DOCUMENT RESUME

ED 314 237 SE 050 681

AUTHOR Bybee, Rodger W.; And Others
TITLE Science and Technology Education for the Elementary Years: Frameworks for Curriculum and Instruction.
INSTITUTION Biological Sciences Curriculum Study, Boulder, Colo.; National Center for Improving Science Education, Andover, MA.; NETWORK, Inc., Andover, MA.
SPONS AGENCY Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE 89
GRANT RI68B80001
NOTE 155p.; For related reports, see SE 050 679-680.
PUB TYPE Viewpoints (120) -- Reports - Descriptive (141)

EDRS PRICE MF01/PC07 Plus Postage.
DESCRIPTORS *Elementary School Science; *Science and Society; *Science Curriculum; Science Education; Science Facilities; *Science Instruction; Science Programs; *Science Teachers; *Scientific Literacy

ABSTRACT

This report is a policy statement for science curriculum and instruction in elementary schools. It describes a set of organizing principles that incorporate what science ought to be taught, and a learning sequence that illustrates how more "hand-on, minds-on" science can become more prevalent in our schools. Chapters included are: (1) "Introduction" (discussing the current situation in science classrooms and the frameworks for curriculum and instruction); (2) "A Conception of Science and Technology"; (3) "The Goals and Rationale"; (4) "A Framework for Curriculum" (describing the organizing concepts, attitudes, skills and topics); (5) "A Framework for Instruction" (describing assumptions about student learning, teacher role, teaching model, and teacher development); (6) "Educational Environment" (including facilities, materials, instructional technology, and classroom management); and (7) "Conclusions." Seven National Science Foundation programs for elementary schools and five exemplary science education programs in the National Diffusion Network are summarized in the appendices. (YP)

The National Center for Improving Science Education

Science and Technology Education for the Elementary Years: Frameworks for Curriculum and Instruction

A PARTNERSHIP OF THE NETWORK, INC. AND THE BIOLOGICAL SCIENCES CURRICULUM STUDY (BSCS)

The NETWORK, Inc.

BSCS
The Natural Selection

Science and Technology Education For the Elementary Years: Frameworks For Curriculum and Instruction

by

Rodger W. Bybee, Chair

C. Edward Buchwald

Sally Crissman

David R. Heil

Paul J. Kuerbis

Carolee Matsumoto

Joseph D. McInerney

1989

The National Center for Improving Science Education

A Partnership of

The NETWORK, Inc.
Andover, Massachusetts
Washington, D.C.

and

The Biological Sciences Curriculum Study
Colorado Springs, Colorado

This report is based on work sponsored by the Office of Educational Research and Improvement, U.S. Department of Education, under Grant number R168B80001. The content of this report does not necessarily reflect the views of OERI, the Department, or any other agency in the U.S. Government.

THE NATIONAL CENTER FOR IMPROVING SCIENCE EDUCATION ADVISORY BOARD MEMBERS

CURRICULUM AND INSTRUCTION PANEL

Rodger W. Bybee
Associate Director
Biological Sciences Curriculum Study
Colorado Springs, CO

C. Edward Buchwald
Professor and Chair of Geology
Lloyd McBride Professor of Environmental Study
Carleton College
Northfield, MN

Sally Crissman
Science Teacher and Lower School Head
Shady Hill School
Cambridge, MA

David R. Heil
Associate Director
Oregon Museum of Science and Industry
Portland, OR

Paul J. Kuerbis
Project Director
The National Center for Improving Science Education
Professor of Education
The Colorado College
Colorado Springs, CO

Carolee Matsumoto
Senior Associate
Education Development Center
Newton, MA

Joseph D. McInerney
Director
Biological Sciences Curriculum Study
Colorado Springs, CO

TABLE OF CONTENTS

FOREWORD

This report is one of a series produced by the National Center for Improving Science Education. The Center's mission is to promote changes in state and local policies and practices in the science curriculum, in science teaching, and in the assessment of student learning in science. To fulfill its mission, the Center develops practical resources for policymakers and practitioners by synthesizing and translating the findings, recommendations, and perspectives found in recent and forthcoming studies and reports. By bridging the gaps between research, practice, and policy, the Center's work is intended to promote cooperation and collaboration among organizations, institutions, and individuals who are committed to improving science education.

The synthesis on curriculum and instruction herein was derived with the help of the study panel, whose members are listed in the front of this report. We gratefully acknowledge the help provided by the many who have supplied materials, offered recommendations, and made suggestions for this report. Although the list is too long to acknowledge each contribution individually, we are indebted to Sharon Smit for her early work preparing materials for study panel members, and to Deborah Hannigan for her review and synthesis of the study panel reports. We acknowledge the work of Barbara Brandt, who pulled the numerous pieces of this report together, Yvonne Wise, who improved the report by pointing out errors and inconsistencies, and Robert Warren, who edited the report and drafted the executive summary. We gratefully appreciate Frances Lawrenz of the University of Minnesota, who acted as an outside evaluator of the report, for her critical comments. Special acknowledgements are also due to the support center's monitors at the U.S. Department of Education: John Taylor and Wanda Chambers.

Two other panels have produced companion reports on assessment and on teachers and teaching. A summary report integrating all three documents will be prepared and will be available from the Center. This integrative report will be supplemented by implementation guides for state and district policymakers and practitioners and by guidelines especially tailored for additional audiences, including teachers, principals, school boards, parents, and teacher educators.

The Center a partnership between The NETWORK, Inc., of Andover, Massachusetts, and the Biological Sciences Curriculum Study (BSCS) of Colorado Springs, Colorado, is funded by the U.S. Department of Education's Office of Educational Research and Improvement. Members of the Center's Advisory Board are listed in the front of this report. For copies of this report, or further information on the Center's work, please contact Senta Raizen, Director, National Center for Improving Science Education, 1920 L Street, Suite 202, Washington, D.C. 20036, or Susan Loucks-Horsley, Associate Director, National Center for Improving Science Education, The NETWORK, Inc., 290 South Main Street, Andover, Massachusetts 01810.

PREFACE

Reports on contemporary education have proclaimed the need for change, have presented the purposes of education, and have provided the justifications for reform. For the most part, recommendations from these reports are general statements that the public and educators alike support. Often study panels, college professors and educational consultants have identified problems and made recommendations with the expectation that the education community would quickly and easily recognize the need to change, and subsequently, begin to change. The expectation is logical and workable, but unfortunately, the gap is too large between statements of new purposes and changes in school programs and teaching practices. There is need for an intermediate step that can be thought of as a series of policies, or general plans that will help direct decisions and actions. These policies are more specific than broadly stated purposes.

This report is a policy statement for science curriculum and instruction in elementary schools. Because this report's focus is on science education in elementary schools, it is more concrete than other national reports. It would be inappropriate, however, to go from this report directly to schools and classrooms. Just as the study panel that prepared the report went through a process of reviewing the data and translating the data into a policy statement, so too must those who use the report consider the unique aspects of school districts, teachers, and students.

The study panel's directive was to concentrate on curriculum and instruction. The panel, however, is fully aware of Garrett Hardin's admonition for human ecology--*You can't do only one thing*. In the context of this report, educators must not only change the curriculum and their instruction, they must also consider assessment, materials, facilities, equipment, teacher education, and staff development, --to mention only a few issues.

The study panel has done its best to bring educational reform in science programs for elementary schools one step closer to reality. But, the final translation is perhaps the most difficult--actually changing extant programs and practices. Difficult as this is, the final step is making reform a reality.

Study Panel on Curriculum and Instruction
National Center for Improving Science Education

EXECUTIVE SUMMARY

Science proposes explanations for that which is observable, whereas technology proposes solutions for problems of human adaptation to the environment. These are the distinctions the panelists make between science and technology, a distinction that elementary school students need not explicitly understand, but rather a distinction that they should tacitly understand. Once the children begin to perceive these differences, they are well on their way to taking control of their lives and functioning productively in a scientific and technologic society. It is to this end that the panelists have designed two frameworks, one for curriculum, and one for instruction. How these two frameworks should be used, where they should be used, and why they should be used are the subjects of this report.

Technology is one of the more unique features of the panel's curriculum and instructional frameworks. Existing programs seldom present technology as a topic worthy of study itself, and, when it is presented, it is usually defined as the application of scientific knowledge, which is less than correct. Technology is more than an applied science, and it is more than a method. Indeed, technology is a process whose endpoint is the solution to a problem. This solution can take many forms, because inevitably there are many objectives, requirements, constraints--*variables.* These variables drive our modern technologic society, yet they are never presented within elementary school curricula. The panel redresses this omission in its curriculum and instructional frameworks.

Science, like technology, is often misrepresented. Many existing curricula present science as a body of knowledge, and only secondarily do these programs present science as a process for establishing new knowledge. Fundamentally, science is a method by which we construct rational explanations for events in the natural world that, at first, might seem incomprehensible, but through study and research become predictable, even manipulable. These explanations are always tentative, they continue to evolve, and it is this understanding of science that the panel's curriculum and instructional frameworks attempt to convey.

Of course, one-line definitions do not sufficiently explain the relationships between science and technology. Although science and technology are differing enterprises, they are inextricably bound, one to the other, and they, in turn, are inextricably bound to modern society. It is incumbent upon the citizen to make informed decisions and to realize that for every technologic application there are trade-offs, and that along with scientific understanding comes responsibility. One purpose of the panel's curriculum and instructional frameworks is to lay the foundation for a technologically and scientifically informed citizenry.

Developing these basic attitudes toward and understandings of science and technology will not be easy, and these goals can only be accomplished through the realization of yet other goals. The students must develop a basic vocabulary and knowledge, without having their natural curiosity stifled by "rote learning." They must broaden their investigative and problem-solving skills and learn how to make informed decisions. Finally, they must develop an understanding of the limits and possibilities of science and technology.

The curriculum framework presented in this report is straightforward. The curriculum should consist of hands-on activities, each of which should relate to the students' world. Further, the students should develop their scientific and technologic concepts and skills within a personal and social context. Rather than skimming a great many concepts, the students will be able to study a few concepts in great depth. The panel recommends a constructivist approach, which means the students should be able to construct their concepts and skills through a variety of experiences. Finally, the curriculum framework gives opportunities and a context for the students to hone their reading, writing, speaking, and mathematical skills.

The foundation of a curriculum framework should be its organizing concepts. Five criteria constitute the "filter"for this curriculum's organizing concepts. The concepts must not only apply to science and technology, but they must have applications beyond science and technology. They must accommodate different developmental levels and apply to each child's personal life. Most important, the organizing concepts must provide powerful explanations.

The panel identified nine major concepts which they believe should be the core of an elementary science program:

- Organization (or orderliness)
- Cause and effect
- Systems
- Scale
- Models
- Change
- Structure or function
- Discontinuous and continuous properties (variations)
- Diversity

Attitudes are also a keystone of the curriculum framework. The students should be skeptical, yet desire knowledge. They should accept ambiguity, and subsequently be willing to modify their explanations. Honesty, a reliance on data, and respect for reason are also important, as is working cooperatively with others.

When designing the instructional framework, the panelists made several assumptions that directly affect how teachers should teach science in the classroom. Some educators assume that a student's learning develops from the sequential acquisition of skills and bits of information. In practice, these educators attempt to teach science by transmitting definitions, terminology, and facts to students who passively receive this information. This approach has clearly failed to provide American students with an adequate background in science--a background that they can apply in a variety of non-school settings. Therefore, the panelists have incorporated a constructivist approach into the framework. Constructivism assumes that students actively learn through hands-on experiences; constructivism also postulates that the students are constantly constructing their world view.

Because of its constructivist approach, the instructional framework has linkages to three related ideas: prior knowledge, student learning styles, and concentration of teaching on depth and understanding, rather than on breadth of coverage and knowledge of vocabulary. These linkages affect the teacher's role in many ways. A student develops a meaningful understanding of a concept only when it is presented in a familiar context. That is why it is important for a teacher to determine what a student's prior knowledge is, and then help the student to link the new concept to the prior knowledge. Just as an effect presupposes a cause, how to present a concept in a familiar context presupposes a need to address learning styles. No two students have exactly the same approach to learning One student may have a sequential learning style, while another has a global approach. Further, a teacher might present information through several modes: tactile, visual, or auditory. No matter which learning style a student might prefer, it will take time for the student to assimilate a new concept and develop a useful understanding of it. This suggests that a student should pursue a theme or topic in depth Therefore, a theme or topic might span several weeks or more. Prior knowledge, student learning styles, and concentration of teaching on depth and understanding, then, all require the teacher to take on a new role--that of facilitator.

A facilitator does not provide expert knowledge, rather, a facilitator manages the students' learning. Facilitators model the qualities they wish to encourage in their students by showing curiosity, awe, and enthusiasm. On an altogether different level, they are strategists who determine whether to use competitive activities, individual work, or cooperative groups.

Teachers have yet another important role to fill--that of assessor. Through assessment a teacher is provided with valuable information on how to increase learning. Assessment helps the teacher determine a student's prior knowledge. The assessment data also helps a teacher establish what the students have learned and motivates the students to attend to the assigned materials.

In addition to defining new roles for teachers, the panel's instructional framework incorporates a four-stage teaching model. Each stage of the model is characteristic of the approach science and technology professionals take when they learn and apply new skills. The model begins with the *invitation*, which is a question about the natural world (science) or a problem in human adaptation (technology). The second stage is *exploration*, in which the students observe, collect data, organize information, and think of additional experiments they might try. The third stage is *explanation*, in which the students begin to construct their new view of the concept by integrating their preexisting conceptions with the new information. The fourth stage is *taking action*, in which the students demonstrate that they have truly integrated the information with their existing network of concepts.

The panel's instructional framework makes heavy demands upon teachers. How can they
manage all the innovations? The panel recommends three changes in teachers' development that should solve this problem. In preservice development, the panel recommends that a teacher major in a discipline. A teacher should take coursework in one or more sciences, as well as in child learning and development. The middle phase of a teacher's development should focus on guidance and feedback in situations that gradually change from "ideal,"one-child, low constraint to real classroom situations At this point the teacher should also attend to developing a repertoire of teaching strategies and to integrating theoretical constructions into a real classroom. Finally, the later phase of development should concentrate on developing a teacher's scientific knowledge and providing the teacher with an environment in which new knowledge is supported and renewed.

In summary, the curriculum and instructional frameworks presented in this report are new, innovative, yet based on sound research. They introduce into the classroom science and technology as the two disciplines are practiced in modern society. This new approach requires elementary school teachers to fulfill new roles and assume new responsibilities. New support structures for teachers must be built, and administrators and teachers alike must be willing to put forth extra effort to implement the frameworks. Despite the difficulties, the rewards will be great: a scientifically and technologically literate citizenry adequately prepared to take its place in the twenty-first century.

I. INTRODUCTION

The following is a scenario on a new approach to teaching science. The classroom unit on seeds takes place over several weeks.

A Science Classroom: An Interdisciplinary Approach

"How do seeds live? Can seeds grow way, way deep in the ocean and make seaweed?" "How do seeds get inside of watermelons?" "Hey! How do they make watermelons without seeds in them? How do seeds grow plants?" These are some of the many questions asked by Ms. Lopez's second graders.

Today, seeds are the topic. As the students are thinking about the origin of seeds, Ms. Lopez writes down their questions on a piece of oak-tag titled: "Questions We Have About Seeds." Another chart titled "What We Know About Seeds" contains such statements as "Seeds grow in gardens," "You can eat sunflower seeds," and "Carrots don't have seeds." Ms. Lopez refers to these charts constantly. She encourages the children to ask questions, and she guides the children as they form their concepts and change their beliefs. She uses their questions and comments to decide whether the children are ready for a "seed walk."

The next morning all the students go to a nearby field and collect seeds. Each student, besides carrying a collection bag, wears a large wool sock, used for collecting seeds, over one shoe and pulled up to the knee. After returning from the walk, each student selects one seed to study carefully with a hand lens. They observe what the seed looks, feels, and smells like, and guessing how it might travel. Then each child makes a presentation to the class, which is gathered in a meeting circle. By taping the seed specimens onto a chart, the teacher keeps track of the different seeds the class discusses. After the students tally how many of each seed they found, they graph their results.

That evening, after the seed walk, Ms. Lopez reflects on the differences in the children's understandings of the structure and function of seeds. She notes which children easily made observations and which ones had difficulty, which children made more obvious or more creative responses, and which children seemed comfortable or uncomfortable using the lens for examining their seeds. While planning the next day's activities, Ms. Lopez consults her notes and places the children in groups that will prompt and challenge each student.

The next day, some groups choose to count the seeds that came back on their socks and then plant the seeds in large, self-sealing plastic bags and water; the groups then set the plastic bags and seeds near the windows. In the days that follow, the groups will observe the germination process carefully and compare the total number of seeds with the number that sprouted by making "ratio" graphs and by writing corresponding sentences. Ms. Lopez invites other children to compare sizes of seeds; she asks them to outline the seeds on graph paper and then count the number of graph squares that each seed covers. The students discover that there is a great diversity of sizes and shapes in different seeds and that the same kind of seed varies in size and shape.

Still other groups choose to continue working on their "seed journals," which Ms. Lopez requires al' the students to keep. The children either paste in or draw the specimen and then write about three seeds of their choice, including observations shared earlier in the meeting circle. Because students of this age have a range of writing capabilities, Ms. Lopez meets with each child and discusses that individual's observations and writing. She uses both the journal entries and group presentations to monitor their understanding of diversity, cycles, and other major scientific concepts.

Ms. Lopez's class spends most of the day working on the concepts of diversity and cycles. She incorporates writing, math, and inquiry-based science activities into the program. The children will also have to write a story about how a Native American girl uses seeds and plants, compose a garden song, and complete additional writing and mathematical assignments.

In successive lessons, Ms. Lopez will call groups together and ask several activity-related questions, the answers to which should be based on the students' explorations. As she records the students' responses, Ms. Lopez will ask the children to clarify their answers. Eventually, she will introduce new vocabulary words and information that will help the students develop scientific concepts. A few of the children may be unsure about the new information; they will need more time for discussion and additional testing of their ideas before the new information becomes a part of their personal understanding of seeds. For instance, last year when they were taught this unit, several youngsters insisted that the lima bean embryos they had discovered inside the seeds would grow into lima bean plants without the seed halves attached. They were convinced that the embryos could "eat" the soil and water and grow into adult lima bean plants. Through careful questioning, Ms. Lopez was able to guide these children to design a test of their beliefs. She found that these children changed their point of view after they conducted the investigation and that they now had additional questions.

After her students have studied seeds for several weeks, Ms. Lopez recognizes that they have learned a great deal about diversity, life cycles, structure, and function. The children become adept observers; they have learned to ask each other and Ms. Lopez about these developing concepts. Ms. Lopez knows they will soon be ready to apply their new knowledge and skills to other science areas. With her class, she will return to the original questions and the children's answers for them. She will point out how much they have learned. The children will, as a group, write and produce a booklet on how to plant seeds and care for the seedlings. Ms. Lopez will keep notes on the progress of each child and the class as a whole. Her notes will then become the source material that will enable her to make more formal assessments for report cards, in conferences with parents, and--for the class as a whole--to Mr. Sandowski, the third grade teacher.

Is this scenario representative of science taught in today's elementary classroom? At first glance, the unit lesson may seem characteristic of a typical classroom lesson. Unfortunately, closer inspection of the lesson and careful comparison with data about science education in elementary schools reveal that Ms. Lopez's unit on seeds is an uncommon approach to teaching science in elementary schools. The teacher-directed activities are "hands on", student oriented. Ms. Lopez carefully orchestrated the class activities and sequence of the lessons.

The lesson began with students' questions about the natural world. The students were mentally engaged in the activity; they had a personal invitation to study science. Ms. Lopez recorded the students' questions and current knowledge. She began the lesson with the origin of scientific investigation--a question about the natural world. This introduction to the lesson allowed Ms. Lopez unobtrusively and uncritically to assess the students' current knowledge and to capitalize on their interests. From this assessment, she helped the students develop a meaningful understanding of a few scientific ideas.

First there was an invitation to learn, then the students' explorations and discoveries, then students' explanations. Throughout the instructional sequence, Ms. Lopez monitored the students' development of concepts and skills, assessed their progress, and accordingly adjusted her teaching strategies.

Although the lesson was about seeds, Ms. Lopez used the experiences to introduce diversity, variation, and cycles, all three of which are important scientific ideas. She taught vocabulary, for example, by relating it to botanical plant names or to seed parts. The lesson extended over several days and focused on major concepts, an approach that encouraged depth of study within a breadth of topics, for example, describing the uses of various plants, diseases, and the development of agriculture. Ms. Lopez also integrated science with the other basics of elementary education--reading, writing, and mathematics.

The Current Situation in Science Classrooms

The following discussion points out the unusual qualities of the lesson Ms. Lopez taught and introduces the panel's recommendations, in the context of the classroom described in the scenario. How does this example compare with elementary school programs and practices? The amount of time allotted to science and the effective integration of science with other subjects reveal why Ms. Lopez's teaching is uncommon. Although research has shown that children learn most effectively through hands-on science, and principals agree with these findings, many teachers do not use this approach.

The 1985-86 National Survey of Science and Mathematics Education collected data from teachers and principals about elementary school science programs (Weiss, 1987). Also, available data are from a similar survey ...npleted in 1977 (Weiss, 1978). Table 1 shows the average number of minutes spent in K-3 and 4 through 6 grade science instruction in both 1977 and 1985-86 (Weiss, 1987).

TABLE 1

AVERAGE NUMBER OF MINUTES PER DAY SPENT ON SCIENCE IN ELEMENTARY SCHOOLS

Grade Range	1977 Minutes	1985-86 Minutes
K-3	19	19
4 - 6	35	38

For comparison, teachers were asked to indicate the amount of time spent teaching other subjects. In order from greatest to least amount of time, the teachers indicated reading, mathematics, social studies, and science.

That teachers are satisfied with the textbooks and depend on them presents a significant obstacle to reforming elementary school science programs. Table 2 shows that teachers use textbooks for instruction in elementary science.

TABLE 2

USE OF PUBLISHED TEXTBOOKS IN SCIENCE

Grade range	1977 Percent of Classes	1985-86 Percent of Classes
K-3	63	69
4-6	90	89

The percentage of teachers who use textbooks has changed little over the nine years between the two surveys. Teachers have also indicated that the quality of their textbooks has not been a significant problem. A majority of K-6 teachers indicated that the textbooks were clearly written, well organized, and interesting. These programs, the teachers said, developed problem-solving skills, clearly explained concepts, and had an appropriate reading level (Weiss, 1987). Teaching science as Ms. Lopez does is not like the teaching norm, which is oriented to textbooks. The panel is critical of the textbook orientation and believes that the most widely used books superficially cover too many concepts, concentrate only on vocabulary, and underplay hands-on instruction.

