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ABSTRACT

This report is a blueprint for the creation of an effective, national program of science education for elementary school children in the United States. It draws together information about curriculum, instruction, assessment, and teacher development for elementary science. It was written in response to a widely expressed need to improve education in general and science education in particular. It is directed primarily to those who have a concern with, and a responsibility for, the education of children in public schools: elementary school teachers and principals, science specialists, curriculum directors, assessment personnel, staff development leaders, school district superintendents and administrators, state and federal education officials, university professors, and policy boards at all levels of education. Thirteen recommendations to federal, state, and local officials are included. An annotated bibliography of 27 references is provided. (CW)

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The National Center for Improving Science Education

Getting Started in Science: A Blueprint for Elementary School Science Education

SE 050 846

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

The NETWORK Inc

BSCS
The Natural Selection

Getting Started in Science

A Blueprint for Elementary School Science Education

A Report From
The National Center for Improving Science Education

a partnership of

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

and

Biological Sciences Curriculum Study (BSCS)
Colorado Springs, Colorado

The mission of the National Center for Improving Science Education is to promote changes in state and local policies and practices in the science curriculum, science teaching, and the assessment of student learning in science. To do so, the Center synthesizes and translates the findings, recommendations, and perspectives embodied in 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 is intended to promote cooperation and collaboration among organizations, institutions, and individuals committed to the improvement of science education.

The Center, a partnership between The NETWORK, Inc., of Andover, Massachusetts and Washington, D.C., 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. For further information on the Center's work, please contact Senta Raizen, Director, 1920 L Street, N.W., Washington, D.C., 20036, or Susan Loucks-Horsley, Associate Director, 290 South Main Street, Andover, Massachusetts, 01810.

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TABLE OF CONTENTS

PREFACE

This report is a blueprint for the creation of an effective, national program of science education for American elementary school children. It draws together the best that is now known about curriculum, instruction, assessment, and teacher development for elementary science. It was written in response to a widely expressed need to improve American education in general and science education in particular.

It is directed primarily to those who have a concern with, and a responsibility for, the education of children in public schools: elementary school teachers and principals, science specialists, curriculum directors, assessment personnel, staff development leaders, school district superintendents and administrators, state and federal education officials, university professors, and policy boards at all levels of American education.

Educational specialists who read this report can delve more deeply into the components of our proposed plan by requesting the longer and more technical reports on which this report is based. Three reports may be ordered from the Center:

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

Assessment in Elementary School Science Education

Developing and Supporting Teachers for Elementary School Science Education

Implementation guides to assist educators in realizing this coordinated approach to elementary school science are also available from the Center.

The synthesis and recommendations in this report were formulated with the help of the Center's Advisory Board and the three study panels, whose members are listed on pages ii through vi. We gratefully acknowledge the help given us by the Advisory Board, by the three panels, and by others who have made suggestions for the text of this report.

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EXECUTIVE SUMMARY

Science and technology are the foundations of modern civilization. The rate at which new discoveries are being made and the benefits of new technologies are being integrated into the average person's day-to-day life is exponential. And, as we make new demands on science and technology, science and technology are making new demands of us. The standards for technical and scientific literacy that the work force must meet are becoming more stringent, not less. Clearly, most Americans *can* learn about science and technology, and, if they are to compete in the global marketplace and exploit their personal potential to the fullest, they *must* learn about science and technology. *Getting Started in Science* is a blueprint for an elementary school educational system that will help meet, well into the twenty-first century, the American student's need for a scientific and technical education. It is the initial effort on the part of the Center to address kindergarten through high school science education.

The hands-on, inquiry-based, constructivist approach to science that the Center recommends in this report is straightforward enough, yet the issues that must be resolved before this approach to science is truly realized in elementary classrooms are complex. The particular issues fall into three general categories: curriculum and instruction, assessment, and teacher development and support.

Clearly, most Americans can learn about science and technology, and, if they are to compete in the global marketlace and exploit their personal potential to the fullest, they must learn about science and technology.

Curriculum and Instruction. The curriculum framework the Center recommends consists of major science and technology concepts, taught so that topics and experiences chosen to illustrate them bear a direct relationship to the students' world. Rather than skimming a great many concepts, the students should study these few concepts in great depth. They are: organization, cause and effect, systems, scale, models, change, structure and function, discontinuous and continuous properties, and diversity. The framework suggested by the Center allows teachers, school districts, and other educational decision makers to create curricula consisting of hands-on activities and visual, auditory, and written information sources that encourage students to develop their scientific and technologic knowledge, skills, and attitudes within a personally and socially meaningful context. Also, the science curriculum should present an opportunity and a context for the students to hone their reading, writing, speaking, and mathematical skills.

The instructional framework takes a constructivist approach to learning, which means the students gradually construct their concepts and skills through a variety of experiences. The framework defines new roles for teachers. They must become strategists who determine whether to use competitive activities, individual work, or cooperative groups. The teacher must learn to address the students' learning styles and manage their learning. Teachers should also model the qualities they wish to encourage in their students by showing awe, curiosity, and enthusiasm. In addition to defining new roles for teachers, the instructional framework provides the teacher with 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, and the model is consistent with current research on children's learning in science.

Teachers must become strategists who determine whether to use competitive activities, individual work, or cooperative groups.

Assessment. When considering how assessment of elementary science education might be improved, the Center focused on four key points. First, national assessments have raised awareness among policymakers and the public about the importance of science learning. These assessments have pointed out serious deficiencies in present science learning outcomes. Second, assessments are powerful tools that can help improve curriculum and instruction, because assessment can and often does define the content of science learning. Third, assessment, curriculum, and instruction are interactive. Ideally, assessment can be precedence for and a consequence of curricular goals. But, more often than not, content not assessed is content not addressed, and the assessment tool can end up undesirably narrowing instruction. Fourth, the power of assessment to shape curriculum and instruction has historically been seen as a negative factor that must by minimized. Recently, however, many states are actively using assessment to deliberately shape curriculum. Unfortunately, these assessments rarely reflect modern understandings of the range of important learning outcomes.

The Center has identified four goals for assessment. First, classroom assessment should be inseparable from and integrated into ongoing instruction. Second externally mandated assessment as well as classroom tests should be developed that better conform to good science curricula and instruction. Third, assessments should be developed that have a dual purpose -- that is, they should serve science instruction at the local level while serving to inform policy at the state and national level. The fourth goal is that assessments should provide an informative analysis and accurately report the results. The reference standards should not be based on national norms that rank order the students; instead, they should reflect the students' understanding of science and technology and their proficiency with scientific and technical skills.

Teacher Development and Support. Much is known about what needs to be done to improve teacher development, and much is known about how to support teachers. One thing waits to be done: forging teacher preparation, induction, ongoing development, and organizational support into a coherent and comprehensive structure that provides support for elementary science education. It is not enough to begin work in one area -- offering newly designed college science courses to prospective elementary school teachers, for example -- rather, work must begin simultaneously on all parts of the system, with full attention to collaboration and articulation across levels, so that the teachers will have adequate materials, equipment, staff development, and educational preparation.

When considering teacher development and support, the Center formulated two goals to guide their recommendations. First, we must develop structures and support, not only at local but at state levels too, that ensure that teachers who know how to teach good science can teach professionally. Second, the means must be provided for all teachers to develop the understanding, positive attitudes, and abilities to teach good science and to continue to grow throughout their careers.

[W]e must admit that reforming elementary school science education will be a difficult task.

Developing and supporting good elementary school science teachers, elementary school science curricula and instruction, and assessment tools will not be an impossible task. But, if we think in terms of conventional education, administrative attitudes, availability of funds and human resources, and in-place structures, all of which are perpetually changing, and not for reasons that necessarily have anything to do with good education, but with short-term gains at the expense of long-term development, we must admit that reforming elementary school science education will be a difficult task. Knowing the difficult task that lies ahead, the Center has sorted its recommendations into three levels, where each recommendation will efficiently achieve the greatest success at reconciling the nation's need for a scientifically and technically literate citizenry with the cherished tradition of local educational control. These levels, then, are the Federal government, state and local government, and policy-making bodies.

Recommendations to the Federal Government

1. Relevant federal agencies should mount a basic research project designed to identify the science knowledge, skills, and attitudes that students will need in future job markets.

2. Relevant federal agencies, or a coalition of state education agencies, should develop assessment exercises and techniques for probing the range of understandings, competencies, and attitudes that make up the goals of elementary science education. The Federal government should also establish a science assessment center or network of science assessment centers to help spread good assessment practice.

3. The Federal government, in concert with a coalition of science educators and administrators, should support programs for training science education leaders. The Federal government should also support research on the impact on science instruction of the current trend toward site-based management of schools.

4. The National Science Foundation and the U.S. Department of Education should create a study panel that will spend no more than eighteen months developing a plan for enhancing existing dissemination systems, and then implement a system that will improve science curriculum, assessment, and staff development and otherwise provide effective services to teachers and local school district administrators.

5. The National Science Foundation, in concert with a coalition of science education organizations, should mount a small study project on the quality of problems and exercises included in science textbooks and related teaching materials.

Recommendations to State and Local Governments

1. States, in collaboration with school districts, should develop comprehensive, coordinated structures for supporting good science teaching.

2. State and regional agencies, in collaboration with districts, schools, and universities, should experiment with varying forms of staff development.

3. State agencies should support university and school district efforts to develop elementary schools that simultaneously demonstrate good science teaching and serve as professional development schools for both novice and experienced teachers.

4. State and local educational agencies should endorse, and make it possible for teachers to implement, those instructional techniques that are known to promote science learning.

5. State and local agencies should adopt a curriculum for elementary science and technology, and major organizing concepts should inform this curriculum.

6. Academic departments in state colleges and universities must create the necessary rewards and incentives for excellence in undergraduate curriculum and teaching so that prospective elementary teachers are equipped to teach science with understanding.

Success will come only if interested individuals at all levels of the system take up the challenge.

Recommendations to National Policymakers

1. Concurrently and reciprocally with state efforts to develop model structures, national educational organizations together with science-based organizations should establish a broad-based group to identify state and local laws, policies, and procedures that inhibit good science teaching, and recommend changes.

2. A consortium of agencies, institutions, and organizations concerns with science education should create a National Assistance Center for Science Education that will put in the hands of agencies serving teachers, science educators, and policymakers the very best that is known about effective science education.

Conclusion

H. G. Wells wrote that human history becomes more and more a race between education and catastrophe. *Getting Started in Science* is a first step in giving American students the scientific and technical education they will need to be productive and responsible citizens of the twenty-first century. Of course, a plan is not in and of itself enough. Success will come only if interested individuals at all levels of the system take up the challenge. Educators, policymakers, and legislators must be persistent and share their energy, inventiveness, and expertise. Finally, the Center believes that America must make the monetary and moral commitment to improving science education.

CHAPTER I

THE CASE FOR SCIENCE EDUCATION IN ELEMENTARY SCHOOL

WHY SCIENCE EDUCATION?

At the very moment in history when science and technology touch American lives more deeply than ever before, there is compelling evidence that only a small percentage of the students who pass through the schools develop any useful scientific understanding. The educational system may be continuing to produce enough highly trained engineers and scientists, but most Americans appear to lack even a basic understanding of science and technology.

Widespread ignorance of science has increasingly unfortunate personal, social, and economic consequences. The inability to take pleasure from the natural world, to delight in understanding it, is a personal misfortune. An inadequate science education is a handicap for the increasing numbers of Americans whose jobs will require at least a basic knowledge and skill in science, mathematics. and technology.

The link between poor science education and America's lagging industrial productivity has not yet been established; the causes of declining productivity are varied and complex. Although some jobs require more knowledge and skill, others require less. But it is clear that some American industries cannot find enough workers with the knowledge to operate complex equipment, to solve problems independently, or even to profit from on-the-job training. The increasing technological sophistication of the work place demands that a far larger share of the population be handy with numbers, comfortable with technology, and able to apply basic scientific knowledge to the solution of a host of daily jobs.

As a nation, Americans seem to have convinced themselves that only a handful of smart students have the capacity to learn science.

Even for most of the population who will not work in science-related or technical jobs, some understanding of science is increasingly important to the quality of their personal and civic decisions. What must they know about acid rain in order to pressure governments to take proper actions? When the town leaders use numbers to express the risks involved in transporting hazardous materials through their town, can ordinary citizens interpret the numbers? As new diet fads wax and wane, how do people sort out the competing claims and choose a safe method of losing weight? Scientific understanding alone may not suffice to guide such decisions, but its absence will likely lead to poor solutions.

