: Not indicated
Science Content: Biology, Physical Science, Earth Science

As indicated by the title, this guide integrates subject matter around the topic of water. Individual modules focus on properties of water; fish and economics; water sports and animals; explorers; legends and strange occurrances; and global responsibility. Topic pages indicate core knowledge, activities, water experiments, and additional resources.

Contact: Indiana Department of Education, Center for School Improvement and Performance
Room 229, State House
Indianapolis, IN 46204-2798
ERIC Document Reproduction Service (refer to number ED 338 478)

Wetlands Are Wonderlands

Grades: 4-8
Science Content: Chemistry

These 4-H marine education guides, intended for students in grades 6-8 and their teachers or leaders, stress the importance of conserving wetlands. New information has been incorporated to update the guides. The information in *Wetlands Are Wonderful* teaches the value of wetlands and why we should conserve them, and includes project activities such as: taking field trips to wetland locations, investigating the various life forms in wetland soils, making model wetlands and then showing the ways humans have destroyed them, and more. The guides provide topics for discussion, questions, and activities, as well as a vocabulary and reference list.

Contact: Illinois-Indiana Sea Grant Program
University of Illinois at Urbana-Champaign
65 Mumford Hall
1301 W. Gregory Drive
Urbana, IL 61801

WOW (Windows on Wildlife)

Grades: 3-6
Science Content: Biology

This environmental science program for grades 3-6 focuses on endangered species and their habitats, but incorporates social studies, mathematics, and language skills into the framework of a wildlife studies curriculum. Teachers attend an orientation workshop, prior to their first visit. Curriculum materials include six booklets entitled: Rain Forests, Deciduous Forests, Wetlands, Desert, Endangered Species, Grasslands.

Contact: Bronx Zoo, Education Department
Bronx, NY 10460

Supplementary Materials

***After The Warming* Teacher's Guide**

Grades: 7-12
Science Content: Earth Science

This guide accompanies the *After the Warming* PBS television special written and hosted by James Burke. The major goal of this guide is to provide teachers with ready-to-use lessons. It has been created as a ready-to-use mini unit with reproducible pages of active involvement activities, and can be used by social studies, geography, environmental education, and general science classes. The guide also contains background notes, a program synopsis, references relevant to teacher resources, and bibliographies for the teacher and students.

Contact: Iris Wingert, Maryland Instructional Technology, 11767
Owings Mills Blvd.
Owings Mills, MD 21117

Bottle Biology Introductory Packet

Grades: 1-12
Science Content: Biology, Life Sciences

Bottle Biology is a classroom-tested approach to hands-on biology which allows students on all levels to become engaged in the actual process and activity of doing science: asking questions, creating experiments, testing hypotheses and generating "answers". Teachers and students working with Bottle Biology reuse disposable containers to explore many areas of the life sciences, leading to a better understanding of ecosystems, local environments, and biotic interactions. The activities give teachers, students, and scientists a low-cost and accessible scientific world, which includes microbes, plants, insects, and environmental interactions, as the ground from which to pose questions and launch investigations.

Contact: Bottle Biology Project
UW-Madison
Plant Pathology Department
1630 Linden Drive
Madison, WI 53706

The Great Lakes in My World

Grades: 1-8
Science Content: Biology, Chemistry, Earth Science

The activities are designed to fit into regular curriculum units in science, social studies, mathematics, and language arts, rather than stand alone as extracurricular "environmental education" activities crammed in at the edges of an already crowded school day. Some of the activities discuss natural processes in the Great Lakes, and some focus on pollution issues that require innovative problem solving.

Contact: Lake Michigan Federation
59 E. Van Buren, Suite 2215
Chicago, IL 60605

OEAGLS- Oceanic Education Activities for Great Lakes Schools

Grades: 5-9
Science Content: Biology, Earth Science

OEAGLS (pronounced "eagles") materials are designed to be easily integrated into existing curricula. Investigations are characterized by subject matter compatibility with existing curriculum topics; short activities lasting from one to three class periods; minimal preparation time; minimal equipment needs; standard page size for easy duplication; student workbook plus teacher guide; suggested extension activities for further information or creative expression; teachability demonstrated by use in middle school classrooms, and content accuracy assure by critical reviewers.