What do teachers emphasize in their objectives and activities? Table 3 lists the objectives that receive greatest emphasis in K-6 science.

TABLE 3

OBJECTIVES OF SCIENCE INSTRUCTION
IN ELEMENTARY SCIENCE

Objectives	Percent of classes with heavy emphasis
Become aware of the information of science in daily life	68
Learn basic science concepts	67
Develop inquiry skills	55
Become interested in science	54
Develop a systematic approach to problem solving	48
Learn to effectively communicate ideas in science	45
Prepare for further study in science	42

Although these objectives are generally congruent with those objectives *stated* in textbooks, the actual programs often do not develop them. For example, there is often little attempt to develop inquiry skills or to develop a systematic approach to problem solving.

Teachers who participated in the 1985-86 survey were asked to indicate class activities that took place during their most recent science lesson. Table 4 shows the results.

TABLE 4

PERCENTAGE OF K-6 SCIENCE CLASSES PARTICIPATING IN VARIOUS ACTIVITIES IN MOST RECENT SCIENCE LESSON

Activity	Percent
Discussion	87
Lecture	74
Demonstrations	52
Students use hands-on manipulative, or laboratory materials	51
Students complete supplemented worksheets	38
Students work in small groups	33
Students do seat work assigned from textbooks	31

Comparing these activities to those in Ms. Lopez's class demonstrates the differences between the general orientation presented in this report and current curriculum and instruction. One of the more discouraging findings of the 1985-86 survey was that since the 1977 survey, hands-on activities have decreased by 10 percent in grades K-3 and by nine percent in grades 4 through 6. Lecturing has increased by 11 percent in K-3 and nine percent in grades 4 through 6. These trends are strangely at odds with the opinions of teachers and principals about hands-on science instruction. Sixty-six percent of K-6 teachers and 76 percent of K-6 principals think that laboratory-based science classes are more effective. At the K-6 level, 89 percent of teachers and 92 percent of principals *strongly disagree* with the statement that hands-on science experiences are not worth the time and expense (Weiss, 1987). Many of these data are corroborated by findings of the National Assessment of Educational Progress (NAEP) report *The Science Report Card* (Mullis and Jenkins, 1988).

At first the panel was pessimistic about the results of the national survey and NAEP report. Then, the panel was puzzled by the discrepancy between what teachers report they *ought to do* and *what they actually do*. In the end, the panel decided to use the discrepancy as a twofold opportunity to construct a new vision for science in the elementary school and to describe concrete recommendations for curriculum and instruction. The panelists realize that elementary teachers have many tasks and priorities, and that teaching science by using a textbook is efficient; it complements the basics of reading and it requires marginal effort on a busy day. Yet it is hoped that both the vision and the recommendations will help teachers change their programs and practices.

In the next section of this introduction, a new vision for those who work with science programs in elementary schools is described. This vision begins the process of changing elementary science programs and instructional practices.

Frameworks for Curriculum and Instruction

The study panel focused on two frameworks, one for curriculum and one for instruction. The study panel articulated a goal statement that guided its elaboration of the frameworks.

> Curriculum and instruction should provide children with appropriate experience with science and technology that enhance their sensibilities about the natural and technological world, improve their skills of inquiry and problem solving, develop their understanding and appreciation for the limits and possibilities of science and technology, and contribute to their civility in the conduct of human affairs.

This goal statement focuses on children and their experiences with both science and technology. An in-depth explanation of the goals for the proposed frameworks follows in the paragraphs below.

Sensibility is a combination of intellectual, perceptual, and emotional responsiveness toward the natural world and human constructions. Sensibility reflects knowledge and values which are educational goals that include traditional skills like manipulation of tools and materials, and skills for rational inquiry, problem solving, and critical thinking. Children should develop some understanding of what science and technology are and are not, and what science and technology can and cannot do.

The statement about civility expresses two important goals. The first relates to being civil in personal interactions; that is, being humane and appreciating differences between individuals and their ideas. The seconds concerns the decisions and responsibilities of citizenship. The summary statement contains no specific reference to school, because children encounter and learn about science and technology in a variety of contexts that include not only schools, but museums, nature centers, clubs, churches, and families.

The curriculum framework fundamentally differs from extant programs in three ways. First, in the curriculum framework, technology is an important area of study and the emphasis on technology balances the emphasis on science. Second, the curriculum framework calls for the students to study fewer concepts in greater depth, thereby concentrating on several major organizing concepts, rather than on specific scientific or technological topics. The panelists realize that focusing on concepts does not automatically result in an in-depth study of them, but it is the first step. The design of curriculum and instruction must complement the emphasis on depth of study and understanding. Third, the time devoted to science and technology in elementary schools is complemented by incorporating reading, writing, and mathematics into the science and technology program; and conversely, science and technology are integrated into other curricular areas.

Each instructional framework complements the curriculum framework. The basis for the instructional framework is scientific inquiry and technological problem solving. Additionally, the instructional framework promotes conceptual change and skill development in all students.

The goal statement indicates that curriculum and instruction for science in the elementary years should give students richly rewarding experiences. Clearly, for a hands-on, inquiry-based program to succeed, facilities, materials, and equipment are required. In addition, time, safety, and management of the science program are critical issues addressed within the two frameworks.

In the following chapter, the science and technology concepts upon which the panel constructed its frameworks are described. Following the discussion are chapters on goals and rationale, instruction, curriculum, and the educational environment. Each chapter has statements that summarize the status of that component in contemporary science programs. The status statements are brief because the panel elected to concentrate on the frameworks. We boxed and shaded the statements for contrast with our discussion of frameworks for elementary school science education. Summary statements of the panel's recommendations are provided at the end of each chapter.

II. A CONCEPTION OF SCIENCE AND TECHNOLOGY

Presented in this chapter is a concept of science and technology appropriate to the development of curriculum and instruction for elementary schools. Elementary teachers often hesitate to teach science, because many lack the knowledge, skills, and understanding necessary to feel comfortable in a scientific environment. Cognizant of this problem, the panelists decided that the place to begin curriculum development is not with topics and specific facts, but with constructing a view of science and technology that elementary teachers can easily assimilate. If they assimilate this view of science and technology, the teachers can expand their knowledge, improve their skills, and develop more effective techniques for teaching science.

A Distinction between Science and Technology

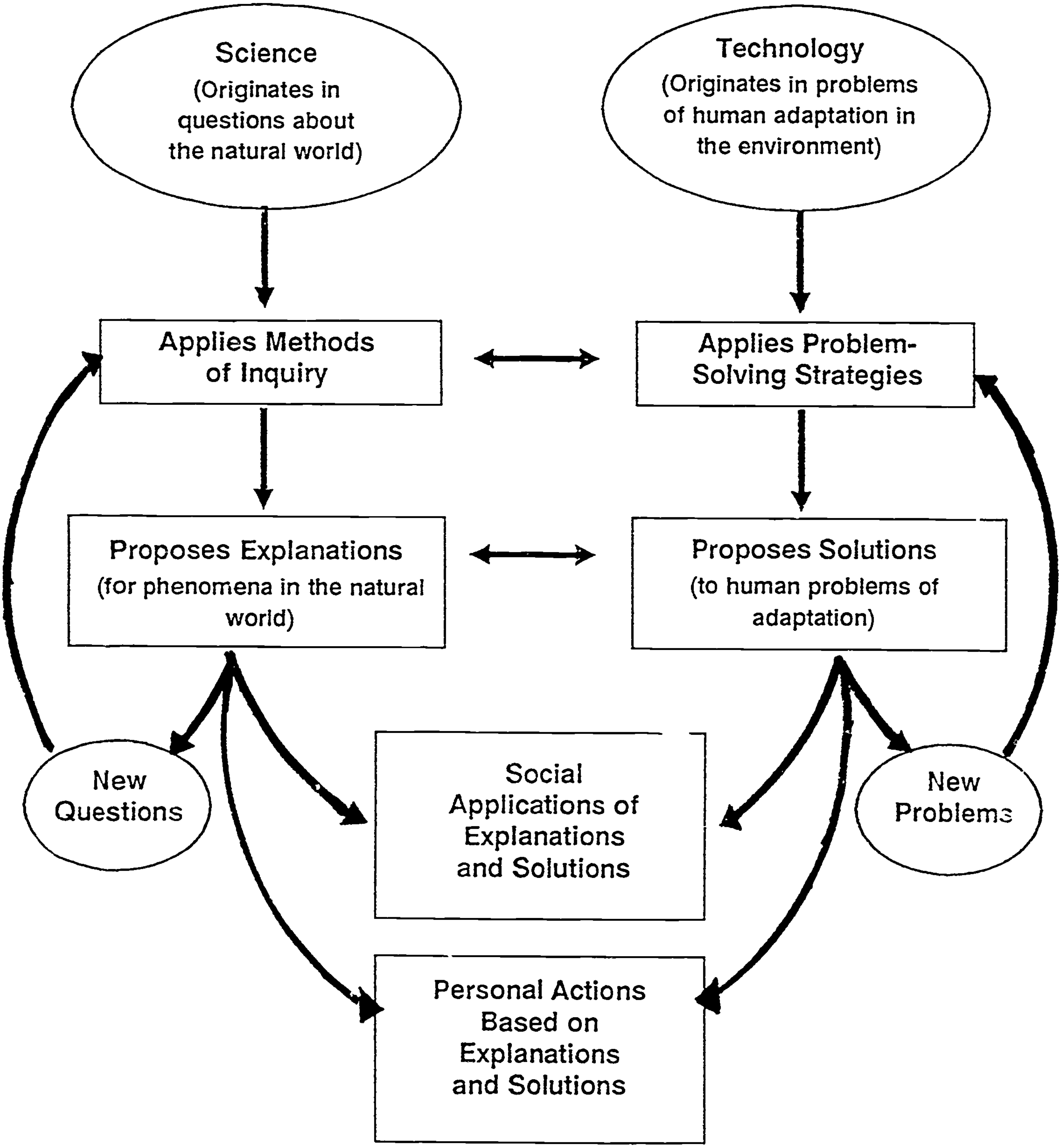
The panel began with the assumption that all children should develop an empirical understanding of the world. In this way they can take control of their lives and function productively in modern society. Most children today, however, encounter science primarily through its technological manifestations and usually cannot distinguish science from technology. The panelists distinguish science from technology as follows:

> **Science** proposes *explanations* for *observations* about the *natural* world.
> **Technology** proposes *solutions* for *problems of human adaptation* to the environment.

Figure 1 is a schematic showing the interrelationships between science and technology and their connections to the goals for the curriculum and instruction frameworks. An explanation of the connections between science and technology as drawn in Figure 1 follows.

Figure 1

The Relationships between Science and Technology and their Connection to Educational Goals



A CONCEPT OF SCIENCE: STATUS

Science is primarily presented as a body of knowledge and only secondarily as a process for establishing new knowledge. The organization of topics and presentation of science in current programs conveys the idea that science is disciplinary, cumulative, and largely independent of the processes used to develop new scientific knowledge. Learning scientific knowledge is the primary goal of science education in the elementary school (Weiss, 1978 and 1987; Harms and Yager, 1981; St. John, 1987; Mullis and Jenkins, 1988).

Science originates in questions about the world. Scientific results are derived from a recognized, though variable, process of rational inquiry. In Figure 1, the word *propose* suggests that scientific explanations are tentative, which is a fundamental idea in science. The word *explanations*, synonymous with meaning, serves knowledge. Explanations proposed by science relate to observations about the natural world and imply that humans have questions about objects and events they observe. "Why is the sky blue? Where did the mountains come from? Why do I look like my brother? and Why do objects fall? are typical questions children and scientists ask about the world. Scientists may phrase questions in a more sophisticated language, but the questions are the same.

A CONCEPT OF TECHNOLOGY: STATUS

Technology is seldom presented as a topic of study. There is little or no distinction between science and technology in current science programs for schools. When technology is introduced, it is usually defined as the application of scientific knowledge. In some instances, technology is synonymous with computers (Panel review of major programs, June 1988).

Traditional definitions of technology, such as "applied science," are incomplete. Technology, which is more than an applied science and more than a method, originates in problems of human adaptation to the environment and results in proposed solutions to those problems.

Humans need protection and food, and they need to move objects and information from one place to another. The means used to satisfy these needs constitutes technology in its simplest form. Historical examples of technology as use of tools, development of agriculture, and use of weapons, illustrate the panelists' definition (Moore, 1984) of problems in human adaptation. There are many possible solutions to problems in human adaptation, and inevitably there also are many objectives and requirements. Some of these are constraints, such as availability of materials, properties of materials, laws of thermodynamics, and societal requirements. Other variables are cost and performance criteria (Caplon, 1988). Engineers often complete several designs for projects so that they can assess trade-offs among constraints and variables before making decisions. Although the methods of scientific inquiry and technologic problem-solving have many common elements, the latter are distinguished by a concentration on decision-making and risk-benefit analysis. Scientific methods of inquiry, on the other hand, focus on explanatory power and like criteria.

Science and Technology

Narrow definitions do not sufficiently explain the relationship between science and technology, and although science and technology are different enterprises, modern science and technology are inextricably bound to one another. Technology, for example, helps formulate basic scientific explanations to the extent that one cannot easily separate science from technology. We propose instead a model in which the contribution of science to technology and technology to science varies along a continuum. Attempts to provide qualitative descriptions of the continuum are likely to be futile misrepresentations.

A CONCEPT OF SCIENCE AND TECHNOLOGY: STATUS

Current programs present very little information about the relationships between science and technology. Most contemporary science programs for elementary school concentrate on science topics such as plants, animals, electricity, and the solar system. Seldom is there a description or experience that identifies the interactions between science and technology. Technology is typically defined early in a text series and seldom mentioned after that. (Panel review of major programs, June 1988; Pratt et al., 1981; Piel, 1981.)

Although it is not important that elementary school students recognize the subtle difference between science and technology, children at this level must begin to understand the following five principles:

1) Science is an attempt to construct rational explanations of the natural world.

2) Scientific explanations about the natural world are always tentative; they continue to evolve.

3) Technologies exist within the context of nature, that is, no technology can contravene biological or physical principles.

4) All technologies have side effects. Furthermore, just as explanations about the world are imperfect and incomplete, technological solutions to problems are incomplete and imperfect.

5) Because technologies are incomplete and imperfect, all technologies carry some risk; correspondingly, the degree to which any society depends on technology is also the degree to which the society must bear the burden of risk.

Science and Technology in Society

Scientific and technological enterprises result in socially useful products. The direct outcome of science is an improved understanding of the world, whereas technological outcomes are generally more tangible, taking the form of products or services. In either case, however, individuals and groups must make decisions and take action in response to these outcomes. These actions or decisions move science and technology directly into the realm of public policy.

SCIENCE/TECHNOLOGY/SOCIETY: STATUS

The science-technology-society (STS) theme is not prevalent at the elementary level. Commonly used textbooks contain little information about the personal and social contexts of science and technology (Pratt, et al., 1981). Current programs give marginal recognition to the nature and history of science (Harms and Yager, 1981). Students are aware of pollution, energy, disease, and other issues, and they are willing to make changes in their lives to solve those problems, but they do not feel that their actions could have an impact on the world's problems (Hueftle, Rakow, Welch, 1983). New state guidelines indicate an increasing recognition of the STS theme (Powell and Bybee, 1988).

Scientific and technological outcomes--proposed explanations and solutions--themselves raise new questions and problems. The process represented in Figure 1 is, therefore, iterative. The iterations can develop new explanations and solutions or amend those already developed. These iterations demonstrate how open-ended science and technology can be. The preceding discussion included a clarification of the panelists' vision of how science and technology should be represented in elementary schools. Unsolved is the overwhelming problem of how to contribute the basic knowledge and fundamental skills needed for understanding and teaching this conception of science and technology. It will not do to leave out technology as an area of study, and it is difficult to place this additional burden on teachers without support. The panelists who were responsible for designing the curriculum framework and instructional framework recognized how difficult it is to change attitudes and assumptions about teaching science. The other study panels (teachers and teaching, and assessment) have combined their efforts with those of the curriculum and instruction panel, and together they have jointly proposed a set of five recommendations (see boxed text). Clearly, all parts of the program are interdependent, with the implementation of the new programs contingent on changes in other components of the educational system. It is important to view teacher development as something that evolves within the total educational system.

A CONCEPT OF SCIENCE AND TECHNOLOGY RECOMMENDATIONS

1) The program should clearly indicate that science proposes explanations for questions about the world.

2) Also, the program should clearly indicate that technology proposes solutions for problems of human adaptation to the environment.

3) Scientific methods of inquiry and technologic strategies for problem solving should be introduced and developed.

4) The relationships between answering questions and solving problems, and the interactions between proposed explanations and proposed solutions should also be introduced.

5) Finally, school science programs should explore the personal and social utility, limits, and consequences of proposed explanations and solutions.

III. THE GOALS AND RATIONALE

The concept of science and technology presented in the last chapter orients the curriculum and instruction frameworks. In particular, the orientatior ,larifies what we mean by science and technology and it identifies parameters that differentiate our frameworks from art, music, theology, and other domains of study.

A Concept of Science Education Goals and Student Objectives

Education, including education in science and technology, is a social institution. As such, education in science and technology shares purposes common to all social institutions in a democratic society: providing for the needs and continued development of everyone and fulfilling the aspirations of the society. These goals are achieved in ways unique to each social institution. For science and technology education, this literally means educating students in the knowledge, skills, and values of science and technology. Personal development and fulfillment of social aspirations, both of which are educational goals, define and delimit the appropriate knowledge, skills, and values. This discussion is elaborated elsewhere in both historical and contemporary context (Bybee, 1987).

THE GOALS OF SCIENCE EDUCATION: STATUS

Scientific literacy is the goal of science education in elementary schools. This goal is translated into objectives, such as learning basic science concepts, becoming aware of science in daily life, developing inquiry skills, becoming interested in science, and developing problem-solving skills (Weiss, 1988). Other goals include learning safety skills, developing effective communication skills, and learning about careers in science (Weiss, 1988). Three factors define the goals for elementary school science: state guidelines, science textbooks, and publications in science education.

Rationale statements are usually presented with little philosophical or historical orientation. If there is any orientation, it is usually psychological. Educators have various definitions of literacy. All are admirable statements but the programs often have little relationship to the stated rationale (Panel review of major programs, June, 1988).

Goals and Objectives for Science Education

The goals set forth in this chapter are for all students, regardless of sex, ethnic origin, or economic status. The compelling report *All One System* (Hodgkinson, 1985) presents demographic trends that indicate many school systems will have "minority majorities" in the near future and that many minority populations will become increasingly heterogeneous. The next decade of population expansion in America will see a significant increase in the cultural diversity of our youth population and an alarming increase in the number of children being born into poverty. Compounding this are spiraling increases in children born to unwed teenagers, children raised in single-parent homes, and latch-key conditions in which children will spend an increasing amount of time unsupervised and dependent on themselves for motivation and social integration (Hodgkinson, 1985).

In the following statements of goals and objectives, the panel attempted to integrate the concept of science and technology as stated in Chapter II with science programs designed to include a broad range of students. These goals and objectives are congruent with other long-standing goals (Bybee, 1977), and they accommodate contemporary trends and issues (Champagne and Hornig, 1986). Each of the following five goal statements is followed by a brief discussion. The panel decided also to include objectives for the students, which follow each discussion.

I.

Education in science and technology should develop the student's natural curiosity about the world.

Children are naturally curious about their world: they investigate, they inquire, they examine. These behaviors demonstrate a combination of perception, intellect, and emotion. Education in the early years must sustain these sensibilities. When educators ignore the origins of science and technology and leap immediately to the correct scientific answer, they often stifle a student's curiosity. We recommend a new acceptance of students' curiosity as the place to begin their education about science and technology. The students' objectives for this goal are twofold:

Students' experience in the elementary years should develop their abilities to ask questions about the natural world.

Students' experience in the elementary years should develop their abilities to identify problems of human adaptation.

Asking questions and identifying problems are the initial steps in the domains of science and technology. Questions and problems also are related to creativity, critical thinking, and reasoning.

After scientific questions are posed or technological problems are identified, the students take the second step, which is to apply methods of inquiry and to employ problem-solving strategies. Figure 1 (in Chapter II) indicates a parallel relationship between these two pursuits, because many of the processes are similar. Methods of inquiry and problem-solving strategies both contribute to an understanding of science and technology and enhance the children's abilities to reason logically, to solve problems rationally, and to think critically and creatively. This discussion leads to the panel's second goal:

II.

Science and technology education should broaden the child's operational and thinking skills for investigating the world, solving problems, and making decisions.

This goal includes observations, experimentation, and other processes that science and technology hold in common, as well as processes unique to technology such as considering cost and risk. Students' objectives are as follows:

Experiences in the elementary years should enrich the students' understanding of, and ability to use, the methods of scientific inquiry.

Experiences in the elementary years should advance the students' understanding of, and ability to use, the strategies of technological problem solving.

The top of Figure 1 begins with the origin of scientific questions and technological problems. The figure then proceeds to chart methods of inquiry and problem-solving strategies, which can include observation, classification, experimentation, and risk assessment. Scientific explanations for phenomena and technologic solutions for problems, regardless of whether the problems are individual or cultural, are derived through these processes. Further, these explanations and solutions constitute basic scientific and technologic knowledge.

III.

Science and technology education should develop the student's knowledge base.

The goals for any science education program should reflect the most important contributions of science and technology to humanity. Clearly, one of the most important contributions of science is its power "as a way of knowing" (Moore, 1984). In that role, it has demystified the natural world and reduced fear and ignorance (Bronowski, 1978). Unfortunately, science is most commonly defined as a collection of isolated facts. Furthermore, the adult public perceives and emphasizes that science is a group of isolated facts. But this is nothing more than substituting one set of mysteries for another.

Most science education programs introduce technology as the application of scientific knowledge. A review of any current elementary school science program supports the assertion that there is no reasonable way that students could come to understand the deep and broad importance of technology in human affairs. Presenting technology "as a way of adapting" is an important recommendation made in this report. Technology has not only alleviated many agricultural, transportation, communication, and defense problems, it has created new problems, such as resource depletion and environmental pollution. Technology has freed us from many dangers and problems, and it has improved our quality of life. Likewise, the students need to recognize new problems created by technology, such as pressures on the environment caused by population growth or the ethical issues raised by modern health care technology. The panel concluded that there is clear justification for including technological knowledge in contemporary science programs.