As a nation, Americans seem to have convinced themselves that only a handful of smart students have the capacity to learn science. The remaining students -- those who are average, and especially, those who are poor, female, or in a minority -- are widely assumed to be incapable of learning the math required in science, too concrete of mind to grasp scientific abstractions, or unwilling to endure the rigors of science education.

There is ample evidence, however, that the heart of the problem is not children's inability but that most children are not taught science at all, and when they are, they are taught in a way that progressively diminishes their interest in the subject and their confidence in their capacity to learn it. Almost all elementary schools serving rural or urban children teach only two subjects seriously -- reading and mathematics -- on the flawed assumption that children cannot learn other subjects until they have caught up with their advantaged peers on standardized tests of basic skills.

American students in general, and at-risk students in particular, are not expected to learn very much about science.

The difficulty with this "first things first" approach is that skills and understanding cannot be separated; good teaching requires that content and skills be woven together from the very beginning of schooling. Moreover, the heavy-handed emphasis on disembodied skills makes schooling seem pointless to many children. Even where children are also taught content, the nature of the content and the way it is presented often fail to engage children's minds.

Even in privileged suburban school districts, elementary children are rarely taught science well. A few are taught science as a series of fun experiments, but for them, the magic goes out of science when they stumble over the seeming rigor or uninspired teaching in junior and senior high school science courses. Others are offered "textbook" science where they are taught facts and concepts but are not given enough time and experience to connect those facts with the realities of the natural world or to grasp the underlying principles that make sense of it all. Students quickly become bored by the seemingly pointless memorization of facts and terms.

By the time these children reach junior and senior high school, they are expected, with scant preparation, to apply mathematics to science and to memorize as many new terms as are required in foreign language classes Not surprisingly, the majority of students from all social classes and ethnic backgrounds decide that science is boring and too hard.

American students in general, and at-risk students in particular, are not expected to learn very much about science. Yet many industrialized nations -- some with growing immigrant and language-minority populations and parallel social problems -- educate a greater percentage of their populations in the basics of science and technology. The differences between American children and children elsewhere cannot be fully explained by race, ethnicity, income, or culture. Instead, there is evidence that large numbers of American children are not learning science because they have not been given the opportunity to do so.

The ideas and recommendations in this report rest on the assertion that the United States can no longer afford its present approach to science education and on the belief that virtually all children are capable of learning science and should have the opportunity to do so.

WHY ELEMENTARY SCHOOL?

Current approaches to science education assume that serious study in science can be delayed until middle or junior high school. But learning science, like learning mathematics and a foreign language, is a cumulative process. To fully grasp the meaning of science, students need a steady supply of experiences with the natural world, repeated opportunities to raise questions and answer them, and time to develop skills and attitudes that are needed to understand and to do science.

Accumulating experience is important to the science learning of all children, especially for poor urban and rural children whose lives are often bereft of out-of-school experiences that stimulate an interest in science. The American ideal of equal opportunity for all rings hollow unless all children have access to a sound education. Yet current practices deprive those children who need it most of a foundation in science that will prepare them to succeed in high school, high-tech vocational programs, or college.

Because the evidence on the cumulative nature of science learning is so compelling, we believe those responsible for elementary school curriculum, if they expect more than a few elite children to become seriously engaged with science, must give it equal billing with reading, writing, and mathematics.

This report advocates a hands-on, inquiry-based science program in elementary school as the best possible preparation for all students, regardless of their circumstances.

This report advocates a hands-on, inquiry-based science program in elementary school as the best possible preparation for all students, regardless of their circumstances. Hands-on science stimulates children's natural curiosity about science and thus encourages them to persist in the study of science. Hands-on science stimulates children to ask questions and to be skeptical of ready-made answers -- good attributes for citizens in a democracy. Hands-on science teaches students to solve problems and to work cooperatively with others in seeking solutions -- skills that are equally useful in advanced study, in work, and in life.

Our vision of an elementary science program does not presume that every topic in science can or should be taught through a hands-on approach. Some topics are better learned by reading, others by lecture, and still others by discussion. Further, we acknowledge that in nations with higher levels of student achievement in science, science is often taught in the rote fashion we lament. We do believe, though, that in the American cultural context, children are most likely to learn and remember if they have many opportunities to observe and touch the materials of science itself -- plants, animals, rocks, electrical circuits, magnets, and the like -- to use the tools of science -- rulers, scales, microscopes, and so forth -- and to raise questions about natural phenomena and answer them through experiments they help shape.

A strong elementary science program provides children not simply with experiences, but with carefully selected experiences that allow them, eventually, to learn the principles of science. If children see scientific principles illustrated again and again, they are much more likely to form correct and important generalizations as they grow older and to appreciate science as a profoundly influential human invention that is nevertheless subject to human error and correction.

THE CURRENT RICHER KNOWLEDGE BASE

There are good reasons to believe that the recommendations in this report -- if taken seriously by policymakers and educators -- will raise American children's achievements in science. The recommendations are grounded in old and new knowledge about how children learn in general and how they learn science in particular. It has long been known, for example, that most children learn best by doing, even though the schools have generally failed to act on this knowledge. New knowledge derived from cognitive research has shed more light on how children think. This new knowledge infuses the recommendations in this report concerning curriculum, instruction, assessment, and teacher development.

Knowledge About Conceptual Change

New research is demonstrating more powerfully than ever before that children hold their own beliefs about the way nature works. To the degree that science is counterintuitive, children's beliefs are sometimes at odds with scientific knowledge. The most significant aspect of the new research is that teachers are often unaware that children hold ideas that get in the way of their learning. Moreover, children don't naturally abandon their views simply by being told they are wrong; rather, they cling to them tenaciously. Children may believe, for example, that molecules are bits of matter suspended in empty space like blueberries in a muffin. They are unlikely to accept the scientific view that molecules are matter, or that what appears to be empty space is composed of molecules, unless they are encouraged to bring their own views to the surface and, over time, have many classroom experiences designed to help them change their ideas.

It has long been known, for example, that most children learn best by doing, even though the schools have generally failed to act on this knowledge.

This body of research strongly suggests that good school science programs should tackle fewer topics and tackle them in greater depth. When the pace is slow, students have time both to reveal their ideas (many student ideas are grounded in their experience, even if the ideas are scientifically wrong), to test their ideas against those of other students, and to accumulate evidence.

Research Comparing Experts and Beginners

Other research has compared how scientists and beginners think about scientific problems and how they approach their solutions. Experts bring to a problem a deep and highly structured knowledge base that allows them to see patterns and relationships and to apply knowledge from one branch of science to another by analogy. Beginners, though, because they barely understand even the facts on a particular topic, have trouble seeing patterns or using analogies.

Schools now try to show students that they need to draw on a large factual base before understanding generalizations and abstractions. The difficulty arises when the curriculum covers too many topics too quickly and fails to help students develop the mental structures that make the factual information memorable and useful. This body of findings also points to a need to treat fewer topics in greater depth so that students have time to absorb facts and fit them into meaningful patterns.

The Social Nature of Scientific Work and Learning

Research on children's conceptions, the way experts solve problems, and the power of the social group to teach converges on one crucial point: less is more.

Scientists rarely solve problems in isolation; they usually work with and learn from other scientists working on the same problem. That same principle applies to students learning science in school; they learn best through well-structured social interaction with one another and their teachers. Students need to test their ideas against those of the group. When students collaborate with others on school science tasks, they sharpen their communication skills and acquire a deeper understanding of what they are doing. Research on children's conceptions, the way experts solve problems, and the power of the social group to teach converges on one crucial point: less is more. Although most educators decry the excessive number of topics covered in most school syllabi and commercial textbooks, their will to address the coverage problem seems weak. These research findings can be used to strengthen the case for teaching fewer topics in greater depth.

Active Learning

Research on learning (not only in science but across the curriculum) shows that students learn more, remember more of what they learn, and are more likely to use what they learn if they are asked to take more responsibility for their own learning. Students are more likely to learn science if they explore natural phenomena directly, pose their own questions, design their own experiments (in elementary school, a "fair test"), and discuss the results with others. Though poorly designed experiments contribute little to learning, a teacher who understands how to help children set up an appropriate experiment can contribute much to student learning.

Moreover, the evidence shows that not all children profit from the same teaching techniques. Some children learn better through cooperation with others than through either solitary work or competitive activities. There is strong evidence that many students would learn more science and like it better if teaching methods required students to be more active and interactive than they are in most of today's science classes.

How Teachers Learn Science and Science Pedagogy

If hands-on science is vital to good elementary science teaching, teachers must themselves be exposed to that approach in their college science classes. Yet few of today's teachers took college science courses, and those courses usually emphasized the facts of science, not its processes or underlying concepts. Since few teachers understand the major organizing principles in science, they are unable to design experiences that will eventually lead students to an understanding of those principles. New cognitive knowledge about learning applies to adults as well as children. Teachers in training and teachers in service need to study both science and science pedagogy in ways that emphasize experience, inquiry, and the continuous weaving together of theory and practice.

Even a brief look at our blueprint will reveal the need for profound reforms in institutional practices and power arrangements among various sectors in American education.

The Nature and Influence of Tests

Teachers emphasize what will be tested because they want their students to do well on tests. Yet the tests most commonly used, whether designed by teachers or mandated by educational authorities, do not reflect a modern understanding of the range of important science learning outcomes

Research on student learning in science suggests that teachers need tools to probe students' conceptions in order to shape their instruction, yet current tests are not designed to do that. Teachers need tests that determine whether students truly understand basic ideas in science, yet the current multiple-choice format of tests favors factual knowledge at the periphery of science and sheds little light on whether students understand connections between facts and concepts. Learning how to conduct a valid experiment is a slow and difficult process, requiring students to use their hands, eyes, and minds with increasing skill, yet these skills are not part of the current testing program.

The chapters that follow are a blueprint for the construction of an effective system of science education in elementary schools. The chapters have been shaped by knowledge about why science seems so difficult to so many people and about how ordinary children and adults come to understand science.

Even a brief look at our blueprint will reveal the need for profound reforms in institutional practices and power arrangements among various sectors in American education. Moreover, many of the changes required in any one sector depend on simultaneous changes in other sectors. Given this country's highly decentralized public educational system and the autonomy enjoyed by colleges and universities, the needed coordination among sectors will be hard to achieve.

Still, other national imperatives have evoked an appropriate response from either the federal government or powerful national organizations. When the need was clear, creative leaders have been able to mobilize politicians, educational leaders, and scholars. They have marshalled public opinion and influenced even the most entrenched institutions. The realization of this blueprint for an effective, national system of science education for elementary children will require just that sort of creative leadership.

AN OVERVIEW OF THE REPORT

The insertion of even a few hours of well-conceived, inquiry-based science instruction into the elementary school day is not a simple matter. It requires a coordinated approach to curricular philosophy, curriculum design, instructional methods, school and school district management, the provision of materials for learning, student and program assessment, teacher education, and the ongoing development of teachers in service.

Chapter II, "A Vision of Curriculum and Instruction for Science Education in Elementary School," deals with the what and the how of an ideal elementary science program. The first half of the chapter lays down a curricular framework that encompasses the knowledge, skills, and attitudes that elementary children are able to learn if they are properly taught. The framework is intended to help states and school districts design a series of experiences for children that will, over time, accumulate into a mature understanding of science.

The second half of the chapter sets forth a framework for instruction that emphasizes the importance to children of direct experience with the materials of science, the truth that students learn more when they probe deeply in search of answers to their own questions about the natural world, and the fact that children learn a great deal from one another if allowed to do so.

[C]hildren learn a great deal from one another if allowed to do so.

Chapter III, "Assessment in Elementary Science Education," presents the case for a changed emphasis in the measurement of student learning -- assessment in the service of learning. Since large-scale, multiple-choice tests seem to have reached the outer limits of their usefulness, we propose a redirection toward the kinds of tests that help teachers do a better job of teaching science. Chapter III also discusses how school districts, in the absence of adequate program assessment tools, can judge the adequacy of their science programs by assessing the essential ingredients of a good science program and how large-scale testing can better serve its intended purposes of monitoring and accountability.

Chapter IV, "Teacher Development and Support," calls for a radical redesign of the scientific and pedagogical training of prospective elementary school teachers and of staff development programs for teachers now in service. Since even the best trained teachers cannot withstand unknowing administrators or unsympathetic school district policies and procedures, a discussion of the necessary administrative supports and attitudes concludes the chapter.