Contact: Ohio Sea Grant
1541 Research Center
1314 Kinnear Road
Columbus, OH 43212

The Outdoor Classroom

Grades: 1-12
Science Content: Biology, Earth Science

The outdoor lessons, concepts, and experiences in this program are designed to encourage teachers to utilize school sites, communities, parks, forests, rivers, ponds, wildlife areas, watersheds, and nature centers to design an in-depth outdoor education teaching plan to enrich the school curriculum.

Contact: Indiana Department of Education
Center for School Improvement and Performance
Room 229, State House
Indianapolis, IN 46204-2798
ERIC Document Reproduction Service (Refer to number ED 338 508)

Project Learning Tree

Grades: 1-12
Science Content: Environmental Education

This activity program is designed to help students develop an awareness and appreciation of their environments, the impact they have on it, and their responsibility for it. It is also designed so students develop skills and knowledge to make informed decisions regarding the use and management of the environment. The program contains more than 175 interdisciplinary activities.

Contact: Project Learning Tree Coordinator
Project Learning Tree
1250 Connecticut Avenue, Northwest
Washington, DC 20036

Project Wild

Grades: 1-12
Science Content: Biology, Environmental Education

This programs purpose is to develop an informed and ecologically literate citizenry who will rake responsible actions to benefit people, wildlife, and the environment. Workshops and books (*Project WILD Activity Guide* and *Project WILD Aquatic Activity Guide*) are available.

Contact: Project WILD State Coordinator
Project WILD
P.O. Box 18060
Boulder, CO 80308-8060

ScienceVision: An Inquiry-Based Videodisc Science Curriculum

Grades: 6-8
Science Content: Multidisciplinary

A product of the Interactive Media Science (IMS) Project at Florida State University; this program provides students with numerous opportunities to become involved in activities that would be impossible for them in the normal classroom setting. Using the ScienceVision program, students are able to conduct experiments, visit locations, listen to experts, make decisions, collect data, and solve the problems posed on the videodisc. The fundamental assumption of ScienceVision is that science education should be multidisciplinary and should provide a general science background for all students. The goals of ScienceVision are twofold: to provide students with a valid understanding of science as a human enterprise and to present science as a search for knowledge based upon interpretation of data.

Contact: ERIC Document Reproduction Service (refer to number ED 336 257)

Sci-Math–Proportional Problem Solving in Math & Science

Grades: 7-12
Science Content: Chemistry, Physics

Sci-Math is a supplement to the science or mathematics curriculum, for grades 7-12, and teaches students to use labeled rates as the key techniques for organizing their approach to word problems. It is designed to give students the fundamental problem-solving skills they need for dealing confidently and effectively with the kinds of problems (proportional comparisons, percents, etc.) they will encounter in mathematics and science courses, as will in everyday life. Sci-Math is the answer for science teachers whose students say they like science but hate the mathematics involved, and for mathematics teachers whose students say they would like mathematics if it weren't for the "story problems." The program includes materials, training, and follow-up services.

Contact: Sci-Math, 4655-25th st.
San Francisco, CA 94114

Starfinder

Grades: 7-12
Science Content: Physics, Astronomy

Starfinder brings the discoveries of the Hubble Space Telescope into the classroom in a context that supports the study of earth science and physics. Each program consists of three parts: "Data Stream" highlights an important finding made possible by the telescope. "Science Links" correlates one specific earth science or physics concept with the working of the universe. "The People Behind HST" profiles the jobs of people associated with the telescope and how their career paths evolved. Thirty programs; 15 minutes each.

Contact: Iris Wingert, Maryland Instructional Technology
11767 Owings Mills Blvd.
Owings Mills, MD 21117

Suited for Spacewalking

Grades: Not rated
Science Content: Earth Science, Physical Science.

This publication is an activity guide for teachers interested in using the intense interest many children have in space exploration as a launching point for exciting hands-on learning activities. The guide begins with brief discussions of the space environment, the history of spacewalking, the Space Shuttle spacesuit, and working in space. These are followed by a series of activities that enable children to explore the space environment as well as the science and technology behind the functions of spacesuits.