The intent of the proposed program is to demystify science by redefining the scientific and technological knowledge in terms of major concepts that are accessible to the majority of people, concepts that are also the foundations of good science and technology. Indeed, curriculum framework in this report assumes that children already have begun to formulate conceptual structures that explain the world. The student objectives are as follows:

Experience in the elementary years should develop the students' scientific explanations of natural phenomena.

Experience in the elementary years should develop the students' understanding of technological solutions to problems of human adaptation.

How do science and technology work? What constitutes an advance in science and technology? When are explanations and solutions acceptable to the scientific and engineering communities? There are habits of mind (Rutherford and Ahlgren, 1988), rules of conduct, and procedural requirements associated with science and technology. When scientists propose explanations and engineers propose solutions, their communities apply rules and evaluate the explanations and solutions. It is possible to examine the development of science and technology and their influences on society.

This constitutes the nature and history of science and technology, and it leads to the panel's recommendation for a fourth goal.

IV.

Science and technology education should develop the child's understanding of the nature of science and technology.

This goal has two parts. First, the students should have some knowledge about the enterprises of science and technology. Second, the students should develop some of the habits of mind normally associated with science and technology. Statements of student objectives include:

Experience in the elementary years should enhance the students' understanding of science and technology as major human achievements.

Experiences in the elementary years should develop the students' abilities to recognize and apply scientific and technological habits of mind.

At some point, each citizen must understand science and technology in a social context. Yet, for the most part, the public has little specific knowledge of scientific study and technological development. "Scientific habits of mind" is a phrase that encompasses several characteristics in general and one characteristic in particular: dependence on valid evidence as the basis for scientific explanations, and, by extension, technological solutions. Dependence on valid evidence points to one critical fallacy in the creationism versus evolution debates. The debate is not simply a matter of two conflicting theories, since the creationists have presented no empirical evidence for their position, and it is therefore, by definition, not a theory. Students should understand and be able to apply such criteria to arguments.

V.

Education in science and technology should increase the child's understanding of the limits and possibilities of science and technology in explaining the natural world and solving human problems.

Science and technology affect our system of beliefs--the way we think about ourselves, others, and the world around us. Scientific and technological advances are accompanied by social, political, and economic changes that may be beneficial or detrimental to society. The impact of science and technology is never entirely beneficial and rarely uniformly detrimental (Bybee. 1986).

There are two parts to this goal; one is social, and the other personal. Following are the statements of student objectives for the goal:

Students' experiences in the elementary years should bring about greater awareness of science and technology as they relate to society.

Students' experiences in the elementary years should increase their ability to use scientific and technological knowledge, attitudes, and skills in making responsible personal decisions and taking appropriate individual actions.

The world is infinitely complex. Children have a need to understand and bring order to the complexities they encounter. Our student goals recognize various dimensions of science and technology that bring order to objects and events. One dimension relates to enduring questions children ask about nature. "Why is the sky blue?" "Where did we come from?" Such questions direct education toward scientific explanations. A second dimension relates to abiding quests of humans to adapt to the environment. "How can we protect ourselves?" "How can we stay warm?" These are problems that lead to technological solutions.

Education in Science and Technology

The goals and objectives of our curriculum framework assume that science and technology must be addressed as separate, yet interrelated areas of study. By their nature, science and technology are "central to our welfare as individuals and to the welfare of our society" (NSTA, 1982). Therefore, knowledge and skills that help learners understand the social usefulness of science and technology will also help students take action as citizens (Rutherford and Ahlgren, 1988).

The most reasonable and effective understanding of the natural world is a dynamic understanding that integrates biological, chemical, physical, and social aspects in each explanation and exploration (Linn, 1987). Our recommendation is that the basic knowledge, skills, and attitudes that foster such an understanding should be made available to, and internalized by, students before completion of their elementary education. This opinion is supported by recommendations of such organizations as the National Science Teachers Association (NSTA, 1982) and the National Forum for School Science (Champagne, 1986).

Harold Hodgkinson (1985:1) points out in *All One System*, that science educators must "begin to see the educational system from the perspective of the people who move through it instead of those who run it, we begin to realize a new obligation at the elementary level in science and technology education." Learning-to-learn skills become imperative (Hurd, 1986), as do specific skills in analytical and creative thinking and problem solving (Hurd, 1984, Welch, 1982). In the context of a rapidly changing society, those responsible for science education must augment what is known about learning and design an elementary curriculum that prepares individuals for interaction in, and constructive contributions to, that society. Although the panel recognizes the enriching opportunities available to individuals who continue their formal education beyond sixth grade, the basic concepts, skills, and values proposed in the framework will enhance *both* the life-long learning of terminal students and the learning of those few who will eventually become professionals in science and technology. The panel also recognizes that "learning occurs as the result of social interactions that take place in formal (school) and informal (family, community, church) settings" (Champagne and Hornig, 1987:9). Contemporary elementary curriculum and instruction in science and technology should develop scientific and technologic explanations, solutions, strategies, and attitudes that build self-confidence in life-long learners. This includes the insight and experience needed for accessing both formal and informal resources that contribute to continued self-growth and development. In addition, learning the social usefulness of science and technology concepts and skills at an early age will contribute to both individual sensibilities and an informed citizenry.

SCIENCE AND TECHNOLOGY EDUCATION: RECOMMENDATIONS

There are five primary goals for science education in the early years:

1. Develop the students' natural curiosity.
2. Broaden the students' procedural skills for investigating the world, solving problems, and making decisions.
3. Increase the students' knowledge base.
4. Develop the students' understanding of the nature of science and technology.
5. Ensure the students' understanding of the limits and possibilities of science and technology in explaining the natural world and solving human problems.

These goals are justified on several grounds. They are congruent with the students' developing understanding of the world. They represent science and technology as ways of knowing about, and solving problems of, the world, and they are applicable to such other unifying goals of elementary education as developing the basic skills in reading, writing, and mathematics.

IV. A FRAMEWORK FOR CURRICULUM

This chapter contains a proposal for a framework for a K-6 curriculum. A curriculum framework is an intermediate formulation between the idea for a curriculum and the curriculum itself; the framework specifies and explains the basic components used to design the curriculum. A complete framework provides information needed to make decisions about activities, lessons, units, and other specifics of the curriculum. At a minimum, a framework defines enough of the proposed curriculum to differentiate it from other curricula.

A curriculum framework has advantages and disadvantages. An advantage of the framework is that curriculum developers at local, state, and national levels have opportunities to provide specific ideas. One assumes those decisions would be made in terms of the unique characteristics of students, schools, and states, yet still fulfill the curriculum developers' requirements. A disadvantage is that it is incomplete. It lacks a scope and sequence, the placement of concepts and skills, the selection of topics and activities, and the solutions for management, materials, and other practical matters.

This chapter sets forth a framework for curriculum design which consists of four sections: organizing concepts, organizing attitudes, organizing topics, and themes. Curriculum developers should use the framework as a guide for constructing a scope and sequence and, subsequently, units, lessons, and other parts of a science and technology curriculum at the elementary level.

ELEMENTARY SCIENCE CURRICULUM: STATUS

Topics, not concepts, are the dominant orientation for science in elementary schools. Scientific information, facts, and processes are presented within topics. Science programs consisting primarily of textbooks, are organized around such topics as plants, animals, rocks, and dinosaurs (Meyer, Crummey, and Greer, 1988; Panel review of major programs, 1988). A few state guidelines or textbook series use conceptual schemes or process skills as organizers (Powell and Bybee, 1988). Laboratory-oriented approaches, as contrasted with textbook approaches, have shown improvement in students' process skills and scientific attitudes. (Shymansky, Kyle, Alport, 1982; Bredderman, 1983). Most elementary teachers, however, are not using a laboratory-oriented approach to science education (Weiss, 1987; Mullis and Jenkins, 1988).

A paradox arises when trying to prepare students for the future. Most science educators are convinced of two equally valid but contradictory ideas, namely that our world is changing at an accelerating pace, and that there are fundamental, enduring concepts for organizing thoughts about the world.

The trite saying, "the only constant in life is change," is a poor description because change itself occurs at increasing rates and in different directions. If this is true, and the panel believes it is, then what can materials for elementary school science include that will have lasting value to the students? What knowledge will help them understand and adjust to change? Are there explanatory concepts that are so fundamental and powerful that they will always be valid and useful? There are fundamental organizing concepts in science that all students, by the time they finish sixth grade, should incorporate into the way they think about and explain their world. These concepts are valuable for five reasons.

- They are applicable to both science and technology.
- They have applications beyond science and technology.
- They accommodate different developmental levels.
- They apply to the personal lives of children.
- They are powerful explanatory concepts.

We now turn to the nine organizing concepts which the panel believes are central to a sound elementary science curriculum. This section defines and describes each organizing concept and lists possible teaching examples. These examples do not constitute a scope and sequence; rather the panel presents these as examples of teaching that make the nine concepts more understandable.

Organization (or orderliness)

Ideas and descriptions about the world can be organized in different ways, including hierarchies, simple-to-complex arrays, and symmetry. Objects in nature or the classroom can be assembled into groups showing hierarchies, such as atoms, molecules, mineral grains, rocks, strata, hills, mountains, and planets. Some organisms contain hierarchies in themselves--the trunk, branches, twigs, stems, and leaves of trees, or the transportation or communications hierarchies within social systems.

Varieties of organisms, from single-celled amoeba, to sponges, to corals, and so on, can illustrate simple-to-complex arrays. Technology provides examples of increasingly complex objects that serve similar purposes. As an illustration, people slide down hills in the winter using sheets of plastic, or they use toboggans, sleds, or aerodynamic bobsleds. The objects are increasingly sophisticated, but all are designed to carry passengers on a thrilling downhill ride.

Objects can be described according to common elements of symmetry and polarity: they possess a top and bottom, a front and back; and in many cases, shapes are repeated when the objects or organisms are turned or inverted.

TABLE 1

TEACHING EXAMPLES
FOR ORGANIZATION

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Sorting objects (e.g., objects that sink and objects that float)	• Identifying levels of organization, such as atoms; molecules; cell-tissue-organs; earth-solar system; stars-galaxies; and organism, population, community, ecosystem
• Ordering events (e.g.,	• Describing the component parts of

identifying the order of planting a seed, sprouting, adult plant, flower, and fruit)	natural and technological systems
• Classifying objects and organisms	• Specifying the hierarchial relationship among parts of natural and technological systems
• Identifying groups of similar animals (e.g., mammals, reptiles, insects)	• Describing the constituents of rocks
• Identifying groups of similar plants (e.g., beans, grass, roses)	• Recognizing patterns of leaves
• Developing a simple scheme for classifying objects or organisms (e.g. animals typically found in certain environments)	• Identifying geometric shapes
• Classifying objects and organisms from simple to complex	• Describing symmetry of objects and organisms
• Identifying solids, liquids, and gases (e.g. water as ice, water, and vapor)	• Dismantling and reassembling a simple machine
• Identifying groups of objects that have been designed or constructed by humans	• Recognizing organization within and among the atmosphere, hydrosphere, lithosphere, and celestial sphere

Cause and Effect

Nature behaves predictably. Searching for causes and explanations is the major activity of science; effects cannot happen without causes. A common error arises when individuals assume that events that occur simultaneously or sequentially have a cause-and-effect relationship. For example, the rotation of the planets and a death in one's family, or a pregnant woman's sighting of a rabbit and the birth of a child with a cleft lip may happen simultaneously, but there is not a causal interrelationship. Some events require that several things must happen to cause an effect.

Classic activities with seed growing can illustrate cause-and effect-concepts. For beans to be healthy, seeds need water, light, and warmth; well-organized experime can show the effect of varying each of these three parameters. Cub Scouts discover that streamlining, carefully aligned axles, and good lubrication all help to make a pinewood derby car run faster. They also discover that, if too much wood is carved off the car body when attempting to make it streamlined, weight must be added to keep it heavy. Optimum performance requires optimum conditions.

TABLE 2

TEACHING EXAMPLES
FOR **CAUSE AND EFFECT**

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Describing health risks (e.g., riding a bicycle, crossing streets)	• Identifying the effects of poor nutrition
• Identifying changes, e.g., heating/cooling, moving/not moving	• Describing cause and effect in simple activities such as growing seeds
• Describing simple technologies (e.g., scissors, paper clips, pencils)	• Describing the effects of various substances on objects and organisms
• Using everyday examples to describe cause and effect (e.g., lights, water, temperature)	• Designing simple machines that achieve a desired effect
• Predicting a sequence of events for natural phenomena and technological objects	• Describing natural phenomena in terms of cause and effect (e.g., weather, erosion)
• Describing interactions between objects and organisms (e.g., eating is related to growth and development)	• Differentiating between correlation and cause and effect
	• Giving evidence for interactions between and among simple systems

Systems

Systems consist of matter, energy, and information, all of which move about from reservoir to reservoir through carefully delimited pathways. Both the amount of matter, energy, and information in reservoirs, and the rate of transfer through pathways vary over time. Systems are understood by tracking changes and drawing boundaries around the constituent parts.

One of the best-known natural systems is the hydrologic cycle. Water in solid, liquid, and gaseous phases moves about the earth's surface, sometimes residing in the atmosphere, sometimes in living tissue, and sometimes in streams, lakes, groundwater, and oceans. Being able to observe and measure this system helps us understand weather, water supply, and pollution.

In the classroom, an aquarium might serve as a system. To make it a balanced aquarium, the plants have to use the fishes' waste products to provide enough oxygen and food for the fish to survive. Of course, the plants also depend on a light source for photosynthesis. Balancing the aquarium requires some knowledge about the matter and energy present and how it follows the pathways from plants to water to animals.

Most technologies can be seen as systems. A common example is the furnace and thermostat. This system is cybernetic; that is, information is related and acted upon within the system in a stabilizing way. A properly tuned heating system keeps room temperatures from fluctuating more than a few degrees from the set point.

TABLE 3

TEACHING EXAMPLES
FOR **SYSTEMS**

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Describing whole systems, such as toys and simple machines	• Taking apart simple machines
• Exploring a simple natural system	• Describing the school's transportation system
• Constructing a simple technological device	• Differentiating systems and subsystems
	• Applying the concept of systems to different objects, events, and organisms (e.g., humans, earth, electrical)
	• Describing the characteristics of different natural and technological systems, (i.e., the boundaries, components, feedback, resources)
	• Identifying matter and energy as essential to systems

Scale

Scale refers to relative and absolute quantities. Thermometers, rulers, and weighing devices help students to see precisely that matter and energy vary in relative quantity. Absolute notions of scale are important because certain physical and biological phenomena happen only within fixed limits of size.

For example, in biology, water striders are superbly scaled; they are able to run across a puddle, suspended by the surface tension of water. If water striders were much larger, they would sink; if they were much smaller and became wet, they would not be able to break away from the clinging water. Full-term newborn babies are not healthy if they are very large or very small. There is an ideal size range for healthy babies

In technology, scale is important to efficient operation. Buses may only get five or six miles per gallon, but they can carry 40 or 50 passengers, thus making them far more fuel efficient than passenger cars. Technological devices must also account for human scale. The bus driver's seat must be designed to accommodate tall, medium, and short drivers.

TABLE 4

TEACHING EXAMPLES
FOR **SCALE**

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Drawing simple objects in actual size and comparing the drawing to scale pictures	• Stating different scales of time, space, and matter
• Recognizing the differences in children and adults	• Mapping a small area
• Knowing that some objects, such as doll houses and toy trucks, are scale models of real objects	• Describing the magnification on a microscope in terms of scale
• Designing a model of a simple object or organism	• Making a solar system to scale for both size of planets and distance
• Defining big/little, near/far, short/long	• Estimating the size of an object
	• Computing the scale of geologic time and astronomic distance
	• Designing a machine and then building the machine

Models

To make sense of the world around them, human beings create models or metaphors that show the essential character of the phenomena that interest them. Furthermore, the models may be conceptual and consist of word descriptions or drawings. The modles also can be mathematical and consist of equations or other formal representations. Finally, there are physical models that consist of real objects that possess some of the characteristics of the real thing.

The solar system is often modeled in the classroom by describing the planets as huge balls moving about an even larger sun. Such a model solar system is usually to scale for both size of planets and distance between planets. A mathematical model of the solar system might include the shape of a planet's orbit as being elliptical. And finally, a physical model of the solar system might consist of a series of scale-sized balls placed at appropriate distances throughout the room or hallway.

Models often serve as prototypes in technology and in that case may be full-sized representations of the final product. Models usually possess only some of the characteristics of the real thing. Children readily understand that most toys are models that look like real objects, such as cars, airplanes, babies, and animals, but do not possess all the attributes of those objects.

Models can be used to test the workings of technology without costly investments in full-scale objects. Small boats and airplanes are tested in tanks and wind tunnels before their full-sized counterparts are built. In this way, many design experiments can be tested inexpensively to find the best results.

TABLE 5

TEACHING EXAMPLES
FOR **MODELS**

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Recognizing numbers as representations of objects or organisms	• Constructing a simple graph
• Describing the differences between a toy car and a real car	• Representing graphically a relationship such as color and wavelength
• Providing a picture of a car or person	• Differentiating between a model and reality
• Identifying models that are bigger than, smaller than, or the same size as the real object or organism and explaining why each is useful	• Constructing models of linear and exponential growth

Change

Change is continuing and ubiquitous in the natural world. Some objects or organisms (species) seem unchanging, but that is a function of our inability to perceive the rate or scale of change. For example, mountains erode and species evolve, but the time required to recognize substantial change is quite long. Changes in the size and structure of the universe are too large for human beings to observe and to measure directly, and mutations in genetic material are hidden unless they affect observable characteristics.

Change in the natural world generally tends toward disorganization unless energy is put back into the system. For example, a child's well-organized bedroom will tend toward clutter (a mess) unless energy is expended to keep the room organized. Similarly, a bicycle will tend toward disrepair and wear out unless energy is expended to maintain it. Some change is cyclical; that is, the direction of the change is reversed. Diurnal cycles, lunar cycles, seasonal cycles, and menstrual cycles are examples. Some change is one-directional; physical growth and intellectual development, puberty, and menopause, for example. The rate of change can vary. For example, although all (normal) sixth graders will ultimately progress through the same developmental stages, not all of them will reach the same developmental landmarks at the same time.

Technology changes as new problems arise and as new solutions supplant old. Historically, many technologies have become more complex and have changed from functional adaptation to convenient utilization.

TABLE 6

TEACHING EXAMPLES FOR CHANGE

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Identifying the different seasons by their attributes	• Naming the stages of development
• Observing and describing immediate changes	• Observing and describing the properties of water, as in solid to liquid to gas
• Observing delayed changes	• Observing and recording the phases of the moon
• Observing personal changes in a day, week, year	• Identifying the changes in an ecosystem
• Identifying different types and rates of change	• Investigating different life cycles
• Describing growth of organisms	• Estimating the rate and direction of simple changes in physical systems
• Identifying indications of seasonal change during a nature walk	• Differentiating between linear and exponential growth
	• Recognizing the limits of change in simple systems

Structure and function

The way organisms and objects look, feel, smell, sound, and taste bears a relationship to the actions they perform. The structure of leaves, for example, affects their functions of energy production and transpiration. Skunks use their scent glands for protection. All automobiles have a similar shape because engineers know that this shape improves the ability of an automobile to move down the highway efficiently. Similarly, round, inflatable tires on a bicycle are conducive to the bicycle's function. More specifically, light-weight tires are designed for racing and knobby tires are better for all-terrain bikes where traction is important.

In the biological world, both structure and function are results of cumulative natural selection. This is the major mechanism of organic evolution. The relationship is not a function of purposeful design, nor does it occur by accident (unless one considers the accidental nature of mutation, which is the ultimate source of all variations that may have adaptive function).

The structure/function relationship also appears in artifacts. Archaeologists explain artifacts by determining the functions of various shapes and forms found. For example, small arrowheads were used for hunting birds, large spear heads were used for larger animals. Some stones look and feel like scrapers or hammers and most certainly must have been used for those purposes. The congruence between structure and function in technology is purposeful. Furthermore, the congruence can be refined by experimentation.

TABLE 7

TEACHING EXAMPLES FOR STRUCTURE AND FUNCTION

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Observing the structure of an animal and its relationship to function	• Designing a plant or animal
• Describing the function of a simple system (e.g., roof shape for shedding rain and snow)	• Inventing a simple device for measuring wind velocity
• Designing a common object, such as a plate, bowl, spoon, or fork	• Interpreting antique objects
• Examining simple plants and describing the parts and functions	• Interpreting animal tracks
• Describing a bicycle in terms of structure and function	• Recognizing the relationship of structure and function in humans, buildings, environments
• Building a structure from simple materials	• Describing the functions of human body parts
	• Describing the structure and function of tools
	• Recognizing the abiotic and biotic structures of an ecosystem

Discontinuous and Continuous Properties (Variations)

All organisms and objects have distinctive properties. Variation is a universal characteristic of the natural world. Some properties are so distinctive that no continuum connects them. Examples of such discontinuous properties are living/nonliving and saltiness/sweetness.

Most properties in the natural world vary continuously; that is, there is no clear demarcation that distinguishes the variation in a population or the properties of objects. The colors of the spectrum, for example, constitute a continuum. Night and day, height, weight, resistance to infection, and intelligence are all continuous properties.

Discontinuous variation lends itself to classification of objects by type; this kind of classification emphasizes general properties rather than specific characters. Continuous variation, on the other hand, makes typological classification difficult, because it emphasizes finely graded, individual distinctions, as well as unity of pattern. An understanding of continuous variation is the basis of thinking about populations and is essential to an understanding of organic evolution and the statistical nature of the world.

TABLE 8

TEACHING EXAMPLES
FOR DISCONTINUOUS AND CONTINUOUS PROPERTIES
(VARIATIONS)

PRIMAPY (K-3)	INTERMEDIATE (4-6)
• Observing different tones of colors (e.g., variations of blue)	• Investigating the changes and continuity in properties in a life cycle
• Listening to different sounds	• Recognizing the continuous properties of color in a spectrum
• Differentiating living and non-living	• Analyzing a graph of height in class--contrast with histogram of boys and girls
• Exploring the properties of objects that sink and float	• Sampling height of individuals over time
• Developing a growth chart over time	• Differentiating between day and night
	• Describing the on-off switch as a discontinuous variable

Diversity

Diversity is perhaps the most obvious characteristic of the natural world. Not only are there many different types of objects and organisms but there also is considerable variation within those objects and organisms. As scientific understanding of the natural world has improved, humans have come to see that maintenance of diversity is important to natural systems. For example, trees, rocks, and people all play important parts in the ecological balance of a tropical rain forest. Should one component be eliminated, the entire rain forest is likely to suffer.