Chapter V, "Recommendations," presents a series of recommendations directed to the appropriate levels of political, educational, or institutional governance. It concludes with a recommendation for a mechanism to coordinate the efforts of all bodies and institutions concerned with the education of the young and the scientific literacy of American citizens.

CHAPTER II

A VISION OF CURRICULUM AND INSTRUCTION FOR SCIENCE EDUCATION IN ELEMENTARY SCHOOL

INTRODUCTION

Presented in this chapter is a vision of science education in elementary school. The following material is not a curriculum waiting to be adopted by a school district in search of a ready-made syllabus. It does not provid~ teachers with a list of topics and processes to teach. Rather, it a curricular framework general enough to accommodate a wide variety of topics and skills and an instructional framework broad enough to address the learning needs of an increasingly diverse student population.

Goals for Curriculum and Instruction in K-6 Science

The goals of the Center's recommendations on curriculum and instruction are:

- To develop children's innate curiosity about the world;
- To broaden their procedural and thinking skills for investigating the world, solving problems, and making decisions;
- To increase their knowledge of the natural world;
- To develop children's understanding of the nature of science and technology; and
- To develop children's understanding of the limits and possibilities of science and technology.

COMPONENTS OF AN EFFECTIVE SCIENCE FRAMEWORK

The Center's vision for elementary science education combines several components widely believed to enhance science learning and better prepare tomorrow's adults for a world increasingly influenced by developments in science and technology.

Hands-On Experience and Scientific Inquiry

At the heart of the Center's vision is the notion that children need to build their knowledge of science on direct experiences with the natural and human-made worlds. Textbooks and lectures have a role in science education, but the education of primary grade children should consist almost exclusively of experiences that reveal, for example, the properties and behaviors of objects. In the primary grades, children need to see, touch, smell, taste, hear, describe, and sort the materials of science and technology. They need to frame their own questions and to have teachers who take their questions seriously.

In the primary grades, children need to see, touch, smell, taste, hear, describe, and sort the materials of science and technology.

In the upper elementary grades, children can further enhance their understanding of science and technology by listening to their teachers and by reading science texts. But even at this level, children should spend most of their time constructing and refining their developing concepts by designing experiments for example to answer the questions they have raised themselves -- even if their experiments are crude approximations of those that scientists conduct.

The case for hands-on, or inquiry-based, science is extremely powerful and has been made repeatedly. Yet, as matters stand, few elementary teachers provide such experiences for children. Too frequently, teachers believe they can speed children's levels of conceptual development and short-circuit the time children need to link new knowledge with existing conceptual understanding, by relying heavily on lectures and readings. Commercial textbooks subtly discourage teachers from organizing hands-on experiences, and policymakers seem reluctant to fund the materials-based curricula that make that kind of teaching happen.

Translating the vision in this report into classroom reality is now feasible. To do so, school districts must take responsibility for materials support and maintenance and for an ongoing effort in teacher education that empowers teachers to use science materials with confidence.

Less Is More: Teaching for Understanding

The evidence presented in Chapter I strongly suggests that if students are more intensely engaged in fewer topics, they are more likely to find meaning in what they are studying and will be better prepared for advanced study. The less-is-more principle leads curriculum designers to a difficult question: Which topics are most worthy of in-depth exploration? We have answered that question by proposing a set of major organizing concepts. Those who design curriculum can judge the value of particular topics and processes in a curriculum by the contribution those topics can make to children's eventual understanding of these broad, organizing concepts.

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A Conceptual Orientation

The curricular framework that follows is organized according to broad scientific concepts that can be applied to both science and technology and to scientific skills and attitudes. The framework suggested in this chapter is intended to address several important issues in science education.

First, for students to grasp difficult scientific ideas, they need repeated exposure, over many years, to varied illustrations of those ideas. Elementary age children will not necessarily draw the scientifically accepted generalizations from a particular school experience, nor should they be expected to. Moreover, elementary school children should not be taught abstractions beyond their level.

We do believe, though, that curriculum designers and teachers should be mindful of the need to design a long and continuing series of experiences that will accumulate and eventually result in the students' ability to understand these important abstractions in later years. Even though the concepts themselves may be too sophisticated for young children, rudimentary manifestations of those concepts can be presented to primary grade children, and progressively more complex manifestations can be presented to intermediate grade children

Unless students are being led gradually to a better understanding of the underlying concepts that make science meaningful, their fascination with particular topics begins to wear thin, and their pride in mastering processes and skills begins to pale.

Second, a conceptual orientation respects the diversity of thought in the United States about the specifics of what to teach in science classes and recognizes that communities offer diverse climates, landscapes, life forms, and human-made systems through which to teach general scientific and technological concepts.

Third, both topical and process approaches to science education can call forth a "so what" reaction from students. (That is the risk associated with programs organized around topics and/or processes.) Unless students are being led gradually to a better understanding of the underlying concepts that make science meaningful, their fascination with particular topics begins to wear thin, and their pride in mastering processes and skills begins to pale.

Technology as a Vital Component of Science Education

The Center's framework for curriculum and instruction also notes that science and technology are increasingly interdependent and mutually reinforcing aspects of the natural and physical world. It has been said that technology is the face that science shows to the world. Few children, or even adults, however, distinguish between science and technology, and it is not important for them to do so. But it is important for curriculum specialists and teachers to clearly understand the differences between science and technology as they write curriculum and plan lessons. We distinguish them as follows:

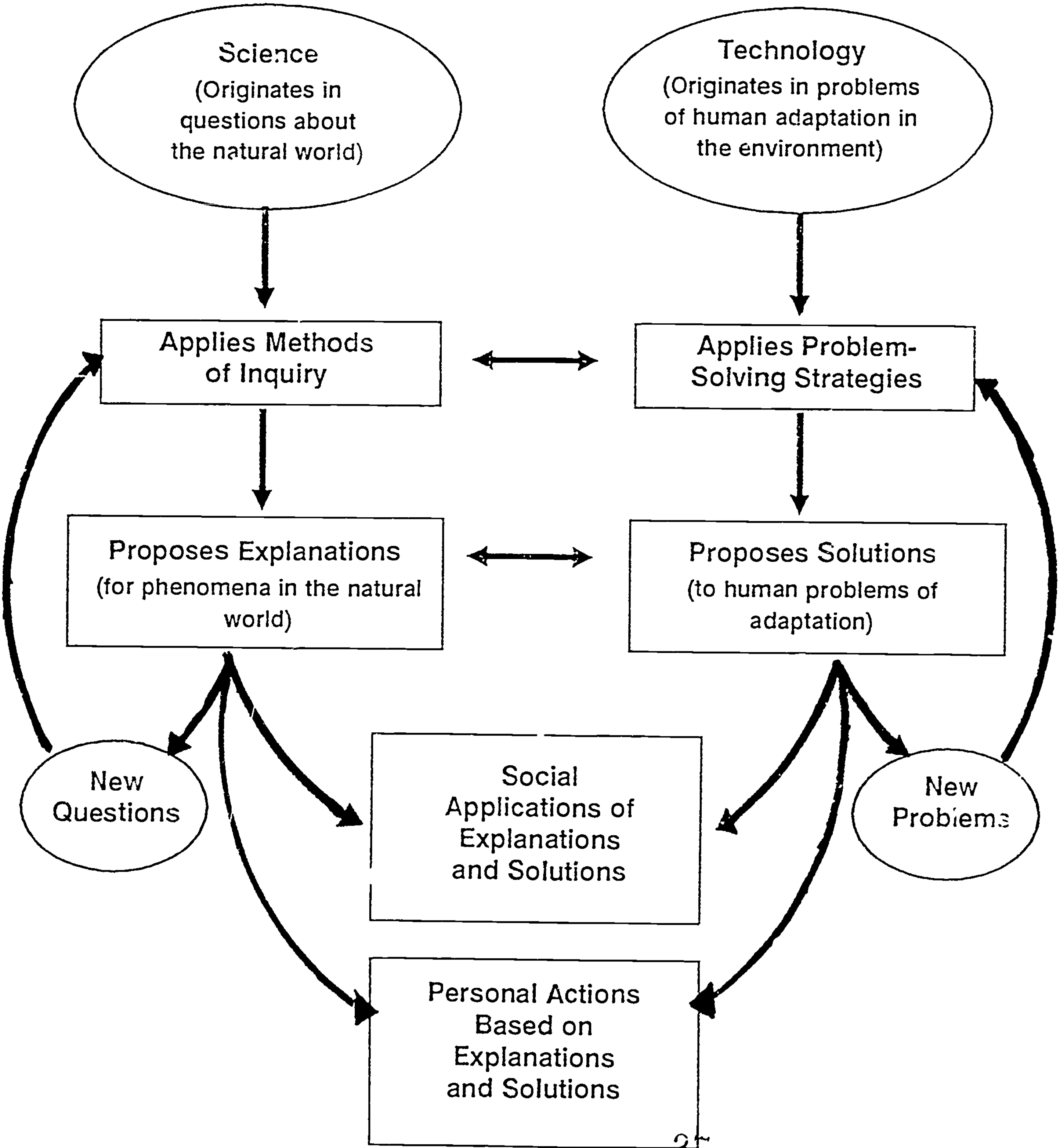
- Science proposes *explanations* for *observations* about the *natural* world.

- Technology proposes *solutions* for *problems* of *human adaptation to the environment.*

Figure 1 schematically represents the relationship between science and technology and their connections to the goals of the curricular framework that follows.

Figure 1

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



Although the relationships between science and technology are beyond the capacity of elementary school children, we believe they can begin to understand the following important ideas:

1. Science is an attempt to construct rational explanations for what is observed in the natural world.

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

3. Technologies exist within the boundaries of nature; no technology can contravene biological or physical principles.

4. All technologies are incomplete and imperfect, and all carry some risk; a society that depends heavily on technology incurs new and complex risks.

5. Scientists use and depend on technology. As technology evolves, so does science.

Current science programs present little information about the relationship between science and technology. Textbooks usually define technology early in a series and seldom mention it again. Although the study of the relationship between science and technology to society is becoming more common, it is still not a prominent feature of most science programs.

A FRAMEWORK FOR CURRICULUM

A curricular framework should shape, but not determine, the particulars of what will be taught. The Center's proposed framework consists of organizing scientific concepts, attitudes, and skills. The concepts are intended to give purpose and direction to the design of a K-6 set of experiences that include the life sciences, the physical sciences, and technology, which will enable students eventually to understand the concepts.

Scientific Concepts

1. *Organization (or orderliness)*. Science is a human invention, and scientists have made the study of science manageable by organizing and classifying natural phenomenon. They have organized the world in different ways, including hierarchies, simple-to-complex arrays, and symmetries. Natural objects can be assembled in hierarchies (atoms, molecules, mineral grains, rocks, strata, hills, mountains, and planets). A range of organisms -- from single-celled amoeba, to sponges, and from corals, and so on, to mammals -- can illustrate simple-to-complex arrays. Objects can be grouped according to their symmetry from top to bottom, front to back, or in the repetition of shapes.

Even very young children can begin to learn the principles of classification that underlie scientific orderliness. Primary grade children can be asked to develop simple schemes for classifying objects and organisms. Intermediate grade children can be asked to classify a group of plants according to the properties they observe in them and then compare their own classification schemes to the scheme currently accepted by scientists.

Searching for causes and explanations is the major activity of science; effects cannot occur without causes.

2. *Cause and effect.* Nature usually behaves in predictable ways. Searching for causes and explanations is the major activity of science; effects cannot occur without causes. Primary grade children can begin to learn cause and effect by observing the varying effects of light, water, and warmth on seeds. Intermediate grade children can discover that streamlining, carefully aligned axles, and good lubrication help a pinewood derby car run faster. They also discover that if too much wood is carved off the car body while streamlining it, weight must be added to keep it heavy.

3. *Systems.* In science, the concept of a system describes the movement of matter, energy, and information through defined pathways. The amount of matter, energy, or information in reservoirs, and the rate of transfer through pathways, varies over time. Children begin to understand systems by tracking changes among the constituent parts of a system.

   Primary grade children can begin to understand the concept of a system by studying the less abstract notion of balance, which an aquarium in the classroom might well illustrate. Fish need a balanced aquarium to survive. Balancing the aquarium requires children to learn how light and food follow pathways from plants to water to animals.