Contact: NASA Teacher Resource Center
JPL Educational Outreach
Mail Stop CS-530
Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109
(818) 354-6919

Teaching Science with Toys

Grades: K-6
Science Content: Physical Science

This book contains 51 activities for teaching science through the use of toys. The activities are designed to use inexpensive materials and to get children involved in investigations and problem solving.

Contact: ERIC/CSMEE
1929 Kenny Road
Columbus, OH 43210-1080
(614) 292-6717

ZEST (Zoos for Effective Teaching)

Grades: 7-12
Science Content: Biology

ZEST provides 12 full-day sessions for teachers in middle schools and high schools, including teacher conferences, peer dissemination, and production of a teacher's manual. Th emphasis is on use of a zoological collection within the required biological science curricula, as well as enrichment for instruction in the physical sciences.

Contact: Education Department, Bronx Zoo
Bronx, NY.

Program Frameworks

National Council on Science and Technology Education. (1989). ***Science for all Americans.*** Washington, DC: American Association for the Advancement of Science.

This document summarizes the first phase of a long-term project (Project 2061) to identify the knowledge, skills, and attitudes that all students should acquire during their school experiences (K–12) in science. A strong case is made for reducing the amount of factual material traditionally presented, and placing more emphasis on active inquiry. The report is strongly influencing science reform efforts throughout the USA as the second phase of Project 2061 engages teams of educators and scientists in the process of developing alternative curriculum models for use in schools. Any school or district engaged in science reform efforts should become familiar with this document. The report is available from: AAAS Books, Dept. 2061, P.O. Box 753, Waldorf, MD 20604.

National Research Council. (1993). *National Science Standards. An Enhanced Sampler.* Available free from National Research Council; 2101 Constitution Avenue, NW; HA 487; Washington, DC 20418.

National Science Teachers Association. (1992). ***Scope, sequence and coordination of secondary school science, Volume 1. The content core: A guide for curriculum designers.*** Washington, DC: Author.

This guide was specifically developed as an aid to designers of science curricula (grades 6-12) and is published by the nation's largest association of science teachers. The first section of the book presents principles and strategies of curricular coordination,with the second section presenting detailed recommendations for scopes and sequences for courses in biology, chemistry, earth and space sciences, and physics. The recommended content core (framework) is presented through a combination of tables and narratives. For more information, contact: Scope, Sequence and Coordination, The Common Core, National Science Teachers Association, 1742 Connecticut Avenue, NW, Washington, DC 20009-1171.

Mayer, V. J. and others. (1992). **The role of planet earth in the new science curriculum.** *Journal of Geological Education, 40,* 66-73.

Though not a curriculum framework by conventional definitions, this succinct article provides an overview of a major curriculum reform effort to place study of planet earth at the center of K–12 science curriculum development. The article provides a strong rationale for rethinking the K–12 curriculum, presents a *Framework for Earth Systems Education*, and describes implementation efforts. This is a good example of how a robust reconceptualization of the curricular core can be concisely communicated in clear terms. Indeed, the *Framework* along can be presented on one page (see Mayer, V. J. (1991). Framework for earth systems education. *Science Activities, 28*(1), 8-9). It is an approach to be emulated.

National Center for Earth Science Education. (1991). ***Earth science content guidelines grades K–12***. Alexandria, VA: American Geological Institute.

This framework represents what can be accomplished by writing teams comprising teachers, science educators, and scientists when consensus-building deliberation occurs. The framework is based on four broad goals for students that relate to literacy in science and earth science. The framework organizes content around essential questions that relate to six content areas: solid earth, water, air, ice, life, and earth in space. The essential questions are distributed across grade levels, and for each essential question the framework provides key ideas and ways of engaging students in the ideas. Finally, some curriculum materials and resources are identified for each of the six content areas. For further information, contact: AGI Publications Center, P.O. Box 2010, Annapolis junction, MD 20701.

National Center for Improving Science Education. (1989). ***Getting started in science: A blueprint for elementary school science education***. Andover, MA: The Network.