Technology proposes diverse solutions to problems of human adaptation to the environment. Snowshoes, cross country skis, and snowmobiles are diverse solutions to the problem of moving people across the snow. Such issues as economics, efficiency, and esthetics will help determine which solution is best. Diversity also is evident in human values and ideas. This diversity influences the problems individuals and societies choose to address.

TABLE 9

TEACHING EXAMPLES
FOR DIVERSITY

PRIMARY (K-3)	INTERMEDIATE (4-6)
• Observing objects and developing a simple classification scheme	• Analyzing height and weight distribution among class members
• Observing different types of objects and organisms	• Identifying the range of similar rocks, animals, or plants
• Identifying the differences in pets	• Studying a simple ecosystem to identify the diversity of organisms
• Observing and describing the differences among students in class	• Describing the components of similar physical systems such as airline and automobile travel
• Listing the natural objects and organisms on the school grounds	• Observing the variations within one type of leaf
• Listing the constructed objects on the school grounds	• Developing a life list of birds
• Collecting organisms or objects	• Making a collection of minerals and rocks
• Observing the differences among leaves	

Organizing Attitudes

Science education in the elementary years should promote attitudinal development. The panel's definition of attitudes includes a disposition to behave in certain ways and habits of mind that may result in predictable actions. For school science, there are at least two sources and referents for attitudes--science and oneself. That is, science is both a source of attitudes and a referent for an individual's attitudes. Individuals can have attitudes about both themselves and about science. It is the interplay of these different attitudes that must be a concern during the early years of science education.

The panel began with the assumption that students bring certain attitudes to school, and some of those attitudes will need to be modified. Some teachers and parents may argue that schools should not impress certain sets of attitudes on learners. However, there is a justifiable position for science teachers in that we are developing attitudes inherent in the scientific and technological enterprise. While individuals may demonstrate those dispositions, they are grounded in the traditions of the scientific and technologic community. In fact, certain attitudes are in many ways unique to science and technology and help differentiate science and technology from other important realms of human knowing.

Scientific Attitudes

Development of scientific attitudes does not occur out of a context. Lessons on "the value of speculation" or "the need for accepting ambiguity" are not recommended. Ways of looking at things develop over time and in the context of participating in and learning about science and technology. The organizing concepts and sample activities described earlier provide the basis for the development of scientific attitudes.

The study panel reviewed recommendations from the 1966 report *Education and the Spirit of Science*, published by the Education Policies Commission of the National Education Association. The panel concurred with the recommendation that science education should promote understanding of scientific attitudes. Some of the most important scientific attitudes that one can possess are as follows:

1. **Desiring knowledge.** Recognizing that science is a way of knowing and having a disposition toward knowing and understanding the world are important for elementary science education.
2. **Being Skeptical.** A part of this attitude is recognizing the appropriate time and place to be scientifically skeptical and to hold a disposition that authoritarian statements and self-evident truths can be questioned.
3. **Relying on data.** Obtaining and ordering data are the basis for explanations of natural phenomena. Relying on data also means rigorous testing of ideas and respecting the facts as they are accrued.
4. **Accepting ambiguity.** Data are seldom clear and compelling; and scientific information seldom, if ever, proves something. New questions and problems arise out of ambiguity.
5. **Willingness to modify explanations.** As data suggest different explanations of objects or events, one must be willing to change one's original explanation.
6. **Cooperating in the answering of questions and solving problems.** Cooperation is important to the scientific enterprise.
7. **Respecting reason.** Scientists value patterns of reasoning that lead from data to conclusions and eventually to construction of theories.
8. **Being honest.** Data should be presented as they are observed, not as the investigator thinks they ought to be.

Attitudes Toward Science

Two major sets of personal attributes should be among the goals of science in elementary school. One set is attitudes toward science, and the other is attitudes toward one self and one's abilities.

Do students like science when they have it in school? Are students interested in science? Do they perceive science as useful in their personal life? The study panel recommends a curriculum and instructional strategies that develop positive answers to these questions. A sense of awe about the natural world, perpetuation of curiosity, creativity, using scientific resources to develop explanations about the natural world--these are positive attitudes toward science that the elementary student should develop.

Self-Esteem and Skill Development

The panel assumes that positive experiences in science education will also contribute to the students' self-esteem. Experiences in school science should help the students develop a positive outlook about their integrity, worth, and esteem. Laboratory experiences in which the students can achieve a sense of accomplishment are especially helpful. We now turn to a further elaboration of those skills that are a necessary component of the curriculum framework.

Organizing Skills

Developing a student's skills is an important part of elementary education, and science can make contributions to this in several ways. First, science instruction can help students develop process skills, such as observing, inferring, and classifying. Second, when the students use laboratory equipment, such as thermometers, balances, and microscopes, they develop dexterity and psychomotor skills. Third, science experiences can contribute to the development of reading, mathematics, and written and oral communication skills.

Skill development, in particular scientific process and thinking skills, are major goals for science educators. In large measure, this goal can be attributed to the Commission on Science Education of the American Association for the Advancement of Science (AAAS). There are three reasons that the processes should be a significant component of any elementary program. Table 10 lists fifteen AAAS process skills.

First, the processes of science contribute to the students' overall development and to other basic skills emphasized during the early years of schooling. Second, the process skills have an enduring quality that will contribute to the students' abilities to answer questions and solve problems even when the information base of science and technology changes. Third, understanding and using the process skills of science contributes to the students' basic abilities in other, non-science areas such as language arts, social studies, and communication. The panel identified three levels of organization for skill development. Those levels are information gathering, problem solving, and decision making.

Information gathering. One of the first steps in answering scientific questions or solving technological problems is obtaining information. Information-gathering activities have traditionally taken place in a laboratory or have been investigations of natural phenomena. The use of these types of activities has declined, but it is nevertheless recommended that they be used. (Weiss, 1987; Mullis and Jenkins, 1988).

TABLE 10

Process Skills	
1. Classifying data	9. Interpreting
2. Communicating	10. Measuring
3. Controlling variables	11. Observing
4. Defining operationally	12. Predicting
5. Designing experiments	13. Questioning
6. Formulating models	14. Using numbers
7. Hypothesizing	15. Using space/time relationship
8. Inferring	

A Student should also develop skills for researching, such as the ability to identify sources of information and to use information-retrieval systems. When gathering information, one must read, write, and speak clearly, all of which are communication skills.

Problem solving. The panel uses the term *problem solving* to express the processes of answering scientific questions and solving technological problems. As with information gathering, problem solving requires skills that are common to both science and technology. These skills include the ability to state questions, identify problems, hypothesize, predict, separate and control variables, infer, design experiments, formulate models, and interpret data. New skills that are technologically important, include the ability to identify alternative solutions and assess the costs, risks, and benefits of technological solutions.

Decision making. Decision making is not a traditional science skill, but is included in the recommendations because decision making is a logical extension of those skills that have been incorporated into school science programs. The recent emphasis on critical thinking and analytic skills is, in many ways, the basis for decision making. Further, decision making is integral to solving technological problems. Also, the summary phrase of engineering--design under constraint--suggests that effective decision making is the essence of technological processes. Once the students have identified the problems and assessed alternative solutions, they must decide on the best solution and then plan and carry out project that meets the required standards. As students go through this process, they must use tools, behave safely, and evaluate their options.

The skills incorporated within the curriculum framework are generally arranged in a hierarchy that complements the development of school-aged children. That is, in the lower elementary grades there is greater emphasis on information gathering and descriptive processes, such as observation and classification. At the upper elementary levels there is more emphasis on deductive skills and critical thinking.

Organizing Themes and Topics

A variety of themes and topics can be part of an elementary science and technology curriculum. The major organizing concepts, attitudes, and skills presented above should be integrated into all themes or topics that school personnel select for study Some possible themes and topics include space, structures, tools, ice cubes, machines, nutrition, patterns, transportation, food chains, fitness, waste disposal, ecosystems, the Arctic, farms, weather, communities, and pond water. Many of these themes and topics were drawn from previously developed programs, while others are drawn from currently operating programs. Many more themes and topics are possible.

The panel suggests at least six criteria for selecting and designing themes and topics:

- They build upon children's prior experiences and knowledge.
- They capture children's interest.
- They are interdisciplinary, so that the children see that reading, writing, mathematics, and other curricular areas are part of science and technology.
- They should integrate several science disciplines.
- They are vehicles for teaching major organizing concepts, attitudes, and skills.
- They allow a balance of science and technologic activities.

The seeds lesson described at the beginning of this report is one example of a theme or topic that meets these criteria. In some teachers' classrooms or schools, the seeds unit could have been a vehicle for transmitting specific knowledge only. As presented in this report, the seeds unit focused on several major organizing concepts, such as structure and function, diversity, and change (cycles). The teacher planned activities that encouraged the children to incorporate reading, writing, and mathematics (e.g. graphing, ratio sentences) into their study of seeds. Ms. Lopez also planned activities that encouraged the children to relate new knowledge to prior knowledge and experiences. The children studied the biological and physical sciences. And the children demonstrated such attitudes as curiosity and skepticism while they developed their thinking, process, and manipulative skills.

Developing themes or topics that meet the six criteria is a challenging task. One aspect of the challenge focuses on interdisciplinary nature of the themes or topics. Curriculum developers can select planning models that range from strictly departmental orientation to a fully integrated approach: parallel teaching, clustering of disciplines, interdisciplinary units and interdisciplinary programs.

In the first approach, parallel teaching, two or more instructors examine their respective scope and sequences to see when sub-topics can overlap or interrelate. By carefully sequencing instruction in each subject, what the students learn in each class becomes mutually reinforcing. For example, a physical education teacher might plan to focus on respiratory (fitness) activities at the same time the classroom teacher focuses on the cardiovascular system. The only change in teaching that is required is timing what is already taught.

A second approach consists of clustering similar disciplines so that teachers can work together from time to time on specific projects. For example, in a setting where each teacher at the same grade level may have expertise in some curricular area, the teachers might work together on the mathematical, social,and science aspects of the topic, ecosystems.

A third approach is to design a complete curriculum unit, such as seeds or weather, that includes contributions from several disciplines. Frequently, this approach may stimulate new ways of looking at knowledge.

The fourth approach involves the development of a full scale interdisciplinary program. At a given grade level, for example, several disciplines are integrated as the students spend one or more hours each day focusing on a central theme, such as the Arctic, for the entire year (Holmes, 1988).

Summary

This chapter presented a four-part framework that curriculum developers and school personnel can use to develop a scope and sequence, and units of study for elementary school science. The scope and sequence and the units of study should be characterized by organizing concepts, attitudes, and skills and by themes or topics that meet the above stated criteria. This framework allows developers and school personnel t include specific knowledge unique to their students, schools, and regions.

The curriculum framework the panel outlined in this chapte provides a general orientation of materials for a K-6 technology and science program. Among the most important characteristics of the instructional activities within the proposed framework are the following:

- Each is a hands-on activity, and the students' lives and their world are the focus of activities.
- Scientific and technological concepts and skil. are developed within a personal and social context.
- Fewer concepts are developed in greater depth.
- The students construct their concepts, attitudes, and skills through a variety of experiences.
- The students also learn basic reading, writing, speaking, and mathematical skills in scientific and technologic contexts.

The panel believes that if curriculum developers attend to the four components of the curriculum framework and to the five characteristics, then they can develop scope and sequences, units of study and individual lessons that represent approaches to science and technology education that are appropriate for the elementary years.

In the course of this study, the panel did identify some programs that exemplify the goals of the framework. Twelve of those examples are included in Appendix A (Contemporary NSF Programs for Elementary Schools), and Appendix B (Science Education Programs that Work: Exemplary Educational Programs and Practices in the National Diffusion Network). Educators interested in other materials, syllabi, and programs that in some measure exemplify portions of the framework proposed here are referred to the NSTA publication, *Focus on Excellence: Elementary Science* (Penick, 1983) and state guidelines on curriculum from California, Wisconsin, New York, and Florida.

A FRAMEWORK FOR CURRICULUM: RECOMMENDATIONS

Curriculum for science and technology education should be based on major organizing concepts. The concepts recommended by this study panel meet the following criteria:

- They are applicable to both science and technology.
- They have applications beyond science and technology.
- They accommodate different developmental levels.
- They apply to the personal lives of children.
- They are powerful explanatory concepts.

The major organizing concepts recommended by this panel are

1. Organization
2. Cause and effect
3. Systems
4. Scale
5. Models
6. Change
7. Structure and function
8. Discontinuous and continuous properties
9. Diversity

School science programs should also encourage the development of attitudes. The study panel recommends that K-6 science programs incorporate the following scientific attitudes:

1. Desiring knowledge.
2. Being skeptical.
3. Relying on data.
4. Accepting ambiguity.
5. Willingness to modify explanations.
6. Cooperation in answering questions and solving problems.
7. Respecting reason.
8. Being honest.

Science programs and science teachers also should be sensitive to the development of the students' attitudes toward science and toward themselves.

Science curriculum and instruction should encourage the students to develop their skills. The panel has identified three levels of organization for skill development.

1. Gathering information.
2. Answering questions and solving problems.
3. Making decisions.

The panel believes that appropriately designed themes or topics can be effective vehicles for integrating the organizing concepts, attitudes, and skills. The panel suggests at least six criteria for selecting and designing themes and topics:

- They build upon children's prior experiences and knowledge.
- They capture children's interest.
- They are interdisciplinary, so that the children see that reading, writing, mathematics, and other curricular areas are part of science and technology.
- They should integrate several science disciplines.
- They are vehicles for teaching major organizing concepts, attitudes, and skills.
- They allow a balance of science and technologic activities.

The use of organizing concepts, attitudes, skills, and themes will encourage students to see the common ground between the sciences. They will learn to better see the similarities and differences between science and technology. Finally, they will learn to see the relationships between scientific and non-scientific thought.

V. A FRAMEWORK FOR INSTRUCTION

The panel believes that science as a way of knowing (Moore, 1984) and technology as a way of adapting are important themes for an instructional framework. Although science and engineering are separate fields of endeavor with distinctly different approaches, as shown in Figure 1, the two are inextricably bound. Only about 30 percent of current research can be labeled "pure" science, while over two-thirds of recent Nobel prizes have been given for technological, rather than scientific, advances (Hurd, 1989). We believe that a distinction between science and technology is not necessary, especially at the elementary level of science education. Children should see science and engineering as ways of asking questions, tinkering, searching for answers, confronting problems, evaluating possible answers, and sharing discoveries. The panel believes that the approach scientists and engineers use to construct new knowledge provides teachers with a model of teaching and learning appropriate for implementing the proposed framework for curriculum. The panel believes that children should become acquainted with science and technology in ways that parallel how scientists know their world and engineers solve their problems.

The framework for instruction is based on assumptions about students and learning. These assumptions are drawn from research, and they are strikingly different from the views held and promoted by many teachers. These new assumptions about students and learning define roles for teachers of science that are quite different from their roles in most elementary classrooms today. In turn, these new roles require fresh approaches to the development of, and support for, teachers.

What are the assumptions the panel holds for students and learning? What implications do these assumptions have for the role of the teacher? Is there a model of teaching that can serve science and technology education? What are some appropriate strategies and techniques for teachers and children within that model? What support system is necessary for teachers to implement the proposed frameworks for curriculum and instr .tion? This chapter explores answers to these questions.

Assumptions About Student Learning

Assumptions About Students and Learning: Status

Contemporary curriculum materials and instructional practices reflect the belief that lea ng consists of information giving. This information is dispensed by the teacher or through the textbook, with the student taking a largely passive role (Novak, 1988). Educators teach this information through a pre umably logical sequence of topics. These topics are repeated systematically over the K-6 time period. Students spend most of their time listening to lectures and reading about science. They have few opportunities to explore natural phenomena directly or to discuss the results of their inquiries (Mullis and Jenkins, 1988).

Current science materials and instructional practices generally assume that there is one style of lear..ing. The dominant teaching model assumes that learning occurs through listening and reading. Current curriculum and pedagogy fail to meet the learning needs and requirements of a population that has diverse learning styles and abilities to conceptualize (Hodgkinson, 1985; Weiss, 1987; Mullis and Jenkins, 1988; Panel review of materials, June, 1988).

For more than half a century, the principles of early industrialized society, with its factories and assembly lines guided by such values as mass production and cost effectiveness, have influenced the design and practice of American education. Many educators see "children as raw material to be stamped into shape, an empty urn into which stuff called knowledge is to be poured" (O'Brien, 1989:360). Educators have come to believe that improved learning comes about when what is to be learned can be spelled out in objectives, which are statements that tell the teacher what to teach and the students what to learn. In science classrooms, many teachers attempt to transmit to passive students scientific knowledge that consists largely of definitions, terminology, and facts. Among these educators there is the assumption that a student's learning develops from the sequential acquisition of skills and bits of information (Novak, 1988; Smith, 1989). It is assumed that the students must learn lower order information and skills before they can engage in higher level problem solving. Because classroom time for science is limited, few students ever have the opportunity to solve science problems.

A second view of learning takes a cognitive perspective and argues that educators should focus on the mental constructs and organizational patterns that students develop and which they use to guide their behavior. This emerging school of thought--which many researchers and educators call cognitive learning theory, or constructivism-proposes that students actively learn and constantly construct their world view (Resnick, 1983; Linn, 1986; Novak, 1988; Tobin, 1988).

This view of learning extends the developmental perspective of Piaget by recognizing that "learners build conceptual frameworks that are complex, highly organized, and strongly tied to specific subject matter" (Linn, 1986:9) and by recognizing that dialogue among children is an important strategy for encouraging them to construct new conceptual frameworks. Although this view is not markedly different from those espoused years ago by Jean Piaget and John Dewey, there is a growing body of research that demonstrates the validity of the constructivist view (Anderson, 1987). This research confirms the view that knowledge is stored as a network of concepts in the brain of the learner. Learners, thus, construct knowledge by making connections between new information and their existing conceptual network (Peterson, Fennema, and Carpenter, 1988). The constructivist view of learning is linked to three related ideas: prior knowledge, student learning styles, and concentration of teaching on depth and understanding, rather than on breadth of coverage and knowledge of vocabulary.

Prior Knowledge

Using the constructivist paradigm, researchers have provided new insights into the important role played by a student's prior knowledge (Linn, 1986; Anderson, 1987). Bartlett (in Champagne and Hornig, 1987) and Ausubel (1963) found that meaningful learning can occur when teachers present new ideas in familiar contexts. Only when the students cannot relate new ideas to already familiar ones will they resort to memorization and superficial learning, which is soon forgotten. Furthermore, research cited by Champagne and Hornig (1986) and that conducted by Anderson and colleagues (Anderson, 1987) demonstrates that students have understandings of science in ways not congruent with viewpoints held by scientists. Driver (1983:3) refers to these incongruent views as alternative frameworks:

> By the time children are taught science in school, their expectations or beliefs about natural phenomena may be well developed. . . .They may be poorly articulated but they provide a base on which formal learning can build. . . . Such beliefs I shall refer to as "alternative frameworks" (p. 3).

Research indicates that students can cling to their erroneous viewpoints into adulthood (Murnane and Raizen, 1988). How can educators help those students develop new, more sophisticated views of scientific concepts and replace these erroneous viewpoints?

It is naive for teachers to believe that they can transmit correct views of scientific concepts to their students through the spoken and written word (Novak, 1988) Even conducting a science demonstration designed to help the students overcome an existing concept is probably not sufficient. Champagne and Hornig (. 7) note . at students who observed such demonstrations ported observations that were more closely aligned with their existing viewpoints than with what actually happened. Learning that leads to change conception takes time, because a student needs to compare and contrast new information (sometimes presented by the teacher while at other times discovered through inquiry) with an existing concept. With time and ample experiences the student gradually modifies or replaces the pre-existing idea with a new, more sophisticated concept (Anderson, 1987). Teachers have a responsibility to select appropriate, meaningful materials, but it is the student who must bring meaning to those materials.

Depth as Opposed to Breadth

Research on the importance of prior knowledge, along with the findings that developing a more sophisticated view of a concept takes time, suggests that students should pursue a topic or a phenomenon in depth (Murnane and Raizen, 1988). Thus, teachers should not require the children to mechanically recite numerous complex scientific concepts, nor should the teachers burden the children with numerous definitions and miscellaneous facts. Rather, a topic, such as seeds-- its emphasis on such major concepts as diversity, cycles, and change--should span several weeks or longer. The teacher should provide many opportunities for the children to ask questions, to conduct inquiries, and to formulate scientific concepts from their tests and observations on seeds. For many teachers, this long-range approach represents a new view on "depth"; the focus is on a deeper understanding of fewer topics rather than superficial coverage of many topics. The decrease in emphasis on facts and definitions should encourage learners to construct meaning, rather than to simply catalog facts and pieces of information. "Less is more" is a guiding principle, for the learning emphasis should be on quality rather than quantity, on understanding rather than memorization (Arons, 1983). The emphasis on teaching science in depth rather than quickly and topically recognizes the complex process of conceptual change, a process that requires that students may either have to relinquish prior knowledge or reorganize it so that their world view embodies new ideas. Learning is not simply the accretion of new knowledge or the absorption of new facts. Rather, it is an active process of construction, "the making of connections between new information and the learner's existing network of knowledge" (Peterson, Fennema, and Carpenter, 1988:43).

Ms. Lopez based her instruction on constructivist psychology. She began the seeds unit by asking the children to help her make charts; one chart was for questions the children had about seeds, and another chart was filled with statements. These charts provided her with information on her students' prior knowledge, and she used this information to decide on activities appropriate for the unit, for example, the seed walk. Rather than focusing on miscellaneous facts and terminology, Ms. Lopez planned activities that caused the children to think more deeply about structure, function, and diversity. The unit spanned several weeks, which allowed the children to fully explore their reconstructions of several concepts.