   Intermediate grade children could gain a more complex understanding of balance by studying the school's heating system. The furnace and thermostat are a homeostatic system; information is relayed and acted on within the system to keep room temperatures from fluctuating more than a few degrees on either side of a set point.

4. *Scale.* Scale refers to quantity, both relative and absolute. Thermometers, rulers, and weighing devices help students see that objects and energy vary in quantity. The idea that certain phenomena can exist only within fixed limits of size is very abstract. Yet primary grade children can begin to understand it if they are asked, for example, to imagine a mouse the size of an elephant. Would the mouse still have the same proportions if it were that large? What changes would have to occur in the elephant-sized mouse for it to function?

The water strider provides an observable illustration of the importance of relative scale in nature. Water striders can run across a puddle supported by the water's surface tension only because they are small enough not to break it. If they were much larger, they would sink; if they were much smaller, they would not be able to break away from the water. Primary grade children could be asked to draw simple objects in actual size and compare their drawing to a small-scale representation of the same object. Intermediate grade children might advance their understanding of scale by describing the magnification of a microscope.

5. *Models.* The concept of a model is important to both science and technology, but it is a difficult concept for very young children. Primary grade children can begin to lay the foundations for this concept by understanding the idea of representation. For example, children at this level could be asked to draw a picture of a cell as they observe it through a microscope. Intermediate grade children could use a model of a segment of the earth's crust to demonstrate the causes of earthquakes.

6. *Change.* The natural world continually changes although some objects or species seem unchanging because of human inability to perceive the rate or scale of change. That mountains erode, or species evolve, is not evident in a person's life span; mutations in genetic material are hidden unless they affect observable characteristics. Some change is cyclic -- diurnal, lunar, seasonal, and menstrual cycles, for example -- whereas others are one-directional -- physical development, puberty, and menopause, for example. Rates of change vary.

   Primary grade children can be asked to observe the changes in the position and shape of the moon over a month's time. By tracking the position of the moon each night at the same time (a good way to involve parents in a science project), and drawing pictures of the moon's changing shape, they will learn that changes take place during the lunar cycle. Intermediate grade children could be asked to observe and describe changes in the properties of water when heating or cooling causes melting, boiling, evaporation, freezing, or condensation.

The concept of a model is important to both science and technology, but it is a difficult concept for very young children.

7. *Structure and function.* There is a relationship between the way organisms and objects look (feel, smell, sound, taste) and the things they do. The scent glands in skunks are related to protection. The hummingbird's tube-like beak allows it to suck the nectar out of flowers. The role of natural selection in the development of particular organic structures may be too abstract for young children, but they can begin to lay the foundation for understanding modification through descent by observing the simple relationship between a plant's or an animal's structure and the things it does. Children can learn to infer what a mammal feeds on by studying its

teeth, or what a bird eats by studying the structure of its beak.

8. *Discontinuous and continuous properties (variation).* To understand the difficult concept of organic evolution and the statistical nature of the world, students first need to understand the notion of properties, which in turn involves some understanding of continuous (and discontinuous) variations. All organisms and objects have distinctive properties, but some of their properties are so distinctive that no continuum connects them (for example, living/nonliving, salt/sugar). In most of the natural world, though, the properties of organisms and objects vary continuously.

Children can explore and investigate a pond, for example, to learn that different types of organisms feed on different things and that these organisms depend on one another for survival.

Young children can hone their skills of observation, and learn about continuous variation, by observing and arranging color tones, for example. Older children can investigate the properties of a butterfly or a mealworm during its life cycle in order to discover both continuities and changes.

9. *Diversity.* Diversity is the most obvious characteristic of the natural world; even preschoolers know that there are many types of objects and organisms. In elementary school, they need to take a step toward understanding that diversity in nature is essential to the survival of natural systems and that the diversity of technological solutions depends on economics, efficiency, and aesthetics. Children can explore and investigate a pond, for example, to learn that different types of organisms feed on different things and that these organisms depend on one another for survival.

At first glance, the organizing concepts may appear far removed from actual curricula. How can one of the nine concepts, models, be translated into practice? There are many ways in which teachers can incorporate this concept into activities across several grade levels.

A kindergarten class can be presented with the following assortment:

- *a bean bag guinea pig*
- *a live guinea pig*
- *an inflated snake model*
- *a large model of a beetle*
- *a goldfish in a bowl*
- *a small plastic farm animal*
- *and so forth,*

making sure there are at least as many items as there are children. The children are already familiar with sorting and classification games, having used attribute blocks, leaves, shells, and rocks. The object of this lesson is to differentiate between real things, i.e., animals that are or were once living and models. The children are asked if they have any models at home: dinosaurs, castles, airplanes, cars, and trucks. The discussion inevitably broadens children's ideas of what characterizes a *model.*

The children sit in a circle on the carpet where two areas are identified with cards labeled "model" and "real". One by one each child is given something from the assortment to place. Is it living? Was it ever living? Is it the real animal or is it a model?

Another sorting exercise allows the children to further categorize the "real" animals into living or previously alive but not now living. The children then categorize the "models" into bigger than the real thing, smaller than the real thing, and the same size as the real thing.

The discussion that follows focuses on why models are useful. It is reasonable to expect children of this age to understand that larger-than-life models are useful for studying real things too tiny to see; a model cow or horse is useful for learning about farm animals at home.

Later in their school career, students make their own models. In fourth grade, as part of an animal behavior study, they make a large-scale model of a crayfish. Working from a grid of centimeter squares, they trace a live crayfish, then in several steps enlarge the size of the squares until the crayfish is 20 times the size of the living crayfish while preserving the proportions.

As part of an insect study to reinforce learning the pattern of the adult insect body (i.e., head, thorax, mouth parts, compound eyes, antennae on the head), the students make an insect model from a photograph of an actual insects, and later perhaps a diorama to show the habitat.

In fifth grade they choose from a variety of materials, paints, inks, and markers, and make a visual representation of the relationship between wavelength, frequency and color in the visible light spectrum. Later in the year force and motion are studied by making and modifying paper airplanes.

In sixth grade students make models of the human heart as a homework assignment, using boxes, tennis balls, bottles, shoes, tubes, styrofoam, water with food coloring, and other objects, and present them to their classmates.

Mathematical models at the elementary level may begin with graphically representing the results of a survey. Kindergartners can take their own surveys, asking their own questions: "What is your favorite farm animal? or "How many pets do you have?" They can then represent their data pictorially using large-squared paper and markers. First and second graders can investigate the changing colors of leaves on a maple tree in the school yard. At weekly intervals each child picks up five leaves from under the tree. The over 100 leaves are then lined up on the sidewalk beside the tree, leaves of each color are counted and recorded on graphs with a leaf stamp for each square which are then colored in. As the weeks pass, the patterns of the colors change, the once predominating green column replaced by yellow, then orange and brown. The children come to understand the relationship of the numerical representation to the real changing event.

Perhaps the most difficult kind of model for elementary children is a conceptual model, because links to physical, observable, experienced reality are tenuous and difficult to establish. However, teachers can *provide experiences that will prepare children for eventual understanding. While one would not expect children to fully understand the concept of the evolution of the earth, some of the evidence scientists have used to put together this model can be presented at an appropriate level. Looking at beaches, roadcuts, and fossils in the locations can begin to set the scene.*

We now turn to the two remaining parts of the proposed framework for curriculum.

[I]t is important for children to begin to learn the ethics of science.

Attitudes

A strong elementary science program can contribute to the development of scientific attitudes, to the development of children's positive attitudes about science, about the study of science in school, and about themselves.

Scientific and technologic attitudes. A collection of attitudes comprise the ethical tradition of the scientific and technological communities. Most of these ideals are also part of the ethical traditions of other disciplines. But the scientific and technological enterprise is closely linked to the life-and-death issues of national defense, medical practice, and public health and safety. When scientists fail to live up to this ethical tradition, the negative consequences for society can be enormous. Therefore it is important for children to begin to learn the ethics of science. Some of these attitudes are:

1. Desiring knowledge -- a disposition toward knowing and understanding the world

2. Skepticism -- a disposition to question authoritarian statements and self-evident truths about the natural and physical world

3. Relying on data -- using data as the basis for rigorous testing of ideas and respecting the facts as they accrue

4. Accepting ambiguity -- data are seldom compelling and scientific information seldom proves something. New questions arise out of ambiguity.

5. Willingness to modify explanations -- a willingness to change original explanations when the evidence suggests different ones

6. Cooperation in answering questions and solving problems -- fundamental to the scientific enterprise

7. Respecting reason -- the quality of reasoning that leads from data to conclusions to the construction of theories

8. Being honest -- present data as they are observed, not as the investigator thinks they should be.

These attitudes can be cultivated in any science program, including elementary programs. They are best approached not as separate lessons, but as part of the daily science experiences. In this way, children begin to see science as one way of knowing their world.

[W]hen students begin to acquire an understanding of science, they also begin to develop a sense of control over their own destinies and thus more self-confidence.

Attitudes about school science. Students should enjoy science in school and find the study of it interesting and useful to their personal lives. The development of a curriculum and instructional approaches that foster positive student attitudes is a serious educational responsibility; conversely, the maintenance of a curriculum that sets most children up for indifference and failure is a serious educational dereliction. Students are far more likely to value the study of science if their ideas, however distant from the canons of science, are respected, if they are given a chance to freely explore and inquire; if the topics chosen are closely interwoven with concepts, processes, and skill development; and if science is presented as the exciting, challenging, and practical discipline that it is.

Attitudes about the self. When children or adults view science as mysterious and difficult, or view scientists as a remote group largely made up of white males in laboratory coats, they tend to believe they have lost any power to influence the forces that shape their lives. Yet evidence suggests that when students begin to acquire an understanding of science, they also begin to develop a sense of control over their own destinies and thus more self-confidence. Helping children succeed in science also helps them develop a greater sense of self-esteem.

Skills

The skills of science include practical laboratory skills, intellectual skills specific to science, and generic thinking skills needed in all disciplines. Practical laboratory skills include such things as the ability to read a thermometer, connect a wire to a terminal, stake out a quadrant, or focus a telescope. The development of these manual skills requires practice; they are best developed in context as students search for answers and try to construct valid tests of their ideas.

Helping children succeed in science also helps them develop a greater sense of self-esteem.

Intellectual skills specific to science include the ability to generate a hypothesis; design an experiment that is a fair test of a hypothesis; and collect, reduce, present and analyze data.

Generic thinking skills include problem solving and quantitative, logical, and analogical reasoning. The development of these skills in science classes not only contributes to students' basic abilities in mathematics but also to their competence in nonscience areas such as written composition and social studies.

Curriculum Selection and Design

A variety of themes or 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 structures, tools, ice cubes, nutrition, patterns, transportation, waste disposal, the arctic, weather, and pond water. Many more are possible. We suggest 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 children see that reading, writing, mathematics, and other curricular areas are part of science and technology;
- they integrate several disciplines;
- they are vehicles for teaching major organizing concepts, attitudes, and skills; and
- they allow a balance of science and technologic activities.

A FRAMEWORK FOR INSTRUCTION

It is increasingly clear that the how of instruction is as important as the what of curriculum. The truism that not all children learn in the same way is becoming a truth well grounded in research. Yet too often the most prominently used method of science instruction at all levels -- lectures, textbook reading, and discussion centered on textbook questions -- fails to engage the minds of a significant number of children.

Few current elementary programs capitalize on the most valuable asset available to teachers of science in elementary school: children's natural curiosity about the natural world. That curiosity can be nurtured best by allowing children to ask questions and to explore those questions, just as scientists do.

With their students, teachers can be co-learners and co-investigators in projects where neither the teacher nor the students know the answer.

To channel children's questions into activities that will lead to greater understanding of scientific concepts, teachers themselves need a basic level of conceptual understanding. Yet teachers do not have to be experts on every aspect of science, nor do they need to have the answer to all the questions children are likely to ask. With their students, teachers can be co-learners and co-investigators in projects where neither the teacher nor the students know the answer. It is important in these situations for teachers to be expert coaches. Good coaching requires teachers to develop their skills in framing questions that probe student understandings of the problems at hand and that lead students to inquire further. Good coaches must develop the patience to wait a few moments after asking questions so that students have time to think about their answers.

Should the teacher be *only* a facilitator? Must all learning be through hands-on discovery? The Center's answer is no. Not all topics lend themselves hands-on lessons. Some teachers are wonderful storytellers. me readings in science are highly motivating, and some a. necessary to help children connect new knowledge learned through experience with their existing knowledge. But there is evidence that merely imparting information -- through lecture or text -- is not enough, especially for young children. Not only do children need to amass direct experience with natural phenomena, they also need time to accommodate their experience by talking about it with their classmates and their teachers.