Though this report treats instruction, assessment, and teacher education in addition to curriculum development, one chapter presents a vision of elementary school science in the form of general curriculum framework that accommodates a broad range of topics and goals. The framework is organized according to broad concepts that relate to both science and technology. Some attitudes associated with scientific enterprise are also presented. For further information, contact: Susan Loucks-Horsley, Associate Director, 290 South Main Street, Andover, MA 01810.

National Center for Improving Science Education. (1990). ***Science and Technology Education for the Middle Years: Frameworks for Curriculum and Instruction.*** Andover, MA: The Network.

This book describes organizing principles that incorporate suggested science content, and a learning sequence that illustrates how more "hands-on, minds-on" science can become more prevalent in schools serving middle grade students. Frameworks are based on the special needs of young adolescents, including the kinds of school settings where science learning can flourish. For ordering information, contact: Publications Department, 300 Brickstone Square, Suite 900, Andover, MA 01810.

State of Connecticut Board of Education. (1991). ***A Guide to Curriculum Development–SCIENCE.*** Connecticut State Department of Education.

This curriculum guide is designed to help districts develop their own state-of-the-art learning programs and opportunities in science. The guide describes what can and should happen in quality K-12 science settings. The guide helps planners view the student as the beneficiary of curriculum.

Curriculum Development Resources

Dunn, G. A. (1990). ***Buggy books: A guide to juvenile and popular books on insects and their relatives***. Lansing, MI: Young Entomologists' Society, Inc.

This unique compilation of 736 resources includes references to several teacher guides and instructional aids. If you are seeking background material for units on insects, you cannot find a more comprehensive or functional listing. Books are organized by title, age-appropriateness, subject, and author. For more information, contact: Young Entomologists' Society, Inc., 1915 Peggy Place, Lansing, MI 48910-2553.

Galda, L., and others. (1990). **Exploration and discovery: Books for a science curriculum (children's books)**. *Reading Teacher, 44*, 316-25.

This article reviews 92 children's books which would enhance many topics in a science curriculum. A good source of titles to complement unit activities or textbook information.

Helgeson, S. L., Howe, R. W., & Blosser, P. E. (1990). ***Promising and exemplary programs and materials in elementary and secondary schools–Science***. Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education.

This document describes 36 programs or sets of materials that have been identified as exemplary in some way. Nominations were solicited from state and local coordinators, science curriculum specialists, and federal program staff members. Entries for each program or set of materials includes a program description, evaluative data or comments, specific materials available, and an address for more information. The publication is available from ERIC/CSMEE Publications, 1929 Kenny Road, Columbus, OH 43210-1080.

National Science Resources Center. (1988). ***Science for children. Resources for teachers***. Washington, DC: National Academy Press.

A valuable compendium of curriculum materials, supplementary resources, and informational sources, with abstracts and price information. A copy of this book has been sent to every school superintendent in the nation and should be in the hands of anyone attempting to use existing materials to update programs. All the materials presented in this guide have been shown effective in activity-based, inquiry-oriented programs. For more information, contact: National Science Resources Center, Arts and Industries Building, Room 1201, Smithsonian Institution, Washington, DC 20560.

Office of Educational Research and Improvement. (1989). ***Science education programs that work. A collection of proven exemplary educational programs and practices in the National Diffusion Network***. Washington, DC: U.S. Department of Education.

A compendium of 16 program descriptions prepared through the efforts of the National Diffusion Network (NDN). The NDN Program Effectiveness Panel reviews programs reported as effective, then disseminates information and materials from programs found to be exemplary. All programs reported by the NDN are supported by evaluative data.

Paulu, N. (1991). ***Helping your child learn science***. Washington, DC: Office of Educational Research and Improvement, U.S. Department of Education.

Though designed for parents, this document provides many good examples of simple science activities for children (ages 3 to 10 years) to do in their homes or communities. A useful listing of science books and resources is also included. This document is available from the ERIC Document Reproduction Service (ask for ED 330 584).