Learning Styles of Students

Some students blurt out responses to questions before the teacher finish them. Others may reflect on possible answers for more than several seconds. Some students learn effectively from lectures and readings, while others benefit from concrete and visual approaches. All of these behaviors reflect what researchers call learning styles. The concept of learning styles dates at least to Hippocrates, who identified four personality types. In recent years, educational researchers have refined our knowledge of learning styles--that is, the ways we perceive, interact with, and respond to the learning environment. Educators have several models of learning styles from which to choose, including those of Dunn and Dunn; Gregoric-Butler; Hanson, Silver, and Strong; and Bernice McCarthy (Kuerbis, 1986).

Children exhibit a wide variety of styles of learning Some can see the big picture, but not the details. Others may have an opposite style of learning: they need to see the trees first before they can envision the forest. Some children are sequential in their style, while others are more global. All children display another aspect of learning style--learning modalities. The teacher can present new science information through several modes or modalities: tactical, visual, or auditory. While most science teaching uses a verbal mode through lectures and text readings, research suggests that "whenever students were taught through resources or approaches that complemented their modalities, they achieved significantly higher test scores" (Dunn and Dunn, 1987:59).

Clearly research on learning styles tells educators that children have diverse approaches to learning. While the American educational system has been successful for the first half of this century, traditional educational practices no longer meet the needs of a population that is becoming increasingly diverse. In the past two decades, the country has seen an increase in students affected by divorces, drugs, and teenage pregnancies. More of our school children are now drawn from homes in which English is a second language (Hodgkinson, 1985). Research on learning styles begins to "point the way to making instruction more responsive to youngsters who do not learn and retain information in ways that conventional education provides" (Dunn and Dunn, 1987:55).

Role of the Teacher

Elementary teachers have a special role they should take when implementing a curriculum framework that includes a constructivist model of learning, studying science concepts in depth, and an emphasis on learning styles. Children arrive at the doors of

ROLE OF THE TEACHER: STATUS

Teachers frequently take a dominant role in which they deliver science information to children through lectures, demonstrations, and text readings Typically, they choose topics with which they feel comfortable, usually in the life sciences rather than the physical sciences. Teachers pay little attention to major organizing principles in science when designing a program; they generally do not assess students' conceptual understanding, nor do they direct their teaching toward students' levels of understanding (Mullis and Jenkins, 1988; Novak, 1988).

elementary schools curious about the natural and human-made worlds around them. From an early age they ask questions that are inherently related to science: Why is the sky blue? How big will I be when I grow up? How come rocks sink and sticks don't? Moreover, the children are unafraid to "mess about" as they become familiar with science and technology.

So often, textbooks and lectures suppress a child's natural curiosity by limiting the time for science and by restricting the child's exposure to science. Educators need to nurture the curiosity that children bring to school. Educators need to begin with the questions children have, and the need to recognize the specific beliefs and concepts children hold. By helping children question their scientific concepts, teachers can help children to seek greater depth of conceptual understanding. Thus, the role played by the teacher can best be described as one of facilitation.

Teacher as Facilitator

Teachers must feel comfortable with their role, not as expert providers of knowledge, but as facilitators of learning. Teachers need to demystify science and change the image many children have of the scientist as a man in a white coat who has all the answers. Teachers can help the students feel confident and successful in science by relating the science activities to the students' personal lives.

As facilitators, teachers greatly influence the climate of the classroom. They can model the qualities they wish to encourage in their students by showing curiosity, awe, and enthusiasm. The teacher also is the strategist who plans and provides materials. The lessons must be appropriate for the age and developmental level of the students. Allotting ample time for science activities also is part of the instructional strategy.

Inquiry and discovery methods of teaching science actively involve the teacher and children in questioning their observations of the natural and technological worlds. Teachers and students should collaborate as co-learners. As the adult, the teacher is coaching the students to probe and question the concept or problem at hand, and to generate new questions that lead to further investigation. Questioning skills, including ample wait-time, should be consciously developed by teachers. In choosing instructional activities, the teachers must analyze *whom* they teach and consider their own personal teaching style, the students' learning styles and abilities, and the dynamics of small groups.

Do our assumptions about learning and the role of the teacher as facilitator require that all learning must be through discovery? Lauren Resnick (Brandt, 1988:15), in reviewing the new principles of constructivist learning tells us that the answer is no but that, "it is not enough just to focus on making an excellent presentation...." Children simply do not obtain the information the way a teacher says it. Resnick tells of Leinhardt's research on expert mathematics teachers who are teaching regrouping in subtraction. Even with a very clear explanation and the use of manipulatives, Leinhardt found children who had only a partial understanding, some who had misunderstandings, and some who had constructed new explanations. Resnick concludes that "We have to figure out how to teach in ways that do not just 'impart' knowledge, but instead help students to construct their own interpretations." (Brandt, 1988:15) In this chapter the panel describes, from a constructivist point of view, the roles of students and teachers who actively implement an elementary science curriculum through a variety of instructional approaches, and the students' roles.

Cooperative Learning. Children working collaboratively in small groups is an instructional approach that provides children the opportunity to verbalize what they know and consider multiple viewpoints. Although constuctivism recognizes the importance of each individual's construction of a conceptual view, research points out that cooperative learning effectively promotes stude[illegible]arning. Competitive learning, in which students compete with each other for grades, and individualistic learning, in which students work independently, are less effective than cooperative learning. When they contrast cooperative learning with both competitive and individualized instruction, the Johnsons (1975:39) concluded that "it is cooperation that is most productive in creating fruitful learning climates and in promoting the accomplishment of most cognitive and affective outcomes." Apparently, as the students construct their concepts, it is important that they negotiate new understandings with their peers and the teacher. They must test their understandings against the understandings of others.

Cooperative learning is not the same as the small-group learning that many teachers use. Rather, members of teams are assigned roles (for example, principal investigator, recorder, and materials manager) and rotate those roles so that members experience the full range of respon[illegible]ilities within their group. Teachers should structure the tasks so that a spirit of positive interdependence develops. Children in a group need to feel that they are responsible for their own learning, as well as that of their teammates. In addition, cooperative learning requires face-to-face interaction among students and individual accountability for mastering the assigned materials. Finally, teachers must expect to help the students develop the interpersonal and small-group skills required so that they can interact successfully in a group.

Science instruction should employ all three modes of instruction: competitive, individualistic, and cooperative. Teachers can improve the effectiveness of their instruction and the quality of their students' learning if they attend to the appropriate uses of each mode. Competitive activities are good for practice, recall, and review in situations where students do not perceive that the goal is extremely important. In this setting, the students can enjoy the activity regardless of winning or losing. Individual activities are appropriate when the student must learn a specific skill or acquire specific knowledge. Here, the goal is important to the student, who must take responsibility for evaluating progress toward the goal. Cooperative learning is appropriate for such activities as problem-solving, divergent thinking, and inquiry. Here, the goal is important for the student and the group. The students need to interact positively, share ideas and materials, support one another as they take risks, contribute to the group effort, and capitalize on the diversity of views among the members of the group.

In view of the growing diversity of students, the growing evidence that substantiates the importance of constructivist learning, and the value of an approach to the science curriculum based on major concepts, the panel believes that teachers should frequently use cooperative learning as a method of instruction in elementary science.

Ms. Lopez used cooperative learning groups extensively because she had a diverse group of children and wanted them to share their current constructions of several concepts (for example, structure and function, diversity, change). But, she also used other modes of instruction to help address the varying learning styles of her students. She used large group instruction, for example, to allow the children to compare their viewpoints.

Problem Solving and Laboratory Activities Problem-solving activities hold promise "because learners are provided experiences which approximate those of scientists engaged in constructing knowledge of science" (Tobin, 1988:6). Of course, many teachers have used hands-on, process-oriented activities with their students. But such activities do not necessarily involve problem solving. When they studied worksheets and exams associated with laboratory activities at the middle school level, Mergendoller and colleagues (1988) found that many of the hands-on activities teachers used presented the students with few cognitive challenges. The activities encouraged students to focus on the trivial aspects of the content, instead of concentrating on strategies that would encourage the students to reconstruct existing conceptual viewpoints. Problem solving only exists when the learner is unclear about what needs to be done to arrive at a solution. The teacher can pose tasks, but the learners determine if the tasks are problems (Tobin, 1988).

Educators have much to learn about how to structure real laboratory tasks so that the tasks become true problem-solving activities that will engage the students in actively constructing new meaning between prior knowledge and newly acquired information. Appropriate problem-solving activities encourage the learners to make the connections between new information, which has been uncovered by solving the problems, and the learners' existing network of knowledge. In mathematics, research has led to the conclusion that "computational skills do not exist as lower order prerequisites for higher order mathematical problem solving, but rather are learned in relation to and as part of problem solving" (Peterson, Fennema, and Carpenter, 1988:43). Thus, mathematics teachers should use problem solving to teach addition and subtraction, rather than using addition and subtraction to teach problem solving. Although we need to understand problem solving in the context of each subject (Brandt, 1988), the research on elementary mathematics problem solving suggests that new science vocabulary, facts, and such process skills as observing and inferring, should be taught through problem-solving activities. Ms. Lopez, our ideal second grade teacher, employed just that approach.

> *In Ms. Lopez's classroom, children began the seeds unit by generating statements from their prior knowledge about seeds and listing questions they had about seeds. Both the seed walk and the planting of their seeds led the children to generate problems that they could solve. In the process of acting on self-generated problems, Ms. Lopez was able to judiciously introduce the children to new information, vocabulary, and interesting facts about seeds, as well as several process skills that encouraged the children to link the new knowledge to that which they already possessed.*

Textbooks and Lectures. As we noted early in this paper, about two-thirds of primary teachers (K-3) and 90 percent of intermediate grade level (4-6) teachers use science textbooks. Similarly, lecturing dominates elementary science teaching (Weiss, 1987; Mullis and Jenkins, 1988). If we should not expect children to discover all learning by themselves, then is there a place for textbooks and lectures within the constructivist learning paradigm?

An important component of constructivism is the active involvement of the learners who construct their own interpretations of knowledge. As Resnick (Brandt, 1988:15) points out, "Comprehension takes place when the speaker and the listener construct a common space of representation." A teacher can be sure that no child will receive the information presented in a lecture precisely as it was transmitted. Most children will get some portion of the information, while a few will receive a garbled message and a few will go beyond the information the teacher delivered (Brandt, 1988).

Textbooks and their printed transmittal of information have produced from students the same learning results as lectures, even though publishers have attempted to present scientific information in innovative ways. In an attempt to increase students' comprehension of textbooks, publishers have improved the sequential nature of the text material, have provided vocabulary lists at the beginning of each section, have emphasized by bold lettering new vocabulary in the text pages, and have provided questions at the end of sections. Unfortunately, the students have responded by rotely learning the new information, by focusing only on the appropriate keyword in a question, by searching for the word in the text, and by copying the sentences that contain the word. Textbooks, as currently written and as used by most teachers, do not encourage the students to interpret the new information in light of their prior knowledge, and consequently the students do not improve their conceptual understandings.

The structure and format of textbooks must change. In a recent study of elementary science textbooks, the authors report that many textbooks, including the ones most commonly found in schools, are characterized by high numbers of content domains and new vocabulary. For example, this country's most widely adopted program introduces third graders to 15 content domains (for example, animals, tools, machines) and 243 new vocabulary words. Furthermore, "the programs with the greatest amount of content also had far more teacher-directed activities" (Meyer, Crummey, and Greer, 1988:460). Although the programs reviewed by these authors displayed great variation in the amount of content presented, the panel's own review of textbooks led to the conclusion that current textbooks emphasize coverage of material, rather than student understanding. The proceedings of a recent national conference on improving textbooks (Educational Development Center, 1987) recommended that a textbook program should do three things.

- Get students ready to learn new information.
- Actively engage students in integrating and organizing new information and old information.
- Accommodate the students' diversity and tap their strengths and interests when helping them extend new knowledge.

This three-phase approach is similar to the instructional model proposed later in this chapter.

Teachers need to use textbooks differently than they do currently. The constructivist paradigm suggests that students need time and frequent opportunities to read, to discuss new words and ideas with peers (for example, in cooperative learning groups), and to relate that information to what they currently know. For example, as we point out later in this chapter, the students can profit from readings after they have initially explored a topic. In addition, teachers should use text materials to help students link the new information to the students' knowledge.

How teachers use, prepare, and deliver information must also change. For the constructivist, "Language is not a means of transporting conceptual structures from teacher to student, but rather a means of interacting that allows the teacher here and there to constrain and thus guide the cognitive construction of the students" (von Glaserfeld, in Tobin, 1988:12). Yet, a clear lecture can be the basis for learning, provided that the students have time to reflect on the new information and link it to their existing knowledge and to problems they are solving. Mary Budd Rowe's 20 years or so of research on wait-time substantiates the importance of pausing about three seconds after questions and after responses (Rowe, 1983). This permits the students to integrate the new information into their existing knowledge. Tobin (1988) found that longer periods of silence effectively improved elementary and middle school students' achievement when compared to teachers who used wait times of about one-half second. Rowe (1983) found that learning increased when high school teachers provided about two minutes of time every ten minutes for reflection and discussion. Clearly, providing the students with ample time to think about and interpret new information, improves the effectiveness of lectures. The panel agrees with David Hawkins who summarizes the case for instruction through lectures and textbooks:

> Past experience must indeed be somehow summarized, must in some way be put in soluble capsules; it cannot be relived in its totality. If we had to relive all past errors and discoveries, it would be a commitment to absurdity. A part--indeed a major part--of the structuring of our minds must come from instruction. But this obvious statement leads much too easily to notions that are, I believe, radically false. *In*struction by a teacher fails without a matching *con*struction by the learner, induction without spontaneity, words without things. The lecture or the textbook passage that succeeds is one that meets an apperception well prepared. When we merely surrender to the textbooks, we surrender defeat (Hawkins, 1983:73).

In this section we have described several instructional activities from the constructivist perspective. The constructivist understands the importance of learners constructing new understandings. This is in contrast to those educators who believe that the transmission of scientific facts is of paramount importance. These educators disdain cooperative learning and problem-solving strategies, for they view these activities as taking an inordinate amount of time. Constructivists, on the other hand, value these approaches for they are congruent with the research, which demonstrates that students need time to think, that students benefit from comparing and contrasting points of view, and that students must have opportunities to experience hands-on, mentally engaging activities.

Children bring to new experiences that teachers have provided a marvelous diversity of understanding. These understandings they have brought from previous experience and past assimilation from adult and peer associations. The teachers' role is to help the children sort and rectify this knowledge. The art of teaching, according to Hawkins (1983:74), "is that of observing and listening, of searching for clues, and of then providing that which may steady and further a budding curiosity, or failing, may lead to further clues." Teaching, then, is as profoundly inductive as the children's own learning, and thus implies another role for the teacher.

Teacher as Assessor

Assessment is an important and integral part of teaching and learning (St. John, 1987). It is especially important within the constructivist paradigm, for how are teachers to know what questions to ask of students, what new experiences and information to provide, and how much time may be required for the children to interpret new information and integrate it with prior knowledge? The Center's companion document, "Assessment in Elementary School Science Education" (1989), presents an extensive discussion of issues in assessment, in assessment of learning, and in assessment of program quality. In this section, we described how assessment can serve instruction. The panel urges the readers to consult the companion document for a detailed discussion of issues surrounding the role of assessment in K-6 science education. All science educators should be concerned about assessment for four reasons.

1. Assessment can be a very helpful tool for guiding instruction and making it more effective.
2. Assessment can impress on students, school staff, and parents the importance of science learning.
3. Assessment can be used as a policy tool for monitoring the outcomes of science instruction and helping improve science programs.
4. For good or ill, assessment can exert a powerful influence on curriculum and instruction.

As mandates for assessment grow, it becomes imperative to establish correspondence between the goals of science education, the curriculum, and the test, and to establish other means of assessment that might be used for correlating what children have learned and accomplished in science. Assessments must support the teaching of professionals like Ms. Lopez, not undermine them.

Ideally, teachers like Ms. Lopez use tests for a variety of reasons, including: (1) finding out about the students' prior knowledge so that they can help students build upon those conceptions; (2) establishing, after a period of instruction, what the students have learned so they can shape subsequent teaching; (3) placing the students in productive learning groups; (4) motivating the students to attend to assigned materials; (5) communicating to the students the teachers' expectations of what they are to learn; and (6) documenting what the students have learned in order to inform them, their parents, and subsequent teachers of individual and group progress.

At best, assessment can be a powerful tool for focusing instruction and providing the teacher with valuable information on how to increase learning. If assessment is thoughtfully incorporated into instruction, it can provide teachers with the feedback they need.

Unfortunately, few teachers use assessment as we have just described. Instead, they use written tests at the end of textbook chapters rather than informal assessments. They use information gathered from these tests to determine grades for students, rather than use assessment information to serve instruction. Much of the information teachers need to guide their instruction should come not from formal tests, but from informal classroom observations. Teachers need to attend systematically to these observations, perhaps by jotting down observations on file cards at the end of a day. Teachers should scientifically observe the children. By observing children over a period of time and by listening carefully to conversations children have with each other and with the teacher, the teacher makes informal assessments reliable and valid.

Formal assessments also need to be reliable and valid. discouragingly, few tests that teachers make are reliable or valid, and the teachers extensively use written tests to assess observing,inferring, and problem-solving skills. Tobin (1988) has noted that

> 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 (p.15).

Science educators and teachers need to develop valid assessment tools that are measures of practical and problem solving skills. Moreover, teachers need tests that de-emphasize facts and encourage students to search for connections between their prior knowledge and new information.

As we saw in Ms. Lopez's classroom, assessment serves both a formative and a summative process and uses methods that range from the informal to the formal.

Ongoing monitoring to find out what students know and the ability to use this monitoring as a basis for shaping instruction is woven throughout Ms. Lopez's instructional activities about the seeds--at the individual, group and class levels. For example, individual students were asked to keep journals--ongoing records not only of student ability to make observations and communicate information, but of growth in concepts and understanding about seeds. In addition to each student's written record, the "What We Know About Seeds" chart was updated at regular intervals. Thus, after each activity, the students were encouraged to add to the chart--not only a variety of facts about seeds, but understandings related to the nine organizing principles that structure the elementary science curriculum in Ms. Lopez's school. For example, even initially after bringing in the seeds and surveying the class's collection, the students might have noticed that there are many different kinds of seeds (diversity) or that sometimes it is hard to tell what is and isn't a seed (organization) or that seeds grow into plants (change, systems).

Ms Lopez had many additional opportunities for evaluating growth of understanding for individual students or groups of students. Each student gave an oral presentation about a seed which had been found and examined, and each participated in a group that was asked to write about graphs and shared in whole-class activities in which each student questioned or issued a statement that revealed an indication of progress (or lack of progress). Ms. Lopez was interested in several different types of understanding: Did the children develop an understanding of the role of seeds and food for animals and humans? More important, did they develop and understanding of some of the nine principles that had been illustrated through the study of seeds? Were they more adept at using a lens and at measuring length, weight, and volume? And did they develop some sense of systematic observation, recording, and analysis of data as they collected seeds, organized their collection, and germinated the seeds? As Ms. Lopez kept notes on the progress of individual children and the class as a whole, *she developed the source materials that would enable her to make more formal assessments to be reported in report cards, to parents, and--for the class as a whole--to Mr. Sandowski, the third grade teacher.*

A Teaching Model

The panel suggests that the instructional framework--methods for teaching and learning science--should parallel the methods scientists and engineers use to uncover new knowledge and solve problems.

The proposed instructional framework is a template which teachers can use to design daily lesson plans and weekly (or longer) unit plans. The panel intends that the framework will help ensure that science teaching and learning embodies multiple approaches to learning (tantamount to the experiences of active scientists and engineers), so that learners are asking questions, experimenting, and communicating their new knowledge to colleagues. The students also should have the opportunity and responsibility to act on newly reformulated knowledge and to ask new questions. The framework should suggest to teachers and students that science and technology, as fields of study and human endeavor, are dynamic. The framework reinforces the generative nature of science and technology: questions and problems lead to tentative explanations and solutions and in turn generate new questions and problems (refer to Figure 1).

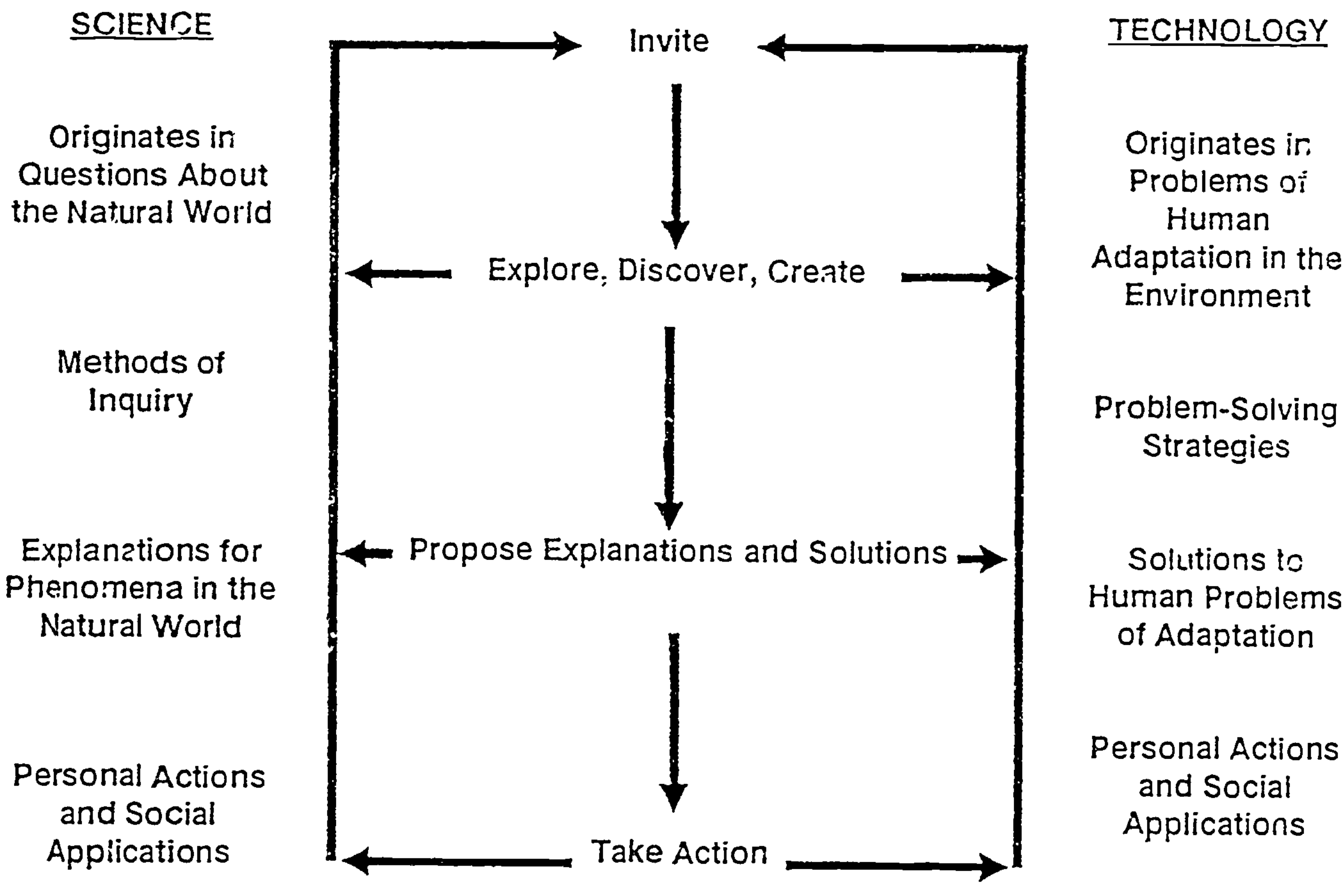
Components of the Teaching Model

The proposed teaching model is based on four stages characteristic of the approach taken by practicing professionals in science and technology when they learn and apply new skills and information within their fields (Figure 2). The descriptive labels for each stage are dynamic, as is the proposed cyclic nature of the model. The instructional model further clarifies for the instructor the dynamic process that is science and emphasizes that although single lessons or units of study may have a beginning (invitation) and an end (taking action), any new skills or knowledge will inevitable lead to new invitations and, therefore a continuation of the cycle.