[S]tudents need time to tinker, think, and thrash things out.

Cooperative Learning

Cooperative learning is not the same as the small group instruction that many teachers use. Rather, members of teams are assigned specific roles (for example, principal investigator, recorder, or materials manager) and rotate those roles so that all experience the full range of responsibilities in their groups. Teachers also structure tasks so that children are required to depend on one another to achieve results.

When children work collaboratively in small groups, they hone their communication skills and develop a sense of responsibility for their own learning as well as that of their teammates. Teachers can help students develop the personal skills required to interact successfully with others -- skills that are necessary in both life and scientific work and that cannot be learned very well working alone at a desk

Cooperative learning is often an excellent technique to help students learn to solve problems and conduct valid experiments because it capitalizes on the diversity of viewpoints and talents within the group. This learning approach should therefore be used frequently in elementary science classrooms.

Problem-Solving and Laboratory Activities

True problem solving exists only when the learner is unclear about what needs to be done to arrive at a solution. Yet there is evidence that many hands-on activities do not necessarily require problem solving. Instead, they often guide students step by step through procedures with no particular problems to solve. Although researchers have much to learn about how to structure laboratory tasks so that students face a legitimate cognitive challenge, even now there is abundant research showing that students need time to tinker, think, and thrash things out. Teachers can be most helpful when they encourage children to observe and search for clues to a puzzle, and then prod them with information and questions that lead them to discover more clues. Teaching, then, is as profoundly inductive as children's own learning and thus implies new roles for the teacher who wants to implement the research findings on how one learns science. How can teachers translate their findings into classroom practice? We believe that if teachers follow a teaching model based on human learning, then they are more likely to involve their children in active learning: asking questions, designing experiments, interpreting data, sharing and challenging points of view, and solving problems.

How can teachers translate their findings into classroom practice?

A Four-Stage Teaching Model

The four stages of the following teaching model parallel the approach taken by practicing scientists both in research and in applying science to create technologies. Moreover, the following model provides teachers with a basis for expanding their own knowledge of science as well as their students'. The model can be applied to any classroom lesson, instructional grouping, laboratory exercise, or field trip.

1. *Invitation.* True learning begins with a question or problem in the mind of the learner. Teachers can invite students to learn by posing problems or by stimulating questions in the their minds. Instead of beginning a class with, "Today we're going to work on Chapter III," a teacher can bring a sample of pond water to class and pose the question, "What lives in this drop of pond water?" Or she can respond to the student who brought to school an empty eggshell he found in the park by stimulating a class inquiry into what once occupied the shell. It is important that the question be one that students are curious about. If it is not, further engagement will be difficult and not likely result in anything but rote learning. When well done, invitations quickly create a classroom of eager learners.

2. *Exploration, discovery, and creativity.* The next stage is investigating the question at hand. Here, the teacher must provide children with the materials they need to observe, to collect data, and finally to begin organizing information and thinking about experiments they might try. The teacher can pose questions that motivate children to link new findings with their previous knowledge.

Through cooperative learning, children learn to propose and accept alternative viewpoints, to listen and to question, and to persist in seeking satisfying explanations of their observations.

3. *Proposing explanations and solutions.* In this stage, teachers help children refine their understandings as they consider the alternative interpretations of their classmates. The teacher can guide children to design additional investigations, usually more focused than the first ones. Through cooperative learning, children learn to propose and accept alternative viewpoints, to listen and to question, and to persist in seeking satisfying explanations of their observations.

4. *Taking action.* In some situations, the new le nings children acquire are socially useful. If so, children can be encouraged to defend their viewpoints before the class or write a letter to a local authority taking a stand on a science-related public issue. In other

situations, new learnings suggest another form of taking action -- applying the new idea to new situations. If so, it is important for the teacher to design a lesson that expands on the new learnings.

Time and Money for Science

Since school boards have seldom provided adequate funds for hands-on science and teacher preparation, it falls to the federal government, business and industry, and parents and teachers to convince them that the investment is worth it.

For any science program, time is the most critical variable. Without adequate time, teachers cannot prepare hands-on lessons, nor can they properly teach them. More time spent on science does not, in itself, guarantee greater science learning. Even spending more time doing laboratory work will not, alone, produce the desired results. Children's minds, as well as their hands, must be fully engaged, and they must be able to see the connection between their activities and the larger patterns of science. Moreover, unless teachers have adequate training and readily available equipment and supplies, a laboratory lesson can fall flat.

Since school boards have seldom provided adequate funds for hands-on science and teacher preparation, it falls to the federal government, business and industry, and parents and teachers to convince them that the investment is worth it. Concise presentations of the evidence on how children best learn science, along with information about society's increasing need for scientifically and technologically literate citizens, would seem to be a good place to start in making the case for increased funding.

Most school boards will want to know how they can determine the educational value received for their greater investment. Chapter III discusses how school systems can organize the assessment of science learning in ways that support, rather than hinder, the efforts of teachers and students.

CHAPTER III

ASSESSMENT IN ELEMENTARY SCIENCE EDUCATION

INTRODUCTION

It is a truism, and a truth, that what gets tested gets taught. Acting on that widely held belief, policymakers have sought to improve student performance by periodic assessment, generally through broad-scale, standardized tests of student achievement.

This improvement policy, however, depends on the quality of the testing. It assumes that testing experts know how to measure the things that are most important for students to learn and that the tests they design do measure these things. It assumes that teachers will be spurred to teach these things, and students to learn them.

It is becoming increasingly clear, however, that the most common form of assessment -- paper-and-pencil, multiple-choice (or short-answer) tests administered to scores of children -- is the weakest link in the educational chain.

Assessment Today

Educational assessments are designed to yield information for particular purposes, but no form of assessment fulfills all the purposes of the various constituencies of public education. The most frequently used form, multiple-choice tests, are efficient to administer and score. Therefore, they can be given to thousands of students, allowing a variety of comparisons. But they are not particularly useful in helping teachers become more effective. And they do not convey to students the importance of science or its essence.

Assessment for policy purposes. Assessment has been most often used to monitor the outcomes of instruction, indicating the condition of education in the nation, a state, a district, or a school. With intensifying public pressure to improve educational results, states and local districts have invested heavily in mass testing programs for the purposes of monitoring and accountability.

Policymakers have used scores on standardized tests to highlight inequities between schools, districts, and states. These inequities gave political leaders a basis for mobilizing public willingness to remedy serious inequities in funding and services. Similarly, leaders have used the performance of American students -- embarrassingly bad compared to students elsewhere -- to motivate a greater public and private investment in American education.

Despite these accomplishments, assessment for the purposes of monitoring and accountability has not lived up to the expectations.

Current tests do not require students to think, to do, or to deeply understand; nor do they shed any light on the reasoning a student has applied to a test item.

Using test results to guide policy decisions has proved difficult because there is no clear-cut relationship between scores and resources; policymakers have found it easier to point out deficiencies than to remedy them. For example, in some states and localities, policymakers have linked teacher evaluation or pay to student performance on test scores, believing that the lure of higher salaries would motivate teachers to work harder and teach better. But the evidence thus far suggests that "high-stakes" testing mainly encourages teachers to drill students on the limited factual information and skills that standardized tests are best designed to measure. Although nearly everyone agrees it is important to test factual and vocabulary knowledge, few (other than the teachers themselves) anticipated that the link between teacher policies and student test scores would narrow teachers' efforts down to the content of multiple-choice tests.

As teachers have found it in their best interests to "teach to the tests," textbook publishers have found it profitable to produce textbooks designed to help teachers improve student performance on standardized tests. Current textbooks emphasize the factual information and simple problems that characterize tests and tend to discourage inquiry and experimentation. Thus an interlocking system of curriculum, textbooks, tests, and teacher and school evaluation systems appears to be driving instruction in the wrong direction by discouraging teachers from stretching their students beyond the tests' requirements.

The prevalent forms of testing pose problems for all curricular areas. The content and format of current tests tell students that the purpose of schooling is the memorization of a great many dry, elaborate, and unconnected details. But short-answer tests pose special problems for science because science is a way of thinking as well as a body of factual knowledge. It also involves doing. Science requires careful understanding of underlying principles, concepts, and theories; without that understanding, the details lose their meaning and are quickly forgotten. Current tests do not require students to think, to do, or to deeply understand; nor do they shed any light on the reasoning a student has applied to a test item.

Not only are the tests limited in the types of knowledge and skills they assess, they also often fail to correspond well to that part of the curriculum they do address. If they measure anything well, it is the students' general knowledge in science, not what students have learned during some period of instruction. Unfortunately, even the measures of students' general knowledge show that American students are not learning very much about science in school.

Teacher-controlled testing. Teachers often devise tests of their own, or use the problem sets and quizzes provided by the textbook, to find out what their students are learning. Ideally, these tests should provide teachers with better information than do standardized tests designed to be valid across many curricula. Yet there is evidence that teacher-made tests, or even teacher-controlled tests, are no better at probing critical and hard-to-test aspects of science knowledge than are conventional techniques used in large-scale tests.

Few teachers have been trained to develop the kind of exercises that probe student understanding, and few have the skill to interpret them or the time to administer them.

Regrettably, assessment that helps teachers teach better -- that gives them immediate feedback on student progress, tests a range of important skills and processes in science, and probes students' grasp of connections and patterns -- has generally been left to the ingenuity of individual teachers or entrusted to publishers of commercial textbooks. This largely ignored, but extremely important, branch of assessment is the primary focus of this chapter.

THE CASE FOR TESTING IN THE SERVICE OF LEARNING

Suppose there were a science assessment system that measured the full range of knowledge and skills required for science. Suppose this system were aligned with the sort of instruction that characterizes good science teaching, combined formal and informal assessment approaches (including performance on hands-on activities), and tested the students' ability to think through a problem as well as their ability to remember facts. Suppose each level of assessment, from first grade on, were carefully matched to children's level of physical and intellectual development -- neither too concrete nor too abstract at any given point.

We argue that such a system is a necessary, if not sufficient, condition for improving the teaching of science and for producing scientifically literate citizens. Since tests *do* drive instruction, teachers would need to change the way they teach science in order to prepare students for these richer and more varied forms of assessment.

A better assessment system would make it necessary for teachers to teach for understanding rather than for factual recall. It would become necessary to teach fewer things in depth, rather than many things superficially. It would also become necessary for school districts to provide students with the needed equipment and supplies, for without them, testing students' skills in laboratory work would not be possible. Since testing these skills would require teachers to administer assessment exercises individually or in small groups -- a time-consuming activity -- school districts would be compelled to provide teachers with the time and training needed to conduct such assessments. Since a full-bodied assessment program of this kind would represent all the aspects of learning critical to science, teaching to the tests would become a positive rather than a negative practice.

[W]e propose a change in emphasis: testing in the service of learning.

Thus we propose a change in emphasis: testing in the service of learning. Later in this chapter, we discuss the kinds of assessments that could be useful to policymakers, but that purpose we have subordinated to the urgent need to help teachers find out what students know and can do in elementary science.

An emphasis on assessment in the service of learning does not compete with other forms of assessment, but it differs from them. Assessing the status of individual learners involves techniques different from those that assess the performance of an institution.

ASSESSING WHAT MATTERS

Whether the long-term goal of science education is to make all students literate in science, or to lay the foundation for the science careers of only a few students, or both, the short-term goals encompass three major categories of outcomes: knowledge, skills, and attitudes (see Chapter II). The challenge to commercial test publishers, or to the states that develop their own tests, is to improve the quality of tests put in the hands of teachers so as to make instruction based on them worthwhile while avoiding certain negative effects of testing.

The informal and formal assessment techniques proposed here have to be used with care. For example, although the assessment techniques we suggest will encourage hands-on activities and laboratory experiments, these may run the danger of being reduced to a set of prescribed behaviors, leading to unreflective, cookbook activities. The right pedagogical moves can never be prescribed ahead of time; they depend on a host of particulars of the context and the learners.

Characteristics of Assessments of the Future

An assessment of science learning for any purpose is authentic only if it matches the curricular and learning goals we have outlined above. What would such assessments look like?

Of most use to teachers of elementary school children, especially those who teach primary grade children, are assessment techniques that are informal, focused, incremental, and closely tied to the particular material being taught. As children grow older and learn more, it is useful to balance informal approaches with assessments that are formal, systematic, infrequent, and based on broader curricular goals.