Appendix C

ERIC CSMEE *Digest*

Assessing Student Performance in Science

David L. Haury

With increased student achievement in science being a national goal (AMERICA 2000, 1991), do we know what students are learning? Given the emerging national standards in science education (National Committee on Science Education Standards and Assessment (NCSESA), 1993), how will we determine whether students measure up to the standards? Radical changes are underway for school science curricula (Rutherford & Ahlgren, 1990; The National Science Teachers Association (NSTA), 1992), but are complementary changes in assessment in progress? States are developing student assessments based on science frameworks or guides (Blank & Engler, 1992; Davis & Armstrong, 1991), but do we know how to assess student performance in all the domains of interest and concern? Assessment of student performance is emerging as a crucial ingredient in the recipe for ongoing improvement of school science. As programmatic change is occurring, there is a need to align student assessment practices with curricular aims, instructional practices, and performance standards. In short, "What we teach must be valued; what we test is what must be taught" (Iris Carl as quoted in McKinney, 1993).

Functions of Assessment

Before considering alternative approaches to assessing student performance, it is important to consider the various functions that assessment serves. Various reasons for assessing student performance have been described in both specific terms (Kober, 1993, pp. 57-58; Raizen & Kaser, 1989) and general terms (Meng & Doran, 1993), with distinctions being made between assessment for reporting purposes and for purposes of diagnosis and program evaluation. Eventually, as National Science Education Standards are developed, guidelines for assessing both student achievement and program effectiveness will be developed (NCSESA, 1993).

In this digest, the focus is on assessment in the service of instruction, for helping students, teachers, and parents monitor learning. Assessment in this context must be unobtrusive and tailored to measure specific learning outcomes, not necessarily norm-referenced and generalizable across schools, states, and countries (Haertel, 1991). What are the issues and methods of assessment in the context of classroom instruction?

New Forms of Assessment

Jorgensen (1993) cited the plethora of new labels for assessment strategies in contrast to the scarcity of expertise, procedures, and guidelines as evidence of a paradigm shift in assessment. There is an urgency to develop innovative forms of assessment that provide valid indicators of student understanding and other learning outcomes, but there is widely divided opinion as to how to proceed. Even though teachers know that students who are most knowledgeable in science are not necessarily the ones that get the highest grades, most continue to depend on multiple-choice test scores to determine grades (Baron, 1990). Furthermore, there is evidence that standardized testing strongly influences instructional planning among teachers (Herman & Golan, 1992). So, "one thing must be made clear from the outset: assessment encompasses more than testing, and much more than standardized testing. It includes such techniques as systematic teacher observation and so-called 'authentic' assessment, in which the tasks assessed more closely parallel the learning activities and outcomes that are desirable in the science classroom" (Kober, 1993)

Among the new labels being used today is *performance-based assessment*. Though there are a variety of definitions, it is clear that performance-based assessment does not include multiple-choice testing or related paper-and-pencil approaches. According to Jorgensen (1993), "performance-based assessment requires that the student complete, demonstrate, or perform the actual behavior of interest. There is a minimal degree of inference involved." Baron (1991) has provided a list of characteristics of performance assessment tasks, with a notable blending of content with process, and major concepts with specific problems. As Kober (1993) has mentioned, "in this type of assessment, students may work together or separately, using the equipment, materials, and procedures they would use in good, hands-on science instruction."

Guidelines for Schools and Classrooms

Today's assessment strategies must be aligned with the emerging vision of "science for all," with all students engaged in science experiences that "teach the nature and process of science as well as the subject matter" (NCSESA, 1993). A first step in considering assessment methods, then, is to become familiar with the wide range of student outcomes that are being endorsed by science teachers (NSTA, 1992), scientists (Rutherford & Ahlgren, 1990), and the National Research Council (NCSESA, 1993). It is also necessary to consider the diverse needs, interests, and abilities of students, particularly girls, minorities, students with disabilities, and those with limited English proficiency. "Assessment should be context dependent; reflect the nature of the subject matter; and address the unique cultural aspects of class, school, and community among culturally diverse populations" (Tippins & Dana, 1992). As White and Gunstone (1992) have stated, "a limited range of tests promotes limited forms of understanding.