To help the reader better understand the model, we describe what might occur at each of the four designated stages. Figure 3 lists key activities that might characterize each of the stages. These stages represent activities that practicing scientists and engineers might engage in as they learn: The states, therefore, parallel suggested activities. The instructional framework incorporates the instructor as an active participant in the learning process and provides a guideline for the teacher's learning as well as the students' learning, because most elementary teachers have limited formal training in science. In fact, the panel considers the model to be universal in describing any learning in science and technology, including learning by professional scientists, teachers, and students. The model is applicable in both classroom and laboratory settings as well as in less formal settings, such as the home, a park, museums, nature centers--literally any place where an invitation to learning may be recognized and accepted.

Invitation. The beginning of any learning process in science and technology is characterized by an invitation. In general terms, the invitation originates with a question about the natural world (science) or a problem in human adaptation (technology). More specifically, an invitation may be quite spontaneous--such as a student discovering an empty eggshell in the park--or it may be elicited by a demonstration of a discrepant event. In both cases, questions emerge immediately, the children and the teachers are observing together, and the stage is set for further investigation. It is important to remember that invitations must engage the learner. Therefore the learner must understand the event, question, or problem well enough to begin actively thinking about the question or problem. If the question, or problem, is not one the students are curious about, or one they initiated, or one they want to

Figure 2


SCIENCE
Originates in Questions About the Natural World
Methods of Inquiry
Explanations for Phenomena in the Natural World
Personal Actions and Social Applications
Invite
Explore, Discover, Create
Propose Explanations and Solutions
Take Action
TECHNOLOGY
Originates in Problems of Human Adaptation in the Environment
Problem-Solving Strategies
Solutions to Human Problems of Adaptation
Personal Actions and Social Applications

address or solve, then further engagement will be difficult and likely will not result in anything but rote learning (Hawkins, 1983).

Invitations can be made to the entire class. For example, to encourage the children to embark on a study of water organisms and environmental issues, the teacher might bring in a sample of pond water and ask the question, What lives in a drop of pond water?

Because recognizing and accepting invitations involve choice, this is a stage in the process to which the teacher should return often. Making new choices based on new opportunities is something that easily excites K-6 students and will quickly create a classroom of eager learners. Figure 3 lists suggested activities that are characteristic of this beginning stage of the model.

Exploration, Discovery, Creativity. This stage of the teaching model builds upon and expands the science learning initiated by an investigation. At this point, it is critical that children have access to materials and that they have ample opportunities to observe, to collect data, to begin organizing information, and to think of additional experiments that they might try. The stage is characterized by a strong element of constructive play or informal investigation in which the children try one approach with the materials, share their findings with each other, and try another experiment. They might use analogies or visual imagery to help them think about the new concepts that they are encountering. They begin to explore how new information gained from their investigations relates to previous experiences and their current level of understanding. The teacher is a co-learner and also a facilitator who chooses materials and activities that are likely to lead the children to new discoveries and information. The teacher observes with the children and asks questions with them. The stage permits a model of

Figure 3
The Teaching Model and Teaching Examples

INVITATION

Observe the natural world
Ask a question
State a hypothesis

Recognize a problem
Take a risk
Engage in play

EXPLORATIONS, DISCOVERIES, CREATIONS

Engage in focused play look for information
Observe specific phenomena
Collect and organize data
Select appropriate resources
Listen to others
Try and try again (editing, re-design, etc.)
Engage in debate (defend your position)
Match strengths with weaknesses
Prioritize information and actions
Recognize and measure progress
Discard irrelevant information and materials
Practice with materials
Define parameters
Question authority

Experiment with materials
Design a model
Share knowledge
Employ appropriate methods and strategies
Access other disciplines
Discuss with others
Identify applications
Make choices and decisions
Take risks
Draw analogies
Ask new questions
Construct and analyze a prototype
Analyze data

PROPOSING EXPLANATIONS AND SOLUTIONS

Communicate information and ideas
Construct a new perception and/or reality
Evaluate peers
Determine appropriate closure

Explain a model
Constructively review
Express multiple answers/solutions
Integrate with existing knowledge and experiences

TAKING ACTION

Apply knowledge and skills
Share information and ideas
Develop products and/or promote ideas

Transfer knowledge and skills
Ask new questions

many of the responses, such as awe, enthusiasm, curiosity, and the temporary suspension of judgement that are characteristic of scientists. The teacher also can informally assess the children's developing understanding of a concept and pose questions that motivate the children to investigate further and try to link the new findings to their current formulations of a concept. Figure 3 lists possible activities for this stage of the teaching model.

Proposing Explanations and Solutions. In this stage, the learners continue to refine their developing understanding of a concept. They construct a new view of the concept by integrating their current conception with new information, which they have gained through their explorations and discoveries. The children then analyze data that they began to organize in the preceding stage and consider alternate interpretations prepared by classmates and the teacher. New explanations can be developed jointly with the teacher and peers by sharing information and actively listening to one another's proposed explanations. Cooperative learning is an important part of the teaching and learning approach. The students, guided by the teacher, may decide to perform additional investigations, usually more focused than those they conducted earlier. The results of these experiments will help resolve conflicts that children have between their previous understanding of a concept and a newly emerging view. Each learner, with the assistance of the teacher, brings new meaning to a concept. This cooperation between students and the teacher is an opportunity for the teacher to model qualities that characterize scientists: proposing and accepting alternative points of view, listening and questioning, persistence in seeking solutions, and working together cooperatively. Figure 3 lists activities that are characteristic of this stage of the teaching model.

Taking Action. Once the students have constructed a new view of a concept, they are usually ready to act on that new level of understanding. Figure 3 lists possible ways in which they can take action and demonstrate that they have truly integrated the newly discovered information and proposed solutions into their existing framework of understanding. They might defend a point of view before the class or write a letter to a local authority. Their new level of understanding may, and frequently does, lead to new questions that provide the foundation for new explorations and subsequent refinement of conceptual understanding. The teacher's role is to encourage the students to take action through the teaching examples listed in Figure 3 and to assist the students in transferring their new knowledge to other fields of study. The teacher also can assess, informally and formally, each student's new levels of understanding and gauge the effectiveness of the science program. This will help the teacher plan future activities appropriate to a student.

In a classroom study on pond water, for example, the students' new understanding of diversity and the intricate relationships of a pond ecosystem may lead them to greater appreciation for, and understanding of, the factors that affect a pond. The students might debate the merits of various methods for maintaining a pond's ecological balance; they might write to a local council to argue that sources of pollution should be stemmed, or explore how proposed measures of controlling pollution might affect the local community beyond the immediate pond that they are studying.

> *Ms. Lopez's unit on seeds began with the children generating both questions and statements about seeds. This approach closely resembles the first stage of the instructional model--invitation. The seed walk the next day is an example of an activity that allows the children to explore and discover--the second stage of the teaching model. During the next few days, the children engage in a number of activities, many of which allow the children to explore further. Some activities, however, also engage the children in the third stage of the model--proposing explanations and solutions. Here, Ms. Lopez takes an active role in posing questions that cause the children to rethink their current beliefs about seeds and several of the concepts upon which they have been focusing. Toward the end of the unit the children are posing questions of their own--setting the stage for additional explorations.*

Other Models

The teaching model stated previously guides teachers as they construct their instructional programs. The teaching model parallels the model of science and technology provided in Figure 1, and it is compatible with the concepts of science and technology presented earlier in this chapter. As with any model, the panel's teaching model fails to capture fully the rich complexity of scientific and technological methods. The model's stages are presented sequentially so that the model can be more easily interpreted; naturally, the practicing scientist rarely, if ever, follows the model step-by-step. In Figure 2, the illustration, with its arrows and possible loops, illustrates the complex nature of scientific investigations. In the classroom, after initial engagement, the children and the teacher may engage in exploratory investigations, propose tentative solutions, and explore concepts several times before coming to the last step, taking action.

The teaching model is compatible with some models of teaching and learning, such as those currently under development at the Education Development Center (EDC) and the Biological Sciences Curriculum Study (BSCS). The EDC framework for instructional strategies has four phases:

1. *Engaging.* The teacher probes the students' prior knowledge, motivates the students, sets goals, and starts experiments. Children ask Why? What is it to me? and What are the goals and expectations? They begin to interact with materials.
2. *Exploring and Discovering.* The teacher is a facilitator who observes, mediates, and assesses. Students experiment, observe, record and interpret data as they solve problems. At this stage, students work in cooperative groups and share materials, coach and monitor each other, and report findings.

3. *Processing for Meaning.* Together, students and teachers question, hypothesize, analyze data, build models, clarify concepts, bring closure and apply new knowledge in other contexts.

4. *Evaluating.* Students apply, integrate, extend, and question their knowledge. The teacher evaluates how the students' concepts, process skills, and attitudes have changed and judges the program's effectiveness in promoting changes in students' concepts.

The BSCS model of teaching and learning is an outgrowth of the three-phased learning cycle proposed by J. Myron Atkin and Robert Karplus (1962) in the early 1960s and later used in the Science Curriculum Improvement Study (SCIS). In more recent years, science educators Anton Lawson, Michael Abraham, and John Renner (1989) have further refined the original Atkin-Karplus learning cycle. In many ways their models parallel the Center's teaching model. As currently envisioned, the BSCS model has five phases:

1. *Engagement.* Activities in this phase mentally engage the student with an event or question. Engagement activities help the students make connections with what they know and can do.

2. *Exploration.* The students work with each other to explore ideas through hands-on activities. Under the guidance of the teacher, they clarify their own understanding of major concepts and skills.

3. *Explanation.* The students explain their understanding of the concepts and processes they are learning. The teacher clarifies the students' understanding and introduces new concepts and skills.

4. *Elaboration.* Activities in this phase challenge the students to apply what they have learned, to build on their understanding of concepts, and to extend their knowledge and skills.

5. *Evaluation*. The students assess their knowledge, skills, and abilities. These activities also allow teachers to evaluate a student's progress.

In contrast to these models stands the Instructional Theory Into Practice (ITIP) model developed by Madeline Hunter (1983). The panel believes that the ITIP model contradicts what is known about how learners develop new conceptual understandings in science. Rather, the ITIP model appears to be more conducive to instruction that focuses on giving information to the students and drill-and-practice methods for developing the students' skills. Conversely, the proposed teaching model, which is based on a constructivist view, is designed to teach the children a knowledge base, scientific attitudes, and scientific thinking and problem-solving skills within the context of active conceptual development.

The ability of the panel's proposed teaching model (Figure 2) to incorporate models, such as those used by current, major curriculum development efforts in elementary science, demonstrates the robustness of the teaching model, and the power of "science as a way of knowing" as a framework for instruction and curriculum. The frameworks we have presented in this chapter and the previous one have significant implications for teachers. The Center's companion report, "Teachers and Teaching in Elementary Science Education" (Loucks-Horsley, et al., 1989) details the changes in the education of beginning and experienced teachers that are necessary if schools are to implement the findings and recommendations of this report on curriculum and instruction. We turn now to a brief summary of the changes in the development of teachers that are necessary to implement the frameworks for curriculum and instruction.

INSTRUCTIONAL FRAMEWORK: RECOMMENDATION

A child's prior experience and knowledge of science and technology provide an essential foundation upon which teachers can base a science program and instructional strategies. At the primary level, teachers should build upon the children's natural curiosity about the world and help them develop the organizing concepts (e.g., change, systems) of the curriculum framework. At the intermediate grades, more attention can be given to activities designed to develop the children's growing understanding of concepts of science and technology. Throughout the elementary years, schools and teachers must provide settings that allow children to reconstruct and refine their view of the world through active, reflective approaches to science as a way of knowing.

To "learn science by doing science," Children need experience with a variety of strategies and materials, rather than merely reading about science or performing experiments that only confirm the information they have read. Moreover, instructional variety is important if we are to meet the learning needs of a school population that is rapidly becoming diverse in terms of learning style and cultural backgrounds.

The programs we envision will provide all children with ample opportunities to experience the natural world directly and to construct refined concepts of the world through discussions with their peers and teachers.

We recommend that schools and teachers frame their instruction around a teaching model that reflects how scientists and engineers know their worlds.

Teaching Model

Invitation. This stage initiates the instructional sequence. The object of the invitation phase is to engage the learner with a question, problem, or event related to the concepts or skills of the learner.

Explorations, Discoveries, Creations. This stage provides students with experiences that will help them to begin answering the questions and solving the problems presented in the lesson. Most of the activity is limited by materials that the teacher provides.

Proposing Explanations and Solutions. This stage allows the students to express their explanations and solutions. It is also a time for the teachers to introduce concepts and vocabulary.

Taking Action. This stage completes the instructional sequences by having the students do something with the knowledge and skills they have developed.

Development of Teachers

The task for teachers in implementing the panel's recommendations is immense. How can they manage it all? Not surprisingly, there is no simple answer. Successful implementation will require several significant changes in the preparation of new teachers and the continuing development of experienced teachers. In this section, we briefly describe some proposed changes. In the chapter that follows, we describe part of a necessary support system: the classroom environment teachers require to implement a successful science program.

Teachers are the primary variable in the educational system. We emphasize that every elementary teacher can teach science. It is time to banish the notion that only science specialists are capable of teaching science and that only the best students can understand the organizing principles and underlying concepts of science and technology. If all teachers are to incorporate the recommendations on curriculum and instruction contained in this report, then major changes in the development of new and experienced teachers will be necessary. Although the Center's panel on teachers and teaching recommend that there be better continuity between preservice and inservice education, they recommend changes across three phases of teacher development: early, middle, and later.

The early phase (preservice) of teacher development should include:

- A major in a discipline (in science, for science specialists).
- Coursework in one or more sciences that allows teachers to experience science the way it ought to be taught.
- An introduction to child learning and development that is simultaneously experiential and theory-based, and to the contextual factors that influence learning and teaching, such as cultural and community differences.

A major change in the science courses that prospective elementary teachers take should have the following features (Champagne, in preparation):

- They should teach science in the way that it is practiced, that is, pursuing real questions about the natural world and incorporating investigative methods with knowledge of the important facts and concepts of the discipline.
- They should be interdisciplinary in that they relate their particular field to related fields (for example, a chemistry course would bring in physics, math, biology).
- They should ground the discipline in its philosophical assumptions and historical context.
- They should help the students relate the content to societal issues.

A course that had these features would do the following:

- Spend relatively more time on fewer concepts than traditional courses, and, as Arons (1983) says, "back off, slow up, cover less, and give students a chance to follow and absorb the development of a small number of major scientific ideas at a volume and pace that make their knowledge operative rather than declarative (p. 97)."
- Require close collaboration with professors of other disciplines, including those outside the natural sciences (e.g., history and philosophy).
- Prepare people with basic facts and principles of the science and some thinking skills so that when they want additional information about the science, they have the necessary data base and skills to access it.

The middle phase of teacher development focuses on teaching and includes the following:

- Development of a repertoire of teaching strategies that apply knowledge of science and of child learning and development.

- Opportunities to practice these teaching strategies with guidance and feedback in situations that gradually change from ideal, one-child, low constraint to real classroom situation.
- Special attention to science teaching and materials.
- Assumption of classroom responsibilities under supervision, also known as student teaching or internship.
- Supported induction activities.

Activities throughout this phase require opportunities for intensive, exemplary experiences in classroom settings where theoretical constructions can be integrated into the real world.

The later phase of teacher development calls for flexible, adaptable teacher development systems and strategies. Effective staff development for experienced teachers has three ingredients:

- Knowledge about science, science learning, and science teaching.
- Strategies to help teachers develop and incorporate that knowledge into their teaching.
- Structures that involve teachers in decisions about their learning and create an environment in which new knowledge is supported and renewed.

If educators make the changes outlined above, then teachers can begin to successfully implement this report's recommended curriculum and instruction frameworks. These changes in the development of teachers, however, must also be matched by changes in the educational environment in which teachers work. In the next chapter, we present the panel's recommendations for changes in the educational environment.

VI. EDUCATIONAL ENVIRONMENT

The educational environment has an important impact on elementary school science studies. The environment of science education in the classroom, therefore, should be dynamic. Unless they pose a safety hazard, equipment should be part of displays that pertain to science. Teaching and learning for an inquiry oriented program requires a spacious room with seating arrangements conducive to a variety of instructional approaches, such as individual work, hands-on laboratories, peer discussion, cooperative learning, and large-group presentations.

We encourage teachers to consider the science classroom as a learning community. Here, the students can learn from textbooks, from visiting guests and teachers, from evidence the students have collected while working with science materials and natural objects, and from communicating with each other and their teacher (Jones, 1987).

We usually think of the classroom as the main influence in science education, but recent research suggests that out-of-school activities are highly correlated with science (Fraser, in Penick, 1982). Experiences outside the classroom are essential to the curriculum. By using a variety of media, the children expand their imagination and have extended opportunities to apply a concept or skill.

The panel recommends that teachers use the community as a classroom and laboratory. Museums, nature centers, zoos, and wildlife reserves are ideal extensions of the classroom. The panel also encourages use of these extensions to make learning personally meaningful for the child. To maximize learning situations, the teacher should give ample preparation for the goals and purposes of these experiences.
Communication, in the form of discussions, writing, reading, and thinking, will help

teachers and students answer the questions: Where are we going? Why are we going there? and What will we learn?

The home is another influential setting in which to learn science. Parental involvement and television are methods of promoting science learning. Homework is a valuable complement to classroom instruction, particularly if it is checked and discussed within the family (Murnane and Raizen, 1988).

Facilities and Equipment

To teach science in the elementary school classroom requires good teaching and good hands-on materials. A teacher also needs plenty of space, tables or desks with ample surface area, running water, and electrical outlets. When these things are not in the classroom, elementary teachers need to make the most of the resources that are available within the school and community, including the physical plant, surrounding grounds, and human services.

A teacher who uses the proposed frameworks will need to depend on a well-maintained facility. The availability and maintenance of equipment, media, and supplies should be adequate to support the program's requirements (Pratt, 1981). Systems should exist to provide materials, collect and replenish materials for the next use, and offer assistance in getting unique materials for interested students and teachers (Pratt, 1981). The school should have allocations for a reasonable collection of science-related children's books in the school library (Huff, et al., in Penick and Bame, 1988).

Within each classroom, a setting should be maintained that allows for flexible seating arrangements and provision of water, fresh air, and like resources. Within the school, there should be space that allows for display of science activities, storage of materials and unfinished projects, and interest centers on science topics under study (Pratt, 1981).

Outside the school, creative teachers can compensate for the lack of facilities and equipment. The concepts of the proposed framework can be applied to any setting: a teacher does not need a designated natural area near the school to teach change, diversity, or systems. In urban settings, the teacher may emphasize technology over the natural world to make the curriculum more relevant to the children's lives.

Communities have resources, such as people, museums, nature centers, zoos, industries, and farms (Penick, 1982). A teacher who uses these resources must make an extra effort to make the experience meaningful, but the cooperation from community groups is usually easily obtained and the rewards for the children are substantial.

Instructional Materials

INSTRUCTIONAL MATERIALS: STATUS

Science textbook series are the dominant instructional materials in elementary schools. Textbooks focus on learning about science rather than encouraging active involvement by students. Subjects are fragmented in most textbooks. Textbooks emphasize description, explanation, and identification, and generally neglect higher order processes, such as interpretation, evaluation, analysis, and synthesis (Blosser, 1986; Weiss, 1977; Weiss, 1988; Jacobson, 1986; Boyer, 1988).

The use of materials in the proposed program will encompass a variety of resources usually overlooked in elementary science classrooms. The orientation of the program requires materials that are both reusable and consumable. Many of these materials will have multiple uses and benefits across the curriculum, including art, social studies, health, and other disciplines. The program will likely require some unique materials. Students who are using the program will interact physically with instructional materials through handling, cooperating, or practicing; the materials will provide greater realism or concreteness (Holdzkom and Lutz, 1984). The program will help the teachers integrate manipulative and visual stimuli with printed matter.

The use of materials will require attention to classroom management, school and district-wide inventory, and financial support. The school budget should provide money for materials, equipment, and books in sufficient quantities to enable all students to have hands-on experience. Teachers should have access to petty cash funds to buy consumable materials. Also needed are funds for staff development in science, transportation costs for trips into the community, and resources for replacing science supplies on a regular basis (Huff, et al., in Penick and Bame, 1988). Schools should look to science centers and other regional resources to help promote student interaction with exhibits and laboratory experiences that cannot be duplicated in the classroom.

The creative use of both formal and informal instructional resources should be a part of this curriculum. Educational TV programs, for example, can be used as topic introductions, surveys, or motivating extensions.

INSTRUCTIONAL TECHNOLOGY: STATUS

While schools continue to acquire microcomputers and similar technologies, research indicates that teachers make little use of the equipment to enhance their instruction. Typically, science students spend fewer than 15 minutes per week working with computers. Moreover, research indicates a need to study ways to improve education in science through information technologies (Bybee and Ellis, 1989; Weiss, 1987; Educational Technology Center, 1988).