Techniques to help teachers teach better. Here are several informal techniques that should help teachers:

- ...ssments would match instruction, and assessment exercises would be indistinguishable from instructional tasks.

As children grow older and learn more, it is useful to balance informal approaches with assessments that are formal, systematic, infrequent, and based on broader curricular goals.

- Exercises would include hands-on performance tasks that allowed students to demonstrate their skills in laboratory techniques and in thinking.

- Assessments would probe the child's depth of understanding as well as his or her mastery of particular facts and terms.

- Assessme ts would reveal to the teacher whether the student used the right method to get a wrong answer, or vice-versa, and thus enable the teacher to address the student's mistake appropriately.

- Assessments would include an array of informal techniques, including systems by which teachers could record their observations of students, document student performance, and evaluate student learning over time.

States, coalitions of states, or the federal government need to invest in the development of appropriate exercises, performance tasks, and an array of informal means of assessment for use at the classroom level.

Techniques for assessing outcomes for policy purposes. The array of informal assessment techniques available to teachers should be complemented by an array of more structured exercises and examinations to evaluate student learning more formally and to help policymakers judge the effectiveness of the instruction. At this level, outcomes should be the primary focus; assessment should be indifferent to the curriculum (by allowing a choice of problems) and to the teaching methods. How one might coordinate informal, classroom-based and formal, systematic assessment techniques is illustrated in the report prepared by a British task force on assessment (Department of Education and Science and the Welsh Office, 1987). The use of mixed assessment techniques, accompanied by specific teacher training, is required as part of a serious effort to achieve the goals envisioned in this report.

Clearly no single test will be able to address knowledge, skills, and attitudes simultaneously, nor demonstrate whether the student has made the right inferences.

Criteria for Choosing Tests and Assessment Techniques

What kinds of assessment instruments should teachers look for? What kinds should school officials and policymakers look for? And what kinds of questions should they ask about tests?

Both informal and formal assessment techniques need to be part of an ongoing process that captures a wide range of student competence and knowledge over time. Clearly no single test will be able to address knowledge, skills, and attitudes simultaneously, nor demonstrate whether the student has made the right inferences. That is why we urge multiple assessments over time.

Improving informal assessments. Informal assessments are most useful to teachers, yet teachers find it hard to systematically and credibly manage the task of recording their observations of student activities and performance. School leaders need to help teachers improve their skills in this area, giving them logistical support and training on the pitfalls of informal assessment.

Teachers need to be alerted to the human tendency to notice the atypical and ignore the commonplace. Knowing that, they can be persuaded more easily to make their observations systematic, observing all students at regular times, for example, rather than when random events would prompt an observation. Teachers might carry around a packet of index cards and spend a few minutes now and then jotting down observations on what students do. Notations about an individual student's growth can be reviewed periodically. Teachers should be encouraged to become scientific observers of their students as the students learn to become scientific observers of nature.

The reliability of teacher observations also can be increased when the observations are replicated in different contexts employing different tasks. If a child can make a drawing illustrating an idea, talk or write about it, and set up a relevant experiment, the teacher can be quite confident that the child has assimilated the idea. And the child's work can be retained to produce a record of progress over time.

It is also important that teachers make explicit their criteria for assessing student performance and learning. Students, parents, principals, and colleagues should know the expectations for learning and the basis for assessing performance.

Improving formal assessments. The following questions are good ones to ask about science curriculum materials and tests:

1. Are there problems that require students to analyze situations; for example, does a particular statement make sense?

2. Does the test feature sets of problems that call for more than one step in arriving at the solution?

Students, parents, principals, and colleagues should know the expectations for learning and the basis for assessing performance.

3. Are there some problems with more than one correct solution?

4. Are there opportunities for students to use their own data and create their own problems?

5. Are students encouraged to use a variety of approaches to solve a problem?

6. Are there exercises that encourage students to first estimate the answer and then check the results?

7. Is the information in the problem accurate?

8. Are there exercises that assess students' skills in hands-on activities?

9. Are there some exercises that need to be carried out over time?

10. Are students occasionally asked to find errors in problems or critique the way a problem is set up?

11. Are students given the opportunity to make up their own problems or questions?

Until formal assessment programs with these characteristics are available, there are some practical things teachers can do. At the intermediate grade levels, teachers can use topics in end-of-chapter quizzes in the textbook as a starting point for assessing in some other mode. Multiple-choice questions can be converted into open-ended questions. Textbook questions can serve as the basis for essay questions, discussion, drawings, or other representations of ideas. Laboratory activities can be modified into performance tasks observed and graded for assessment purposes.

Making Good Use of Assessments

[S]tudents should be asked to communicate what they have learned; if they cannot communicate their science knowledge, they probably haven't gained much understanding.

Short-term assessments. Ongoing, informal assessments should be emphasized in elementary school, especially in the primary grades. Such assessments are important before, during, and after instructional units:

- Before instruction begins, teachers need to find out what students already know about the content and skills relevant to the unit to be taught so that they can frame the range of the students' understanding and plan the series of lessons intelligently.
- During instruction, teachers should continually observe students and ask them questions. By listening to young children's oral reports, and by reading the written reports of children in the intermediate grades, teachers can find out how students are progressing and adjust their teaching accordingly.
- After instruction, teachers need to use both informal and formal ways of finding out what students have learned. Whether teachers encourage class discussion or conduct structured tests, they need to emphasize additional applications of the new ideas students have learned to find out whether students have gained understanding or are simply regurgitating content in a rote fashion.

As children move into the upper elementary grades, teachers can expect students to become more proficient in written and oral communication and in laboratory activities. End-of-unit tests should not revert to exercises in rote recall. As an alternative, teachers can observe students' performance during hands-on activities and examine portfolios of the students' work during the unit of study. Whatever method of more formal assessment is used, students should be asked to communicate what they have learned; if they cannot communicate their science knowledge, they probably haven't gained much understanding.

Long-term assessments. Certain kinds of learning -- problem-solving skills and the development of laboratory skills -- occur in such small increments that short-term assessments do not register any discernible change in performance. Thus long-term assessments are needed both to monitor individual student development and to shed some light on program quality and the articulation of programs from grade to grade.

Some skills -- writing, for example -- cut across content areas. Monitoring the development of these general skills provides important information about the overall success of the school program. Data for this type of assessment can be amassed by keeping portfolios of student products across the curriculum. Students could be asked to write about each subject including science every month, to respond to teacher critiques by rewriting, and to add the finished pieces to their portfolios. In a spring conference with each student, teachers can compare their work at the beginning of the year with their work at the end of the year. The comparisons give students a good opportunity to learn how to judge their own performance and take pride in their growth.

[A]dequate measures of student achievement will require a national research effort.

The development of adequate measures of student achievement to guide teachers, and to inform local, state, and national educational policy, will require a national research effort. This effort will need to be supported by networks of other agencies and institutions to test out, refine, and disseminate a coherent set of assessment designs. Beyond that, states and districts will need to train teachers to use new assessment tools and encourage textbook publishers to improve the problems and exercises in textbooks.

Assessing Attitudes

Although there are now no technically credible methods to find out whether students apply scientific habits of mind to out-of-school situations, students' attitudes about science can be probed informally. There may be merit in asking students whether they like science and in monitoring differences in attitudes toward science among subgroups -- for example, males and females; whites, African-Americans, and Hispanics; poor and middle-class students. There may also be value in keeping record on how many students, and what kinds of students, go on to take optional science courses in high school. If informal surveys and course-taking data show that some groups of students do not take advanced science courses, school planners need to determine whether the students have been inadequately prepared, whether they believe that science careers are not pertinent to their lives, or both. Whatever the cause, the condition needs to be remedied.

Consequences of Good Assessment

The approaches to assessment we have outlined above would have several desirable consequences for science teaching and learning.

[T]he boundary between teaching and testing collapses when the student is expected to apply knowledge to the solution of problems.

First, the issue of teaching to the test will become moot; if the content is worthwhile, teaching to the test is worthwhile. Since only a small portion of our proposed assessment program involves rote memorization and recall, it largely resists manipulation through coaching or drilling. Moreover, many of the assessment exercises are designed to teach as well as test; the boundary between teaching and testing collapses when the student is expected to apply knowledge to the solution of problems. When teachers' assessment questions are well framed, and when teachers provide students with effective and immediate feedback, the very act of answering a question teaches the student to think and to harness knowledge and skill for both intellectual and practical purposes.

Second, the assessment system will not be tightly compartmentalized into subject areas. Though some of our proposed assessment techniques are labor intensive and time consuming, a good part of the extra time is paid back to all other disciplines, including not only mathematics (the most obviously related discipline) but also reading, writing, social studies, and history. When an assessment exercise calls for the use of mathematics to solve a science problem, students are learning to apply math. If a science assessment exercise requires students to write a paper explaining a scientific phenomenon (and if the teacher critiques the paper and encourages rewriting), students are learning to write. The "thinking skills" that have become such a concern of late are exercised when children are asked to think through a meaty assessment task.

Third, the very act of assessing science learning will communicate to elementary school children that science is at least as important as reading and mathematics.

Fourth, in a well-designed assessment program, the knowledge, skills, and attitudes being taught and assessed will be imbedded in rich content. When choosing the particular subject matter to teach, it is important to choose topics and exercises that bear some relationship to the broad concepts set forth in Chapter II. Although elementary school students are too young to understand these concepts in their abstract form, they can be provided with experiences that they can draw on in forming these concepts in the higher grades. Assessments should register student progress toward the understanding of these concepts.

Fifth, a good assessment design also will build on the new knowledge about how children learn science (see Chapter I): it is important to find out what children already know; children's prior conceptions can get in the way of their learning; students need time to construct their own knowledge; children learn more when they study fewer topics in greater depth; and students learn a great deal through interaction with other students.

A good part of the extra time is paid back to <u>all</u> other disciplines, including not only mathematics (the most obviously related discipline) but also reading, writing, social studies, and history.

Sixth, if taken seriously by states, school districts, schools, and teachers, the less-is-more principle means that curriculum writers in various localities will chose fewer topics from a wide variety of possibilities. Thus not all students will be studying the same topics. Some topics might be chosen because they are immediately important to children and their parents and communities. For example, such current and hotly debated issues as acid rain, oil spills, epidemics, or earthquakes can be vehicles to teach fundamental scientific concepts and skills. Other topics might be chosen because curriculum writers support a national consensus that certain learning outcomes are important whether or not they are currently relevant. As state or school district leaders develop banks of assessment exercises to support their curricula, they need to recognize that the particular topics students will be studying will vary as public issues emerge and as national scientific organizations change their formulations of what students should learn. Therefore assessment instruments too closely tied to particular examples may miss the mark.

In Britain as well as in the United States, assessment leaders have advocated a way to assess student progress in a manner that recognizes a legitimate variety in the choice of particular t‹ es: Students (or teachers) can be given a choice of assessment problems to solve. Giving students or teachers a choice of problems conveys that not everything has to be covered. Moreover, fewer problems to answer during a testing period permits an emphasis on depth -- problems with many parts that require time to understand and solve.

ASSESSING PROGRAM FEATURES

Several states, including California, Connecticut, Illinois, Massachusetts, Michigan, and New York, are trying to develop assessment exercises that will come closer than can paper-and-pencil tests to probing some of the important goals for science education in elementary school. But the full development of those exercises will be a long time coming.

Meanwhile, school leaders need to develop assessment techniques that will circumvent the tendency of current testing programs to narrow science teaching so that students will "look good" on limited outcome measures. An assessment of program features can at least determine whether a school district or school provides the conditions that permit good science instruction to take place: time and the opportunity to learn, facilities, materials, staff preparation, and expectations. The presence of these conditions does not guarantee effectiveness, but their absence certainly constrains teachers' abilities to be effective. Collecting and displaying information about these enabling conditions may be, in the short run, the best way to counterbalance the negative effects of limited outcome measures.

Time and the Opportunity to Learn

The assessment of two critical program features -- time and the opportunity to learn -- can be most useful to policymakers when the data permit an analysis of the experience of subgroups of students. Not only is it useful to gather data according to race, class, gender, and school; it is also important to find out how different subgroups of students experience the same programs in different class assignments within the same school.

[S]chool leaders need to develop assessment techniques that will circumvent the tendency of current testing programs to narrow science teaching so that students will "look good" on limited outcome measures.