As an example of how alternative assessment strategies can enable students to show what they know in a variety of knowledge domains, consider the approach taken in one urban school (Dana, Lorsbach, Hook, & Briscoe, 1991). Concept mapping and journal writing techniques are used to document conceptual change among students, and student presentation and interview techniques allow learners to communicate their understanding in ways that rely less on reading and writing skills. For additional samples of techniques being used, see the Appendix of Kulm and Malcom (1991).

Among the promising alternative assessment techniques are the use of scoring rubrics to monitor skill development and the use of portfolios to assemble evidence of skill attainment. Scoring rubrics can be used to clarify for both students and teachers how valued skills are being measured (Nott, Reeve, & Reeve, 1992). Portfolios documenting student accomplishments can take a variety of forms, with student products, collected data, or other evidence of performance being used as information for self, peer, or teacher evaluation (Collins, 1992).

It should be acknowledged that there are drawbacks to performance assessments. Staff development will be required, performance assessments take more time than conventional methods, standardization is difficult, and the results may not be generalizable from context to another. These problems reinforce the importance of practitioners, assessment specialists, and assessment "consumers" being clear on the purposes of specific assessment activities. There is no one approach to assessment that will best serve all functions, knowledge domains, and learners.

Resources

Educational Leadership, *49*(8). (This special issue of May, 1992 includes sections on Using Performance Assessment and Using Portfolios. A synthesis of what research tells us about good assessment is also included. One article, "What we've learned about assessing hands-on science," pp 20-25, addresses the specific concerns related to assessing inquiry-oriented teaching outcomes.)

F in, G. (Ed.). (1990). *The assessment of hands-on elementary science programs*. Grand Forks, ND: Center for teaching and learning, North Dakota University. ED 327 379 (This document examines a wide variety of issues related to assessment, including a section on new approaches to science assessment.)

Herman, J. L., Aschbacher, P. R., & Winters, L. (1992). *A practical guide to alternative assessment*. Alexandria, VA: Association for Supervision and Curriculum Development. (This resource addresses several key assessment issues and provides concrete guidelines for linking assessment and instruction, and for assessment design.)

Kulm, G., & Malcom, S. M. (Eds.). (1991). *Science assessment in the service of reform*. Washington, DC. American Association for the Advancement of Science. (This is a compilation of contributed chapters that treat policy issues and the relationships between assessment and curriculum reform, and between assessment and instruction. Several practical examples from the field are also included.) ED 342 652

Meng, E., & Doran, R. L. (1993). *Improving instruction and learning through evaluation: Elementary school science*. Columbus, OH: ERIC Clearinghouse for Science, Mathematics, and Environmental Education. (This is a practical guide for teachers and anyone else involved in assessing student performance in elementary school science. Separate sections focus on assessing science process skills, concepts, and problem-solving.) SE 053 614

Raizen, S., & others. (1990). *Assessment in science: The middle years*. Andover, MA: The NETWORK, Inc. ED 347 045 (This document is part of a set of reports that focus on science and mathematics education for young adolescents. Practical guidelines for assessment are provided for policymakers and practitioners on the basis of research findings and recommendations gleaned from the literature. New directions in assessment are discussed.) ED 347 045

Science Scope, 15(6). (This issue of March, 1992 includes a special supplement on alternative assessment methods in science, including sections on performance-based assessment, the use of portfolios, group assessments, concept mapping, and scoring rubrics.)

Semple, B. M. (1992). *Performance assessment: An international experiment*. Princeton, NJ: Educational Testing Service. (This document describes an attempt to supplement the pencil-and-paper approach of the International Assessment of Educational Progress in mathematics and science with a performance component. Both the results of the experiment and full descriptions of the performance tasks are provided, including tasks that focus on problem solving, the nature of science, and physical science concepts.)

White, R., & Gunstone, R. (1992). *Probing understanding*. New York: Falmer Press. (A practical but theoretically sound guide to alternative approaches to assessing understanding through application of nine types of *probes*: concept mapping, prediction-observation-explanation, interviews about instances and events, interviews about concepts, drawings, fortune lines, relational diagrams, word associations, and question production.)

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