Technology pervades the children's world, and can be used selectively to enhance the learning process. There are several functions of technology for instruction in the classroom, including the use of computers for organization, presentations, simulations, and data collection. Computer technology can also help the teacher to simplify grade books, to produce posters and banners, to provide access to word processing, and to deal with other classroom management problems.

Schools need to budget for the use of technology in the classroom. First, training must be paid for. Second, someone must keep track of the hardware and software, as well as evaluate new products and recommend purchases. Third, the cost of hardware repairs and service contracts must be budgeted for.

Most schools have technologies consisting of chalkboards, overhead projectors, movie and slide projectors, and televisions. While taking these technologies into account, the proposed framework should accommodate the newer technologies, such as computers, video/VCR, and camcorders. In addition, the curriculum should be ready to incorporate the newest technologies, such as hyper-card references, microcomputer-based laboratories, and interactive video.

Bybee and Ellis (1989) have outlined recommendations for the appropriate use of information technologies in elementary science programs. Their recommendations are divided into two categories--microcomputer courseware and video courseware.

Microcomputer Courseware

There are several types of courseware, depending upon its instructional purpose. Below are descriptions of the major types.

Information Processing. Here, students use the microcomputer to enter, store, revise, and print hard copy of text. An information processor should have the extended abilities to process and present both tabular, graphics, and audio information; to insert figures, charts, pictures, graphs, text, and audio into a computer program and to accept text, data, graphics, and audio from other utilities (for example, scanner, video disc, and microcomputer-based laboratories). The information processor should include the functions typically found in spreadsheet, database, statistical analysis, and graphing programs.

Microcomputer-based- Laboratory (MBL). With an MBL, students can use the microcomputer to gather, store, display, manipulate, and analyze data. MBL software and hardware packages will process data collected through probes and sensors. The students can measure temperature, sound, light, pressure, distance, resistance, voltage, heart rate, blood pressure, and electro-dermal activity. The microcomputer can store and display all data the students gather from the probes and sensors. Data gathered by the MRL package can control the operation of the system modelers, interactive videodisc, and simulation packages described below.

Telecommunications. This involves transferring information from one site to another using microcomputers linked via cables, telephone lines, satellite communication systems, or a combination of the three. The telecommunications package should enable students to search large databases and information networks (for example, CompuServe) and to share information about their own investigations (for example, KidsNetwork). By participating in the social enterprise of science, students can enhance their understanding of the nature of science.

Systems Modeler. A systems modeler should be available to enable students and teachers to express their thoughts about how systems work. The user can construct a structural diagram of the compo nts of a single system and define the interrelationships among the con ents. System modelers can teach cause-and-effect relationships a d the systems approach in modeling such phenomena as a food web, population growth, digestion, sexually transmitted diseases, and soil erosion. In some cases, the systems modelers will present students with a simulation of a system and its model. The students can then manipulate the inputs and explore the relationships among the components of the system.

Simulations. Microcomputer courseware should also include simulations for imitating imaginary or real phenomenon. The students will have opportunities to provide input, perhaps from a list of options, or to manipulate objects that the program graphically represents on the screen. The input requested of the student will simulate the activities that scientists do and actively involve the students in learning science.

Tutorials. An intelligent tutor should be a component of the information processors, microcomputer-based laboratories, telecommunications package, system modelers, and simulations packages. An effective tutor can engage the student in learning activities by asking questions, giving directions, providing clues, and giving feedback.

Programming and practice represent two additional uses of the microcomputer in the classroom. Not all school districts will choose to acquaint elementary children with a computer language, but when it is offered, LOGO, or a similar language, should be used. Drill-and-practice computer programs should be part of an overall instructional package.

Video Courseware

A technology-oriented classroom can include three types of video presentations--sequential, archival, and interactive. Sequential video can present motion segments, still frames, and time lapse segments to engage the students and dynamically present new information.

Interactive video gives the students the chance to explore concepts in depth and to control the learning experience. The students can use two kinds of interactive video--an archive of still and motion frames and an interactive package that uses motion and still images. With the archive video, the student is in complete control and can explore the collection of images while seeking to understand a topic. With interactive instruction, an intelligent tutor will guide the student through a series of interactions with the video program. The video segments will be stored on laser-read discs, such as videodiscs and compact discs, so that retrieval of information is easy and efficient. A microcomputer will control the presentation.

Much work has yet to be done on the appropriate use of technologies for instruction, but we are already learning much about the promise that information technologies show. A long-term study of the use of new technologies to enhance student understanding is underway at the Educational Technology Center of the Harvard Graduate School of Education. The group's Weight/Density and Heat/Temperature projects use a hybrid of direct instruction and episodes of inquiry to explore the use of computer-implemented interactive models that help students achieve conceptual change in science. Prelim nary findings indicate that the approach helps students advance their conceptual model of weight and density. The ETC's Nature of Science Project, which uses software that includes multiple visual representations, has been successful in increasing ratio and proportional reasoning in upper elementary students who failed with more traditional methods (Educational Technology Center, 1988).

Time

TIME: STATUS

Teachers and principals report that there is not enough time to teach science and that teachers lack planning time. Inadequate time is a serious obstacle to teaching science. K-3 classes devote an average of 19 minutes per day to science and grades 4-6 devote 38 minutes per day to science. Of this time, lecture and discussion dominate 74 percent of the time in K-3 and 87 percent in 4-6. Although teachers and principals believe that "hands-on" approaches promote effective science teaching, time devoted to this approach is less than one-third (29 percent) in science classes (Weiss, 1978, 1987; Powell and Bybee, 1988; St. John, 1987; Johns, 1984; Cawalti and Adkisson, 1985; Mullis and Jenkins, 1988).

In advocating the new framework, we recognize that science learning will occur in many different ways--during laboratories, museum visits, reading lessons, math lessons, and writing lessons. As science slips into different disciplines, the topics in the program are instructionally integrated, and the students will study science and technology for a larger percentage of time than in previous programs.

The move toward the basics in education hurt the study of science in the elementary school by lowering it on the priority scale of disciplines. Like math and reading, science needs an established place in the curriculum. We recommend integrating disciplines and incorporating more science. In this way, more time is devoted to science instruction. This approach will also circumvent the traditional problem that science as a discipline endures. It is a subject taught at the end of the day, a last priority in a busy schedule, and often not taught at all (Murnane and Raizen, 1988).

We recommend that teachers in the primary grades spend a minimum of 30 minutes per day or 2½ hours per week on science. In the upper elementary grades, teachers should spend 60 minutes per day or five hours per week on science, allowing 50 percent of this time for experiential learning in the form of laboratories and activities. It should be noted that, in 1982, the NSTA recommended levels half this high (NSTA, 1982) and *Focus on Excellence* currently recommends 100 minutes per week for K-3 and 150 minutes per week for 4-6 (Huff et al., in Penick and Bame, 1988). Given our integrated approach, we recommend an increased time requirement. Much of our suggested science time is integrated with other subjects. Activities include reading science stories, doing arithmetic related to science, and writing about science.

Increased time spent teaching science in elementary schools does not, in itself, guarantee higher achievement in science, but greater amounts of time spent by students on active learning does lead to higher achievement (Stallings, 1975), and class time devoted to active teaching and learning of relevant skills is a powerful factor influencing school learning (National Academy of Science, 1985). Like sporting or music skills, science skills need practice time. It is unrealistic to imagine that 45 minutes a week can make anyone a competent measurer or scientific problem solver (Hein, 1987). In addition, learning concepts in depth requires time, so learning opportunities and curricula should have extended time for exploration and reflection (Newmann, 1988).

Groups

GROUP WORK: STATUS

Students work alone or listen to the teacher about two-thirds of the time. The best estimate of group work is based on a review of instructional strategies in textbooks. Groups of students are not structured as groups for cooperative learning and the mode of interaction does not simulate scientific collaboration (Weiss, 1988).

The proposed program assumes a variety of student grouping arrangements and suggests appropriate teaching strategies for those groupings. For example, suggested groups might include full-class involvement, small-group cooperative learning, and individual projects or independent study. Effective groups are designed to address student interest, management of equipment and lab space, abilities, and t' need for some random divisions. Grouping should always reflect the best benefit to the learner and avoid convenience or restrictive groupings that foster bias by gender, culture, ability, or handicap. Constructing effective learning groups holds great promise for increasing quality learning time (National Academy of Science, 1985).

CLASSROOM MANAGEMENT: STATUS

Management of materials and students continues to be a significant barrier to science teaching in elementary schools. Teachers and principals believe that active, hands-on instruction is preferred; but, the special materials, equipment, and especially management of students and materials, is the cited reason such approaches are not extensively used (Weiss, 1987, 1988; St. John, 1987).

By its nature, the proposed curriculum implies a classroom in which talking, sharing, and movement are not only acceptable, but necessary. By using groups, the teacher can shift from the role of leader to that of expeditor, facilitator, and co-learner. The organization of tasks and preparation of materials is increasingly important, because the teacher is not controlling each action. The responsibility for care of the classroom materials must shift to the students.

Support from co-workers, principals, and the administration is invaluable to teachers who use this framework. School personnel must accept noisier conditions. Aides and research specialists can be of tremendous support to classroom teachers. A school-wide policy for storage and maintenance of materials will help to alleviate management problems. There should be a district science coordinator available when a problem arises with a program, its structure, or its materials.

THE EDUCATIONAL ENVIRONMENT: RECOMMENDATIONS

An effective K-6 science program requires a unique educational environment. The study panel recognized this and made recommendations for facilities and equipment, instructional materials, instructional technology, time, student groups, classroom management, and assessment. Some of the specific recommendations include the following:

- Facilities should include appropriate flexibility for hands-on activities, peer discussion, cooperative learning, and large-group presentations.
- Facilities should include outdoor environments, resource people, museums, nature centers, zoos, industries, and businesses.
- Instructional materials should include a variety of resources that support instruction which uses a hands-on approach.
- Technology should be a regular part of the curriculum and instruction.
- Computer technology should be used for instructional purposes and for classroom management.
- In the primary grades, children should spend a minimum of five hours a week on science.

- In the upper elementary grades, teachers should spend a minimum of eight hours a week on science. Fifty percent of this time should be on hands-on activities.
- Use of computers and cooperative groups will contribute to more efficient classroom management.
- Assessment must be consistent with the goals of the curriculum.
- Assessment should include an evaluation of high-order attitudes, and thinking and problem-solving skills.

VII. CONCLUSION

The panel's vision for better elementary science presents a challenge that may be unparalleled in the history of science education. Never before have we known so much about how children learn and, consequently, so much about elementary science curriculum. Happily, we have this knowledge at a time when the citizenry of our country demand improvements in the education of our youth.

A variety of people and groups must work together to meet the challenge. The panel's vision needs teachers who can orchestrate classrooms for success. These teachers, both new and experienced, must understand science and technology, see the interrelationship between the two, and know how to teach science through technologies. It is insufficient, even harmful, to simply require new and experienced teachers to take several college level science courses. While science and technology coursework is necessary, the courses must be designed in ways that allow the prospective teachers to interact with the materials and their colleagues, in a manner similar to what we have proposed for children. Teachers, like children, must actively construct new conceptual understandings.

School leaders, especially principals, can play a key role in implementing the recommendations of this report. Principals are more than building managers. They serve as instructional leaders who must believe that science and technology are important for their students and who can lead teachers toward the vision the report presents. In addition to leading the teachers, a principal must support them as well. We cannot expect teachers to implement new elementary science programs without encouragement and financial support. Moreover, the principal must be pivotal in enlisting the support and understanding of parents. Informed parents can demand that the school district's resources and priorities be aligned in support of the panel's recommendations.

The panel's vision of the future also needs the support of educational, business, and government policymakers. There is no question that the recommendations mean that schools will need money for improving science teaching facilities, and for purchasing new science curriculum programs and materials. Money must be found to fund appropriate electronic technologies that will enhance science teaching and learning. Finally, the cost of supporting the preparation and development of the teachers must be underwritten.

The panel is asking for dramatic changes, in what science we teach our children and how it is taught. We hope that you share our vision of the future and that you will work toward improving elementary science education by implementing the recommendations contained in this report.

REFERENCES

Anderson, C.W. "Strategic Teaching in Science." *Strategic Teaching and Learning: Cognitive Instruction in the Content Areas.* Alexandria, VA: Association of Science Curriculum and Development, 1987.

Arons, A. "Achieving Wider Scientific Literacy. *Daedelus* (1983):91-122.

Atkin, J.M and Karplus, R. "Discovery or Invention?" *Science Teacher* 53 (1962):45.

Ausubel, D. *The Psychology of Meaningful Verbal Learning.* New York: Grune and Straton, 1963.

Bartlett, F.C. Reviewed in "Cognition and Science Education." *Students and Science Learning.* Washington, D.C.: American Association for the Advancement of Science, 1987.

Bennett, W. *First Lessons: A Report on Elementary Education in America.* Washington, D.C.: United States Department of Education, September 1986.Blank, R. "State Network for Indicators of Science and Mathematics Education." Paper prepared for the annual meeting of American Educational Research Association, April, 1988.

Blosser, P. E. "Learning In Science as Indicated by Achievement Data from National Assessment of Educational Progress." A paper presented at a meeting of the National Association for Research in Science Teaching, Atlanta, GA: NARST, 17 March 1986.

Boyer, E. *Report Card on School Reform.* NY: The Carnegie Foundation for the Advancement of Teaching, 1988.

Brandt, R. "On Learning Research: A Conversation with Lauren Resnick." *Educational Leadership* 46(1989):12-16.

Bredderman, T. "Effects of Activity-based Elementary Science on Student Outcomes: A Quantitive Synthesis." *Review of Educational Research* 53(1983):499-518.

Bronowski, J. *Magic, Science, and Civilization.* NY: Columbia University Press, 1978.

Bybee, R. "The New Tranformation of Science Education." *Science Education* 61, 1(1977):85-87.

Bybee, R. "The Sisyphean Question in Science Education: What Should the Scientifically and Technologically Literate Person Know, Value, and Do--As a Citizen?" *Science-Technology-Society*, 1985 NSTA Yearbook. Washington, D.C.: National Science Teachers Association, 1986.

Bybee, R. Science Education and the Science-Technology-Society (STS) Theme. *Science Education* 71, 5(1987):668-683.

Bybee, R. "Teaching about Science-Technology-Society (STS): Views of Science Educators in the United States." *School Science and Mathematics* 87, 4(1987).

Bybee, R. and Ellis, J. "A Technology-Oriented Elementary School Science and Health Program: Implications for Teacher Education." *Information Technology and Science Education: 1988 Yearbook of the Association for the Education of Teachers in Science.* Columbus, OH: SMEAC Information Reference Center, Ohio State University, 1989.

Cawalti, G. and Adkisson, J. "Association of Science Curriculum and Development Study Reveals Elementary School Time Allocations for Subject Areas: Other Trends Noted." Supplement to *Association of Science Curriculum and Development Update*, 1985.

Caplon, J. "Science and the Liberal Arts." A presentation to a panel of the American Association for the Advancement of Science, 1988.

Champagne, A. and Klopfer, L. "Problem Solving as Outcome and Method in Science Teaching: Insights from 60 Years of Experience." *School Science and Mathematics* 3 (1981).

Champagne, A. and Hornig, L., eds. *The Science Curriculum.* The Report of the 1986 National Forum for School Science. Washington, D.C.: American Association for the Advancement of Science, 1986.

Champagne, A. and Hornig, L. "Practical Application of Theories About Learning." *Students and Science Learning.* Washington, D.C.: American Association for the Advancement of Science, 1987.

Champagne, A. "Issues in the Assessment and Teaching of Thinking Skills." A paper for the American Association for the Advancement of Science, In Press.

Driver, R. In Olson, J. "Computer Based Learning and Conceptual Change." *Schoolworlds/Microworlds: Computers and the Culture of the Classroom*. Kingston, Canada: Pergamon Press. 59 (1988).

Dunn, K. and Dunn, R. "Dispelling Outmoded Beliefs about Student Learning." *Educational Leadership*, 44, 6(1987):55-62.

Education Development Center. *Improving Textbook Usability*. National Conference on Improving Textbook Usability. Newton, MA: Educational Development Center, 1987.

Education Policies Commission of the National Education Association. *Education and the Spirit of Science*. Washington, D.C.: NEA, 1966.

Educational Technology Center. *Making Sense of the Future*. A position paper on the role of technology in science, mathematics, and computing education. Cambridge, MA: Harvard Graduate School of Education, 1988.

Harms, N. C. and Yager, R. E., eds. *What Research Says to the Science Teacher*. Washington, D.C.: National Science Teachers Association, 3 (1981).

Hawkins, D. "Nature Closely Observed". *Daedalus* (1983):65-90.

Hein, G. "The Right Test for Hands-on Learning?" *Science and Children* 25, 2(1987):8-12.

Hodgkinson, H. *All One System: Demographics of Education, Kindergarten through Graduate School*. Washington, D.C.: Institute for Educational Leadership, 1985.

Holdzkom D. and Lutz, P., eds. *Research Within Reach: Science Education*. Washington, D.C.: National Science Teachers Association, 1984.

Holmes, E., ed. *Integrated Curriculum*. Winchester, MA: Winchester Public Schools 1, 2 (1988).

Hueftle, S.; Rakow, S.; and Welch, W. *Images of Science: A Summary of Results from the 1981-82 National Assessment in Science*. Minnesota, WI: University of Minnesota, 1983.

Huff, P. Elementary Science Revisited. *Focus on Excellence*. Washington, D.C.: National Science Teachers Association, 1988.

Hunter, M. *Mastery Teaching*. El Segudo, CA: TIP Publications, 1983.

Hurd, P. "Science Educati .n: The Search for a New Vision." *Educational Leadership*, (December 1983/January 1984).

Hurd, P. "Perspectives for the Reform of Science Education." *Phi Delta Kappan*, (January 1986).

Hurd, P. Personal communication. 1989.

Jacobson, W. "The Current Status of Science Curricula: Insights from the Second International Science Study." *Students and Science Learning*. Washington, D.C.: American Association for the Advancement of Science, 1986.

Johns, K. "Wanted: Money and Time for Science." *School Science and Mathematics*. 84, 4(1984):271-76.

Johnson, R. and Johnson, D. "Reexamination of the use of Cooperative, Competitive, and Indivudualistic Goal Structures." *Learning Together and Alone: Cooperation, Competition and Individualization*. NJ: Prentice-Hall, Inc., 1975.

Johnson, R. and Johnson, D. "Cooperative Learning and the Achievement and Socialization Crises in Science and Mathematics Classrooms." *Students and Science Learning*. Washington, D.C.: American Association for the Advancement of Science, 1987.

Jones, L. *School Achievement Trends in Mathematics and Science: Findings and Policy Issues*. August 1987.

Kuerbis, P. "Learning Styles and Elementary Science." A paper commissioned by the Biological Sciences Curriculum Study, Colorado Springs, CO, 1986.

Lawson, A.; Abraham, M.; and Renner, J. *A Theory of Instruction: Using the Learning Cycle to Teach Science Concepts and Thinking Skills*. NARST Monograph One, 1989.

Linn, M. *Establishing a Research Base for Science Education: Challenges, Trends, and Recommendations*. Berkeley, CA: Lawrence Hall of Science and the Graduate School of Education, 1986.

Linn, M. "Designing Science Curricula for the Information Age." A paper commissioned for the Biological Sciences Curriculum Study, Colorado Springs, CO, 1987.

Loucks-Horsley, S.; Carlson, M.; Brink, L.; Horwitz, P.; Marsh, D.; Pratt, H.; Roy, K.; and Worth, K. *Teachers and Teaching in Elementary Science Education*, Washington, D.C.: The National Center for Improving Science Education, 1989.

National Research Council. *Mathematics, Science and Technology Education: A Research Agenda*. Washington, D.C.: National Academy Press, 1985.

Mergendoller, J; Marchman, V.; Mitman, A.; and Packer, M "Task Demands and Accountability in Middle-Grade Science Classes. *The Elementary School Journal* 88, 3(1988):251-65.

Meyer, L.; Crummey, L.; and Greer, E. "Elementary Science Textbooks: Their Contents, Characteristics, and Comprehensibility.' *Journal of Research in Science Teaching* 25, 6(1988):435-64.

Moore, J.A. "Science as a Way of Knowing--Human Ecology." *Science as a Way of Knowing*. American Society of Zoology, 1985.

Moore, J. A. "Science as a Way of Knowing--Evolutionary Biology" *Science as a Way of Knowing*. American Society of Zoology, 1984.

Mullis, I. and Jenkins, L.B. *The Science Report Card: Elements of Risk and Recovery; Trends and Achievements Based on the 1986 National Assessment*. Princeton, NJ: Educational Testing Service, 1988.

Murnane R. and Raizen, S., eds. *Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12*. Washington, D.C.: National Academy Press, 1988.

National Science Teachers Association. "Science-Technology-Society: Science Education for the 1980s." National Science Teachers Association position statement. Washington, D.C.: National Science Teachers Association, 1982.

Newmann, F. "Can Depth Replace Coverage in the High School Curriculum?" *Phi Delta Kappan* (January 1988):345-48.

Novak, J. "Learning Science and the Science of Learning." *Studies in Science* (1988):77-101.

O'Brien, T. "Some Thoughts on Treasure-Keeping." *Phi Delta Kappan* 70, 5(1989):360.

Penick, J., ed. *Elementary Science Focus on Excellence Series*. Washington, D.C.: National Science Teachers Association, 1982.

Penick, J. and Bame, M., eds. *Focus on Excellence: Elementary Science Revisited*. Washington, D.C.: National Science Teachers Association 4, 3 (1988).

Peterson, P.; Fennema, E.; and Carpenter, T. "Using Knowledge of how Students Think about Mathematics." *Educational Leadership* 46 (1988):42-46.

Piel, J. "Interaction of Science, Technology, and Society in Secondary Schools. *What Research Says to the Science Teacher*. Washington, D.C.: National Science Teachers Association 3 (1981):94-112.

Powell, J. and Bybee, Rodger W. "A Survey of State Guidelines for Elementary School Science." A study conducted for Biological Sciences Curriculum Study/International Business Machines, May 1988.

Pratt, H. "Science Education in the Elementary School." *What Research Says to the Science Teacher* 3 (1981):73-93.

Raizen, S. A.; Baron, J. B.; Champagne, A. B.; Haertel, E.; Mullis, I. V.; and Oakes, J. *Assessment in Elementary School Science Education*. Washington, D.C.. The National Center for Improving Science Education, 1989.