Recent data from the International Association for the Evaluation of Educational Achievement's (IEA) Second International Mathematics Study demonstrate this point nicely. The study collected data about the types of classrooms 8th graders were enrolled in (remedial, typical, enriched, algebra) and the type of calculus classrooms 12th graders were enrolled in (calculus or pre-calculus). An analysis of the data suggested that the students enrolled in the "easier" class levels accounted for much of the low achievement of U.S. students compared to equivalent students in other nations. The study also collected information about opportunity-to-learn, finding that students in the easier class levels had much less exposure to the topics and skills tested than their peers in other countries and their peers in more rigorous courses in the United States. Thus one clue to the poor showing of U.S. students was that many of them simply hadn't been taught the material.

Time for science in elementary school need not come totally at the expense of other subjects.

Time for instruction and student activities is critical to science learning at the elementary level, yet the typical K-6 curriculum minimizes the time available for science. Time for science in elementary school need not come totally at the expense of other subjects. Reading, writing, and mathematics can be closely interwoven with science; social studies, art, and music can also, though less so. And science can provide topics for use in the other subjects. Thus, the matter of more time devoted to science is not, and should not be, a simple matter of taking time away from other subjects and giving it to science.

Curriculum Content and Materials

An assessment of program features should also collect data on the curriculum content, as embodied in the curricular framework, textbooks, hands-on exercises and laboratory materials, additional reading materials, audiovisual materials, and availability of computer hardware and software. Data collection must then be followed by an evaluation of the quality of these materials. Judgments about the quality of materials for elementary children might involve evaluation of the importance and accuracy of the science content, what teachers say about the usefulness of the materials in their teaching, and about children's interest in the materials, what the children themselves say about the materials, and what classroom observers report about their actual use.

School Structures

Assessing student access to science knowledge also involves measuring the following tangible program features: Do student assignment practices and the curriculum associated with ability groupings restrict the exposure of subgroups of students to science instruction? Are there science specialists available either to teach science or to help regular teachers teach more effectively? Are there after-school tutoring programs to help students who fall behind? Do schools provide science fairs, field trips, assemblies, museum programs, or other program enrichments? Are parents asked to involve themselves with their children's science projects and activities? Do teachers have opportunities to learn more about science teaching and science itself? Do school staff members believe that science is important for all students? Do teachers assign science homework?

[S]cience education in the elementary school is not likely to flourish unless the school district's leaders believe it is important.

A Systemwide Press for Science Achievement

Whatever the views of individual teachers and local faculties, science education in the elementary school is not likely to flourish unless the school district's leaders believe it is important. A school district's intentions can be assessed by the following features: Does the system organize opportunities for schoolwide and systemwide recognition of student achievement in science? Does the board and superintendent support, by word and deed, science in elementary schools? Do district hiring practices and staff development programs recognize the relationship between teachers' knowledge of science and their ability to teach it well? Does the school system permit or encourage nonacademic interruptions that interfere with science teaching? Does the school district purchase an adequate supply of kits, equipment, supplies, and materials and organize a system that makes them available to teachers when needed?

Professional Conditions for Science Teaching

Teacher satisfaction and the professional climate in the schools are related, even if indirectly, to teacher effectiveness in science teaching. An assessment of program features should therefore include a review of program ingredients that contribute to teacher satisfaction: teacher salary levels compared with those of nearby districts; teachers' class size and pupil load; the adequacy of clerical support for noninstructional tasks; time for school-based, collegial goal setting, program planning, curriculum development, and staff development; a voice for teachers in schoolwide decisions; and the principals' commitment to, and support for, science teaching and professional experimentation.

These conditions are only proxies for good science instruction, but the collection, analysis, and dissemination of data about these program features will at least tell policymakers if their policies and budgets help or hinder science programs.

ASSESSMENT FOR MONITORING AND ACCOUNTABILITY

State and local educational officials will continue to seek information about whether students have made progress over time, whether state and district policies and resources have made a positive difference, and whether some of the children they are accountable to are achieving better than others. They also will want to compare the achievement of their own students to those in other states and nations. For these reasons, testing for the purposes of monitoring and accountability appears to be a permanent fixture in American education.

The weakness of the current tests and their inability to measure student understandings and skills essential to science underscore the need to improve broad-scale testing programs so that they will support and guide excellence in science teaching and learning. We therefore advocate the following:

- The development of externally mandated assessments that conform closely to the characteristics of good science curricula and instruction, as set forth in this report, including the requirement that students interact with objects and apparatus as well as with paper and pencils; attention to student understandings of concepts as well as to their factual knowledge; and the evaluation of individual and group approaches to the solution of problems as well as evaluation of their answers.

- A coordinated national effort to align assessments conducted at different levels for different purposes so that national and state assessments encourage better science teaching at the local level and local assessments inform state and national policies.

- More attention to careful and informative analysis of assessment results and to the manner of reporting and disseminating the results. A simplistic ranking of schools, or of students, especially when accompanied by rewards or sanctions, may quickly erode the validity of the assessment as teachers try to improve scores without improving the student understandings that the scores were intended to represent.

Surmounting the present limitations of accountability testing is an urgent and attainable goal. Properly constructed and used, a coordinated assessment program designed to test the full range of desired learning outcomes has the potential to improve teaching; to teach children even as they are being tested; and to inform the decisions of those who design curriculum, manage school systems, and are accountable to the public for the effectiveness of educational programs.

CHAPTER IV

TEACHER DEVELOPMENT AND SUPPORT

INTRODUCTION

The Center's proposed reforms in teacher education, staff development, and organizational support are the most radical and far-reaching component of its design for elementary science education, but they are essential. The plan set forth in this chapter requires nothing short of a fundamental change in the content and pedagogy of science education for undergraduate students preparing to be elementary teachers and in the professional development and support of current teachers.

Before any of these proposed changes can occur, the rhetoric of cooperation between science faculties and educational school faculties will have to become a reality. The long-lamented obstacles to better coordination between the colleges and the schools will need to be removed. The plan set forth here requires change -- from the classroom to the federal government -- in the policies and practices that now inhibit good science teaching.

Although the changes proposed here have long been proposed by others, the institutions involved have thus far resisted them. But in our view, major shifts in institutional norms and boundaries are required if policymakers and educators at all levels are seriously interested in creating a scientifically literate population in the next generation. Our case for significant changes in teacher development begins with what is known about elementary school teachers' knowledge of science and how they currently teach science.

WHAT TEACHERS KNOW ABOUT SCIENCE

Surveys conducted by the National Science Teachers Association show that only 31 percent of K-3 teachers and 42 percent of 4-6 teachers have taken its recommended series of beginning courses in biology, physics, and earth science. Fewer than half the states require elementary teachers to take a course in the methods of teaching science. A 1985-1986 survey showed that 82 percent of elementary teachers felt qualified to teach reading, but only 27 percent felt qualified to teach either physical or earth/space science.

Although teachers report that they use inquiry-based methods and stress higher-order thinking and concept development, researchers who observe teachers repeatedly find that they stress factual learning. Studies of both preservice and inservice elementary teachers show that teachers' knowledge of science resides exclusively in memorized names and technical terms, and because they lack an operational understanding of these names and terms, they are unable to reason with them in specific instances. Many teachers lack sufficient understanding of science to distinguish between memorization of facts and the concepts and reasoning processes that make science intelligible, interesting, and usable.

Some states have responded to this discouraging state of affairs by simply requiring teachers to take more science and science methods courses. We believe, however, that such a policy will fail unless colleges and universities fundamentally change their approach to the education of prospective teachers.

Most current lower-division college science courses assume that an overall survey of a discipline is the best way to prepare students for further and deeper study in that discipline or is best if the students will take only one or two courses. Yet the evidence on science learning shows that learners are buried in an avalanche of difficult and unfamiliar terms and facts when too many topics are "covered" in the typical college (and school) course. The underlying principles and explanatory theories get lost in a blizzard of details.

The less-is-more principle set forth in Chapter I applies as powerfully to college students planning to be teachers as it does to the students they will eventually teach. College courses need to be redesigned so that prospective teachers acquire an understanding of basic scientific concepts. That understanding needs to be firm enough to permit teachers to apply those concepts across the topics and scientific disciplines typically taught in public schools.

But a deep understanding of content is not enough. Teachers also need a rich and flexible understanding of a teaching model appropriate to young children. Teachers cannot become masters of the four-stage teaching model sketched in Chapter II by sitting in a college lecture hall; rather, achieving this requires repeated exposure to both theory and practice.

HOW TODAY'S TEACHERS ARE TAUGHT SCIENCE AND PEDAGOGY

Teacher development is currently compartmentalized, occurring in discrete phases and different locations:

- The first phase usually involves liberal arts coursework in academic departments.
- The second phase usually involves professional coursework in schools or colleges of education.
- The third phase usually involves inservice education planned by administrators in local school districts.

Rarely is there coherence or continuity across these phases, nor is there much meaningful contact among the parties involved. There is usually a sharp separation between the acquisition of subject matter knowledge and its application to teaching in education courses.

At the end of their preservice preparation, which is usually tantamount to state certification, newly hired teachers are assumed to be ready to take full responsibility for a class -- often, a class so difficult to teach that experienced teachers have been able to escape it through seniority.

Once on the job, teachers' opportunities to continue learning usually consist of personal decisions to take advantage of a smorgasbord of inservice workshops or courses, which are either short term and practical or long term and theoretical. Teachers are seldom engaged in a coherent, long-term, development effort.

HOW SCIENCE AND PEDAGOGY SHOULD BE TAUGHT TO TEACHERS

Over the last few years, many states, universities, and local school districts have tried to address these well-recognized deficiencies in teacher preparation and development. Although we support some of these efforts, others seem to fall short of the goal of improving science education in elementary schools. Our vision of excellent education for teachers of elementary science has the following characteristics:

1. Teacher development is organized so that its components -- scientific knowledge, professional knowledge, experiences with children, and the assumption of full responsibility for students -- are more gradually and continuously interwoven.

2. The theory of learning applied to the education of teachers in training parallels the theory of learning they will apply to the education of their future students. Adult beginners in science experience the natural world directly, and they assimilate knowledge in collaboration with others engaged in the same quest. After being exposed to knowledge about stages of development in children's language and thinking, and to the art and craft of science teaching as practiced by master teachers, teachers in training have opportunities to absorb and appropriate that knowledge through repeated cycles of theory and practice. Learning through experience is good for both the mastery of scientific content and the mastery of good science pedagogy.

Learning through experience is good for both the mastery of scientific content and the mastery of good science pedagogy.

3. Campus instruction, field instruction, and inservice education overlap. As prospective teachers progress through their training, they spend less time on campus and more time with children in schools. As they gradually assume teaching responsibilities, teachers are more and more under the tutelage of expert elementary science teachers and less under that of university faculty; this transition is gradual rather than abrupt.

4. University faculties, school districts, state certification agencies, and teacher unions develop a consensus and collaborate because all parties recognize that productive change in one part of the system almost certainly rests on simultaneous changes in another part of the system.

5. Teachers exemplify the ideal of continuous learning by seeking out opportunities to learn more about science and science teaching. The school district creates inservice opportunities that teachers relish, rather than disparage, and children find value and pleasure in learning because their teachers demonstrate a love of learning.

THE EARLY PHASE OF TEACHER DEVELOPMENT

Given what elementary school teachers need to know and be able to do, the first phase of teacher development should include (1) a major in an academic discipline rather than in education, (2) the study of one or more of the sciences in courses where teachers experience science as science rather than as an exercise in memorization, and (3) coursework in child learning and development that involves theory and experience and that includes the study of cultural and community influences on teaching and learning.

Prospective elementary teachers need to major in an academic discipline, rather than in education, which typically includes one or two courses from a large number of disciplines. Majoring in one discipline gives prospective teachers depth of understanding, so they know what a body of knowledge is -- a requirement if they are to represent bodies of knowledge to their students and encourage their students' pursuit of in-depth study.

All prospective elementary teachers, whatever their college major, need to know enough science to teach it well. The National Science Teachers Association recommends one course each in life, physical, and earth science. Others recommend at least two courses in one science, with exposure to other sciences as well. Although we support the idea that elementary school teachers should study several branches of science, far more critical is how those sciences are taught.

Prospective elementary teachers need to major in an academic discipline.