Resnick, L. "Toward a Cognitive Theory of Instuction." In Parls, S.; Olson, G.; and Stevenson, H., eds. *Learning and Motivation in the Classroom*. Hillsdale, NJ: Erlbaum, 1983.

Resnick, L. *Education and Learning to Think*. Washington, D.C.: National Academy Press, 1987.

Rowe, M. "Science Education: A Framework for Decision-Makers." *Dadedalus* (1983):123-42.

Rutherford, F.J and Ahlgren, A. "Rethinking the Science Curriculum Conten at the Curriculum." *Association of Science Curriculum and Development 1987 Yearbook*. Washington, D.C.: Association for Supervision and Curriculum Development, 1988.

Shymansky, J.; Kyle, W. Jr.; and Alport, J. "The Effects of New Science Curricula on Student Performance." *Journal of Research in Science Teaching* 20 (1983):387-404.

Smith, F. "Overselling Literacy." *Phi Delta Kappan* 70, 5(1989):360-64.

St. John, M. *An Assessment of the School in the Exploratorium Program.* Inverness, CA: Inverness Research Associates, October 1987.

Stallings, J. *Implementations and Child Effects of Teaching Practices in Follow Through Classrooms.* Monographs of the Society for Research in Child Development, December 1975.

Tobin, K. "Learning in Science Classrooms." Paper presented at the Biological Sciences Curriculum Study 30th anniversary symposium on curriculum development for the year 2000, Colorado Springs, CO, November 1988.

Weiss, I. R. *Report of the 1977 National Survey of Science, Mathematics, and Social Studies Education.* Prepared for the Center for Educational Research and Evaluation. Research Triangle Park, NC: Center for Educational Research and Evaluation, March 1978.

Weiss, I. R. *Report of the 1985-86 National Survey of Science and Mathematics Education.* Prepared for the National Science Foundation. Washington, D.C.: National Science Foundation, November 1987.

Weiss, I. R. "Indicators of Science and Mathematics Education: Providing Tools for State Policymakers." A paper commissioned by the Science/Mathematics Indicators Project, April 1988.

Welch, W. "Inquiry in School Scie *What Research Says to the Science Teacher.* Washington, D.C.: National Science Teachers Association 3 (1982).

Yager, R. E. and Penick, J. "One Way to Fix School Science." *Science Teacher,* 1980.

APPENDICES

APPENDIX A

Contemporary NSF Programs
for Elementary Schools

THE LIFE LAB SCIENCE PROGRAM
Life Lab Science Program, Inc./Addison-Wesley

This is a broad expansion of a program that has had ten years of successful piloting and tryouts throughout the country, particularly in California. It previously had National Science Foundation and U.S. Department of Education funding.

This K-6 program functions mostly in a garden. It will expand the proposers' current life science program into a comprehensive elementary science program. It offers an explicit plan to involve students in a substantial number of good hands-on experiences and it offers teachers friendly and manageable materials. The materials for hands-on work are not only familiar to most teachers, but in terms of their quantities and cost, are both affordable and manageable.

The Life Lab Science Program integrates conceptual learning and practical applications. The applications demonstrate to the students how science relates to their everyday life. They learn, for example, how their bodies, like plants, need nutrients, which are available from various sources. They learn this through chemical experiments with, and data analysis of, nutrients in soil. A variety of learnings are derived from this work, including some relating to ecology, ethical issues, and decision making.

Roberta M. Jaffe and Gary W. Appel, the co-Principal Investigators of Life Lab Science Program, Inc. (a non-profit organization), will have the support of their own staff and advisors, schools from around the country, and a major educational publisher. Addison-Wesley Publishing company will provide strong staff and financial support from development through dissemination and teacher training, and assures potential for broad use of this program in our schools.

THE SCIENCE CONNECTION
Houston Museum of Natural Science/Silver, Burdett and Ginn

This supplementary program for grades 1-6 is designed to take advantage of an existing vehicle, the Silver/Burdett basal science textbooks, which are now in broad use, to improve the quality and quantity of science being taught. The materials described below will include correlations to those programs.

A *Science Discovery Reader*, which is for each grade level, introduces concepts within the context of the students' experiences. The readers are fun for children to read. Critical thinking questions throughout these books checks the students' understanding of the concepts being taught, and the teacher's editions suggest additional activities and references.

The *Science Shoebox Recipe File* provides teachers with plans for self-contained, hands-on activities. The activities coordinate with the plot and action of stories in the *Science Discovery Reader*.

The *Science Extension* relates the concepts developed in the basal textbook series and in the *Science Discovery Reader* to other school disciplines and to the students' out-of-school environment.

Ancillary audio and video tapes are also available.

Carolyn Sumners and Terry Contant, the Principal Investigators, have the support of their own institution, the Houston Museum of Natural Science, plus an array of university and school advisors and a major educational publisher. Silver Burdett, and Ginn publishing company provides financial support and a strong staff from development through dissemination and teacher training, and assures potential for broad use of this program in our schools.

SUPER SCIENCE: A MASS MEDIA PROGRAM
Scholastics, Inc.

The Scholastic, Inc. project, *Super Science: A Mass Media Program*, has launched two classroom science magazines, one for grades 1-3, another for grades 4-6, with a companion series of computer-disk materials. They stress hands-on and inquiry activities that mix science with reading, math and social studies. The science-and-technology skills and know-how that students will need as consumers, workers, and citizens are important to the development of the project. The magazines have teachers' guides and a special periodical for early grade teachers.

The project's staff used a three-part, team support effort to develop Super Science. First, a panel of leaders in science education has served as advisors and consultants. They ensure the pedagogical soundness of the program. Second, administrators and teachers in nine ethnically diverse districts nationwide have helped formulate the scope and sequence plan for the magazines and software and have tested for class practicality. Third, The Triangle Coalition for Science and Technology Education will invest inexcess of $5.2 million during the four-year development phase and will continue the activities in subsequent years.

FULL OPTION SCIENCE SYSTEM (FOSS)
Lawrence Hall of Science/Ohaus Scale Corporation

The Center for Multisensory Learning of the Lawrence Hall of Science, with this *Full Option Science System* (FOSS), provides, for grades 3-6 a collection of multisensory, laboratory-based science activities. Some of these will be products of new development, and some will be from the 1986 FOSS pilot project, which received National Science Foundation funding.

The FOSS project will produce five products that will be developed with the cooperation of Ohaus Scale Corporation, who will bring the FOSS project to the market after the third project year. The products will include 16 modules of laboratory activities; a materials assembly procedure document, which should help teachers gather equipment for the activities; a set of correlation tables that will assist with textbooks, with other hands-on resources and with the integration of FOSS activities into a particular framework; laboratory equipment; and worksheets and instruction sheets.

Lawrence P. Lowery, the Principal Investigator, will have the support of his Lawrence Hall of Science staff, and will work closely with local school districts and with the nationally established Ohaus Scale Corporation.

NATIONAL GEOGRAPHIC KIDS NETWORK PROJECT
Technical Education Research Centers, Inc.

The National Geographic Kids Network Project is a series of exciting, flexible elementary science units that feature cooperative experiments in which students in grades 4-6 share data nationwide through the use of telecommunications. Topics will involve the students in issues of real scientific, social, and geographic significance. The Network project combines basic content from typical school curricula with guided inquiry learning. Kids Network can be used to supplement textbooks and existing materials or to form complete, year-long science courses.

Technical Education Research Centers are producing six units and software for sending, processing, and displaying data. The National Geographic Society is helping to develop at least four additional units as well as publish all the materials. Materials and telecommunications are being designed for practical use. The telecommunications will be software controlled for ease of use and reliability.

The National Geographic Society and a network of professional organizations, state education agencies, and museums will widely disseminate information about the program. Local support and technical assistance is being generated through industry members of the Triangle Coalition for Science and Technology Education, school boards, and community groups.

SCIENCE FOR LIFE AND LIVING:
INTEGRATING SCIENCE, TECHNOLOGY, AND HEALTH
Biological Sciences Curriculum Study
Kendall/Hunt Publishing Company

Science for Life and Living is a comprehensive K-6 curriculum that focuses on science as a way of knowing, technology as a way of doing, and health as a way of behaving. Such a focus makes the study of science relevant to the personal and social issues that affect everyone's daily life. This program incorporates a contemporary instructional model, engaging hands-on activities, cooperative learning, and a strong emphasis on oral and written communication. The complete program will be available in November 1990 from Kendall/Hunt Publishing Company. Science Kit, Inc. will supply the hands-on materials for each grade level of the program.

This curriculum encourages children and teachers to use a variety of methods as they construct their own understanding of the world. The program concentrates on a few major concepts and skills that are common to the three disciplines of science, technology, and health. By focusing on depth rather than breadth of knowledge, the students are allowed the time and opportunities they need to develop a richer and more meaningful interpretation of the world.

The project will produce a teacher's edition and student's text for each grade level, an implementation guide, and supplemental materials designed to help busy teachers incorporate science studies into the other basic subjects of reading, writing, and mathematics. Supporters of the BSCS project include the National Science Foundation, IBM Corporation, Gates Foundation of Colorado, and Adolph Coors Foundation of Colorado.

IMPROVING URBAN ELEMENTARY SCIENCE: A COLLABORATIVE APPROACH

Education Development Center, Inc.

This project will undertake the design of a program to improve students' abilities to think critically, use language, and solve problems. This science program is specifically aimed at urban systems, which face unique and complex problems. Cleveland and San Francisco are collaborating in the development effort. Los Angeles, Pittsburgh, Philadelphia, and Boston will provide input and feedback, to ensure that the program meets the needs of a number of urban systems operating under a variety of state and local mandates.

The project will involve teacher development teams in the design of 24-36 activity-based modules for grades K-6. The project is trying to balance life, physical, and earth sciences and tie the experimental base to the urban setting where appropriate. The new modules will be informed by teacher's reviews of existing materials; and they will integrate science with the rest of the elementary curriculum, particularly language arts and mathematics.

Boston College Center for the Study of Testing, Evaluation, and Educational Policy is serving as the outside evaluator.

APPENDIX B

Science Education Programs That Work:
Exemplary Programs and Practices in
the National Diffusion Network

Science Education Programs That Work

A Collection of Proven Exemplary Educational Programs and Practices in the National Diffusion Network

Compiled by
Mary G. Lewis

Recognition Division, Programs for the Improvement of Practice of the

Office of Educational Research and Improvement
U.S. Department of Education, 555 New Jersey Avenue, NW.
Washington, D.C. 20208 1525

1988

CONSERVATION FOR CHILDREN. A practical, economical program to increase conservation awareness, understanding, and action of elementary school children through a variety of basic skill activities.

Audience Approved by JDRP for children in grades 1-6.

Description Through a variety of basic skill activities intended for use in the classroom, Conservation for Children teaches about the interdependence of plants and animals, requirements of life, energy sources and use, pollution problems, recycling, and other conservation concepts based on scientific principles. The grade level conservation guides provide instructional materials which combine basic skill practice in the areas of language arts, math, social studies and science with a conservation concept. Program materials are used to supplement or replace presently used skill materials, so that no additional preparation time or equipment is needed. 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. No change in staffing, physical setting, equipment, or instructional methodology is required. Criterion-referenced tests allow teachers to determine which materials are appropriate for individual students or groups. Special education teachers have found the materials valuable for use with their students due to the high interest level of the worksheets and the choice of ability levels and basic skill concepts.

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 in writing that they had observed their children implementing conservation practices at home which they had never seen before the children used the program materials

Requirements The program may be used in any type of facility or setting and does not rely on any particular methodology or teaching style. The program is designed for use in the classroom and does not require any materials or equipment that are not normally found in any school. The curriculum guides may be reproduced in whole or in part with the permission of the authors. Inservice training as to implementation and material usage is minimal, usually two hours. The program requires no staffing changes as the classroom teacher continues to provide instruction.

Conservation for Children materials include six grade-level curriculum guides and one all-levels guide (activities, resources). After the initial purchase of the guides, $25 per grade level or $165 for the complete program, there are no ongoing costs for personnel, materials, or inservice training. A per pupil cost for installation is only $.70. There are no recurring costs.

Services Awareness materials are available at no cost. Visitors are welcome at the project site any time by appointment. Project staff are available to attend out-of-state awareness meetings (costs for travel expenses to be negotiated).

Contact *Marilyn Bodourian, Project Director, Conservation for Children, John Muir Elementary School, 6560 Hanover Drive, San Jose, CA 95129. (408) 725-8375.*

Developmental Funding ESEA, Title IV-C

HANDS-ON ELEMENTARY SCIENCE. An instructional program intended to provide elementary students with hands-on instruction emphasizing the processes of science.

Audience Approved by JDRP for students, grades 1-5.

Description The Hands-On Elementary Science provides elementary students with instruction that emphasizes the development of science processes as an approach to problem solving. In fostering positive teacher attitudes toward teaching science, it increased both the amount of science taught and the proportion of instruction dedicated to the processes of science. The curriculum employs a set of higher order of processes at each grade level consisting of three basic units. The units consist of lessons concerning a unifying topic. The topic is based upon the skills identified for that grade level. First grade students work primarily on observation in the three units of seeds, patterns and "magnetism." Second grade emphasizes classification skills through the study of insects, sink or float, and measurement. In the third grade, experimentation skills are developed by units on flight, measuring and plants. Fourth grade focuses on analysis in units on bio-communities, electricity and chemistry. The fifth grade curriculum emphasizes application and consists of units on earth science, soil analysis and small animals. Since this is not a text program, all lessons are based upon hands-on activities supported and defined by curriculum guides at each grade level. They provide a sequence of basic lessons and incorporate all necessary materials to support the program lessons. A unique feature of the program is an optional package of materials students may request to work on over the summer.

Requirements The Hands-On Elementary Science program is transportable to other sites where a commitment exists for hands-on science instruction. Adoption of this program requires at least a half year planning and preparation followed by a staff development program. Teacher preparation consists of two days training prior to the implementation of the program followed by at least two followup workshops to resolve problems of implementation. Materials required include both a curriculum guide and a kit of materials of the appropriate grade level for each teacher and copies of the voluntary summer program for dissemination to interested students.

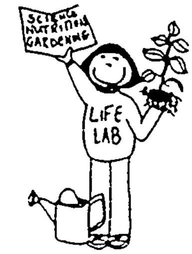
The cost of the program in the installation year is approximately $27 per student, assuming 25 students per class in a school of 800 students and with the training involving 20 teachers at a grade level. Subsequent year costs to maintain the program through the replacement of consumable supplies equal $1.50 per student. Teacher guides are available for $10 each and kits are available from a national vendor at costs ranging from $400 to $600 depending upon the grade level.

Services Awareness materials are available at no cost. Visitors are welcome by appointment at project site and additional sites in home state. Project staff are available to attend out-of-state awareness meetings (costs to be negotiated). Training is available at project site and also at adopter site (costs to be negotiated). Implementation and follow-up services are available to adopters (costs to be negotiated).

Contact *Dr. Dean A. Wood, Hands-On Elementary Science, Education Department, Hood College, Frederick, Maryland 21701, (301) 663-3131 (Ext. 205 or 350).*

Developmental Funding: Federal, State and Local

LIFE LAB SCIENCE PROGRAM. An applied science program emphasizing a hands-on "living laboratory" approach to elementary science education.



Audience Approved by JDRP for elementary students, grades 2-6.

Description The Life Lab Science program strives to ensure students' future interests and success in science by improving student attitudes toward the study of science, and increasing students' level of knowledge and skill acquisition in science. The instructional approach is a combination of indoor and outdoor hands-on science activities with the key component being the garden lab (e.g. indoor grow box, greenhouse, planter boxes, vegetable beds, etc.). Students and teachers collaborate to transform their school grounds and/or classrooms into thriving garden laboratories for the study of scientific processes. In this setting students conduct experiments using the scientific method. They observe, collect and analyze data, establish worm colonies, raise vegetables, herbs and flowers, and have responsibility for maintaining their living laboratory. A structured course of study is followed in science, nutrition and gardening. Instructional time varies from two to four hours per week. Teachers are responsible for all classroom instruction and use *The Growing Classroom*, a three volume curriculum guide, for the bulk of their science lessons.

Requirements The critical learner setting is the "living laboratory" whether an indoor grow box, containers adjacent to the classroom, a greenhouse or a three acre school farm. As such, all elements of the program are transportable. The primary curriculum guide is *The Growing Classroom*, which contains three volumes—Science, Nutrition and Gardening and is accompanied by a scope and sequence outline. No textbooks are required, however, gardening tools are needed. Learning materials are predominantly household items. Prior to implementation, the program has a two-day workshop at the school site or at project site that prepares teachers for using the program, teaching techniques and the "living laboratory" approach. Following the initial training, staff development and program implementation become the responsibility of a Lead Teacher in each school. Advance training is available for Lead Teachers and technical assistance will continue to be provided throughout the installation year. Adopters of the Life Lab Science Program typically generate a great deal of community support and resources. Cultivating the community is an important requirement of a successful adoption.

The adopter is responsible for travel and per diem costs. Trainer fees are to be negotiated. Implementation costs vary by site and the extent of "living laboratory" development. A set of *The Growing Classroom* curriculum must be purchased for each implementing classroom teacher at $40 per set.

Services Awareness materials are avilable at no cost. Visitors are welcome by appointment at project site and additional sites in home state and out-of-state. Project staff are available to attend out-of-state awareness meetings (costs to be negotiated). Training is conducted either at project site or adopter site (costs to be negotiated). Follow-up technical assistance is also available.

Contact *Lisa Glick/Gary Appel, Life Lab Science Program, 809 Bay Avenue, Suite H, Capitola, CA 95010, (408) 476-7140, Ext. 223.*

Developmental Funding: ESEA, Title IV-C; Packard Foundation, California State Department of Education, National Science Foundation

MARINE SCIENCE PROJECT: FOR SEA. Comprehensive, activity-oriented marine science curriculum which teaches basic science skills and knowledge on or away from the coast.

Audience Approved by JDRP for all students, grades 2, 4, 6, 7-8 and 9-12.

Description By the year 2000, three out of four Americans will live within an hour's drive of the sea or Great Lakes coasts. The impact on these coastal waters will be severe. The nationally validated curriculum materials of Marine Science Project: FOR SEA are designed to equip students with information necessary to protect and maintain the world of water.

FOR SEA provides comprehensive, activity-oriented, marine education curriculum to be used in addition to or in lieu of an existing science program. Curriculum guides for each of the grade levels contain teacher background for each activity, student activity and text pages, answer keys for student activities, a listing of vocabulary words for each unit, and a selected bibliography of children's literature of the sea and information books of the sea.

The Marine Science Project: FOR SEA is documented effective in teaching basic science skills and knowledge as measured by the CTB McGraw-Hill CTBS Science Test and by project-developed tests. The magic draw of water provides incentive to teach and learn science.

Requirements The Marine Science Project: FOR SEA is designed to be implemented in classrooms at a room, grade, school, or district-wide level. Eight hours of inservice training provide implementing classroom teachers with an overview of the project, text implementation procedures, and activities designed to familiarize them with the materials. A copy of the appropriate grade level curriculum guide must be purchased for each implementing classroom teacher at $35 per guide. Student text materials in the guide are designed to be reproduced by the adopting sites. Hands-on materials are generally found in the school setting or are readily available at local grocery or variety stores. The startup costs vary by site.

Services Awareness brochures and samplers of curriculum are available. Project staff are available to attend out-of-state awareness sessions, with negotiable costsharing. Inservice training is provided to adopter site, again with costsharing negotiable. Followup services are provided by the project in appropriate cost-effective ways, including telephone, mail cassette tape, and visits.

Contact *Laurie Dumdie, Demonstrator/Trainer, Marine Science Center, 17771 Fjord Drive N.E., Poulsbo, WA 98370. (206) 779-5549.*

STARWALK. A comprehensive earth/space science program for elementary students.

Audience Approved by JDRP for grades 3 & 5. The program has also been used in other grades.

Description Project STARWALK provides differentiated instruction in earth/space concepts which accommodate various developmental levels. Students receive a series of lessons structured around three visits to a planetarium to prepare them for their activities at the planetarium and to consolidate and further the learning after the visit. Planetarium handbooks and teaching packets provide the instructional materials for these lessons. Classroom teachers participate in the activities along with their students. Students in grade 3 are introduced to the Milky Way and the concept of time. Students in grade 5 study the planets and the solar system configurations, and seasons around the world. Inservice orientation and technical assistance are available as well as a management system for scheduling of students, equipment or service purchase, and dissemination and evaluation.

Requirements The availability of a planetarium model in a laboratory or classroom is a component of this program. The program should be implemented on a district-wide basis on the elementary level because lessons on each grade level are sequential. A science teacher or other staff member can be trained to carry out the program. There is a minimal amount of instructional material needed.

Evaluation kits are $25 each. Two are available, one for third grade and one for fifth grade. They include 50 student scan sheets, student response summaries for pre- and posttests, classroom means for pre- and posttests, and statistical report of student growth for pre- and posttests. Cost of the instructional, management, and training materials packet is $25 per packet. Teacher guides from the packet may be duplicated for participating teachers at an adoption site. Per pupil cost per year is dependent upon costs for student transportation, planetarium utilization fees, supplies, and indirect costs.

Services Awareness materials are available at no cost. Developer is available to attend out-of-state awareness meetings (costs to be negotiated). Visitors are welcome at project site during school year by appointment. Training is conducted at adopter or project site (training no cost at project site, adopter pays own expenses, training no cost at adopter site, adopter pays developer's expense). Training is conducted at adopter site during school year by appointment. Implementation/followup services are available to adopters (costs to be negotiated).

Contact *Mr. Bob Riddle, Project STARWALK, Lakeview Museum Planetarium, 1125 W. Lake Avenue, Peoria, Illinois 61614. (309) 686-NOVA.*

Developmental Funding. ESEA, Title IV-C, State and Local

The National Center for Improving Science Education, funded by the U.S. Department of Education's Office of Educational Research and Improvement, is a partnership of The NETWORK, Inc. and the Biological Sciences Curriculum Study (BSCS). Its mission is to promote changes in state and local policies and practices in science curriculum, science teaching, and the assessment of student learning in science. To do so, the Center synthesizes and translates recent and forthcoming studies and reports in order to develop practical resources for policymakers and practitioners. Bridging the gap between research, practice, and policy, the Center's work promotes cooperation and collaboration among organizations, institutions, and individuals committed to the improvement of science education.