Courses designed for students intending to become scientists usually deal with the facts and principles of sciences but seldom with the history and philosophy of science or the nature of scientific thinking. Because public school teachers will come into contact with parents and other laymen who fear science, or who believe it is hostile to their religious or personal values, students who intend to become public school teachers also need to answer questions such as: What is unique about scientific knowledge? Which aspects of scientific thinking are like "common sense" thinking? Which are not? What kinds of questions can science answer? What kinds cannot be answered by science? Redesigned science courses for teachers should:

- Teach science in the way it is practiced, which means that students pursue real questions about the natural world and incorporate investigative methods with knowledge of the important facts and concepts of the discipline

- Relate one branch of science to the others

- Ground the students in the philosophical assumptions of modern science and provide historical context

• Help students relate scientific content to social and economic issues

A course with these features would spend more time on fewer concepts than current courses do. The instructor would back off, slow down, and give students a chance to follow and absorb the development of fewer major scientific ideas. The development of such courses requires collaboration among professors of different scientific disciplines and between science professors and professors of history and philosophy. In the research universities, where professors are rewarded only for research and publications, the needed interdisciplinary cooperation will probably require professors to make some small sacrifices -- unless those concerned with tenure criteria are willing to depart from standard practices.

We are *not* calling for a course called "Science for Nonscience Majors" or "Science for Elementary Teachers." If prospective teachers are isolated in special, watered-down courses, they are deprived of both the content and the high-level discourse that science majors can stimulate in class. Prospective elementary teachers (as well as prospective scientists) benefit from science courses that involve experience and exploration as well as reading.

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For teachers of young children, the early phase of teacher development also requires the study of child development and the school context. Teachers are usually unaware of the concepts about the natural world that children have formed for themselves or even that children have such concepts. A well-designed course in child learning helps prospective teachers learn to structure and interpret their observations of children's conceptions and to probe children's ideas skillfully.

The importance of the research on children's prior conceptions is *not* merely that children come to school with some "wrong" beliefs about the physical world: that has long been known. Rather, it is that good teaching requires teachers to know what children do not know, or incorrectly know, which is far more difficult than it seems. Much knowledge and skill are required to find out what is in the children's minds and to help them replace seemingly reasonable ideas about the world with the canonical ideas of science.

Study of the social organization of schools, as well as the influence of culture, social class, income, values, and politics on schools, helps teachers understand more about what makes students and schools tick. The country's changing demographics -- where cultures, first languages, and everyday experiences of children in America's schools are rapidly becoming less like those of their teachers -- make it even more important that prospective teachers have opportunities such as these. With these understandings, teachers can better distinguish between helpful and harmful school structures and attitudes and are thus in a better position to reform unsupportive learning environments when they find them.

Learning about child development and school organization must be grounded in both theory and experience. When students merely study theory in class, they do not learn how to recognize manifestations of the theory. Merely observing children in their school and home environment is not enough either although that is what prospective teachers are often sent out to do. Observations of children take on meaning only when they are structured by a sound intellectual framework and when the learners are helped to interpret what is happening and why.

THE MIDDLE PHASE OF TEACHER DEVELOPMENT

In this phase, prospective teachers move from studying about science and children to learning how to foster children's academic growth in the classroom and school through practice teaching or internship. As they move towards teaching, prospective teachers must:

- Develop a repertoire of teaching techniques, including those that specifically apply to children's growth in the understanding of science

- Practice those techniques in various teaching situations with guidance

- Acquire a knowledge of science teaching and materials

- Assume classroom responsibilities under supervision (student teaching or internship)

- Receive continuing feedback from experienced classroom teachers and science specialists

Giving prospective teachers lectures on "teaching strategies that work" has not proved to be a very effective method. Effective training also requires beginners to observe, practice, and master both subject-specific and general teaching techniques. Some techniques can be applied across disciplines, cooperative learning, for example, can be used to teach science, language, or history

But teaching techniques, however useful, are only vehicles for teaching particular content to particular children at various ages and stages of development. Unless instructors are as versed in content as they are in technique, and unless the examples they use to illustrate techniques are appropriate to both content and developmental level, the training will not be very effective.

After prospective teachers have been exposed to a repertoire of techniques, and understand the theory and rationale for each, they need to practice the technique on others (videotapes are especially helpful) and receive feedback from them. Then they need to do as much in a classroom with one child or a small group of children, with coaching from an experienced practitioner. Because the key to good teaching is making appropriate decisions on when and how to use each technique, prospective teachers need a lot of time to discuss with experienced observers the use of various techniques in particular situations.

Good science teaching, however, requires more than a mastery of techniques. Teachers need to be able to answer the questions, "What science should teach?" and "How should I sequence my instruction?" Well-conceived lessons are much more than a set of fun experiences of science content. If children are to accumulate the experiences that eventually 'ead them to understand the underlying concepts set forth in Chapter II, teachers need to learn how to organize specific content in reference to those long-term, conceptual goals.

Frospective teachers best learn to make connections between particular lessons and ' arning outcomes by seeing, using, and adapting lessons and activities from various sources -- textbooks, science kits, and some of the more up-to-date programs developed with federal or district support. Finally, they need to learn about, and in 'ome cases develop and use, assessment techniques that test a variety of science outcomes in a variety of ways.

With the growing number of at-risk children in today's schools, elementary school teachers are faced with difficult questions about classroom priorities. During the middle phase of their development, when teachers are not yet burdened with the anxiety of full responsibility, teachers can more thoughtfully answer these questions: Is science a priority when the kids don't know how to read and compute? How can I teach hands-on science when I can't keep the class under control? What science content is most relevant to these children's lives? Why should I teach science when I am evaluated only on my ability to teach reading and math?

Much of the mind-numbing drill imposed on at-risk children today has no apparent purpose.

Prospective teachers preparing to teach at-risk students should learn that the kind of science teaching described in this report is good for *all* children. All children have a low tolerance for uninteresting activities that they see no purpose for. Much of the mind-numbing drill imposed on at-risk children today falls into that category. But science, properly taught, is perhaps the subject with the most intrinsic appeal to children because it involves things they can see, manipulate, and change; it allows them to explore, investigate, and test.

All children, but especially children at risk, are more likely to become engaged with school science if teachers plan learning experiences that pay attention to:

- Content that draws on the students' immediate environment and thus relates to their daily lives outside school
- Content that makes it clear to students, through biography and history, that science is not the exclusive province of white males
- Content that uses out-of-school resources, such as museums, zoos, gardens, and hospitals, to expand students experiences
- Cooperative learning, which is not only good science pedagogy for all science students but may also significantly affect the achievement levels and social skills of poor and minority children

- Instruction based on experience and inquiry, which fosters a student's cognitive growth, confidence in his or her ability to learn, and a sense of control over his or her fate -- issues for every child, but especially for the vulnerable child

Unless teachers in training have direct contact with outstanding teachers of elementary science, they are unlikely to teach science well, or at all, when they assume full classroom responsibilities.

- Instruction informed by the knowledge that children from various cultures view the natural world differently and approach learning variously

Prospective teachers also need exposure to and experience with the potential of new electronic learning technologies. Projects across the country (and across the world) are developing ways for microcomputers, videodiscs, and other tools to expand student learning. These tools can create microworlds where students can manipulate variables more quickly and accurately than otherwise possible. They permit an individualization unheard of today, and they motivate even the most recalcitrant youngsters to learn. Opportunities to work with these technological innovations, and to determine how they can enhance the learning of the concepts, skills, and attitudes discussed in Chapter II, are important features of the preparation of teachers in the middle phase.

Student teachers or interns should have the opportunity to observe and work with teachers who teach science well and are committed to it. This ideal differs sharply from current practice, which emphasizes mimicry of a particular teacher who wants to supervise a prospective teacher but who may not exemplify a range of desirable practices. Unless teachers in training have this direct contact with outstanding teachers of elementary science, they are unlikely to teach science well, or at all, when they assume full classroom responsibilities.

The continuum of teacher development now moves to a critical place -- the teacher's first year. The first year of teaching is very stressful, and because it is, far too many well-educated, enthusiastic, and potentially great teachers leave teaching prematurely. Policymakers and administrators have begun to recognize the folly of the "sink or swim" approach to first year teachers, especially when they face nearly certain shortages of well-qualified teachers. Twenty-two states now have special programs for beginning teachers, and other states and local school districts are developing them. The best of these programs have well-chosen, well-trained mentor teachers who are good at teaching both children and adults. Budgets and schedules allow mentors and beginning teachers to observe one another and share their observations. Beginning teachers are given relatively easy assignments rather than difficult ones.

Policymakers and administrators have begun to recognize the folly of the "sink or swim" approach to first year teachers, especially when they face nearly certain shortages of well-qualified teachers.

Good induction programs help beginning teachers become comfortable with inquiry-based teaching methods, guide their choice of curriculum and materials, develop their skill in the use of hardware and software, and help them establish workable routines so that the burdens of teaching are bearable. They also reinforce the norm of continuous learning so that teachers, from the start, seek ways to grow in science knowledge and teaching skill.

THE LAST PHASE OF TEACHER DEVELOPMENT

Few of today's teachers have had the kind of preparation just described. They vary widely in their preparation to teach science, their comfort with teaching it, and their commitment to continuous learning. The varied nature of the present teacher population calls for an equally varied approach to the development of teachers in service.

Much of what we have already recommended for preservice and beginning teachers we also recommend for inservice teachers. Current teachers need more knowledge of the primary concepts and principles of the scientific disciplines, an understanding of their own and their children's conceptions of science, and a repertoire of techniques to help children understand science. This scientific and pedagogical knowledge should be the content of good staff development for elementary teachers.

Staff Development Approaches

Typically, teachers renew or fill gaps in their knowledge through brief, inservice workshops or in highly theoretical university coursework. Either way, teachers are unlikely to change their practices because the training is either too superficial or too removed from classroom realities to have a lasting effect.

Even the NSF-sponsored institutes of a decade or two ago, which were long and intense and combined theory with practice, often failed to produce meaningful change because the institutes removed teachers from their home context. When solitary teachers returned to their districts, they had little administrative support for trying out new approaches and no support from peers who had experienced the same training.

Over the past decade, researchers have learned a great deal about what kinds of staff development do produce lasting changes in teachers' practices. Effective approaches allow for intensive study and engagement with new knowledge and skills over time, with time to practice and work out problems of implementation.

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The didactic approach to teacher training seems to dominate current approaches to staff development, yet this approach is often done poorly. When done well, didactic training (which is only one of several effective approaches) includes:

- Exposition of the theory and rationale behind new teaching approaches to be learned
- An opportunity for teachers to see experts demonstrate a new approach
- An opportunity for teachers to practice the approach with other adults in the training setting

- An opportunity for teachers to practice the approach in their classrooms with children and to be observed and given feedback by either trained administrators or peers.

Another approach to staff development puts more emphasis on observation and assessment. The key components of good science teaching can be described, and these descriptors can be used by a trained principal, peer, or science specialist to observe teachers and then work with them, individually or collectively, to remove barriers to and provide support for good science teaching.

The entire weight of the institution works against change.

Another approach is to ask teachers to develop curriculum. As teachers gather information and materials, and review research about effective science teaching and learning, they enhance their knowledge of appropriate science content and learn to design and test coherent programs. In doing so, they develop their own knowledge and skills for good science teaching.

Capturing the Benefits of Inservice Training

The changes in science teaching brought about by even good training programs are fragile, although they are less fragile than the usual short-term, hit-and-run workshops. The teaching act is highly complex, and science is only one of the many responsibilities an elementary school teacher must juggle. Moreover, the entire weight of the institution works against change. If teachers perform new techniques awkwardly at first, and are discouraged on that account, they tend to revert to teaching the way they were taught -- telling, assigning, and testing.

Even exemplary staff development programs work only when the school district advocates better practices, permits teachers to refine those practices, and allows teachers to work together to reinforce new behaviors, solve problems, and continue their professional growth. Good structures convey that the smooth acquisition of unfamiliar and effective teaching techniques is important and that teachers are expected to learn and use them.

Institutes similar in design to the NSF-sponsored institutes permit an intense, in-depth experience that allows teachers to experience science the way scientists do. By drawing several teachers from one school (and if the principal can attend, so much the better), who can then reinforce one another when they return to their school, the problem of the lone teacher returning to an unsympathetic school is alleviated.

Teacher centers, sometimes in the school and sometimes within the district, provide close-to-home support for teachers' use of new practices. Centers can use a number of staff development models: convening and supporting groups, finding and assembling materials, bringing in expert consultants or trainers, coaching in classrooms, and generally providing the kind of ongoing support that keeps an inservice effort from fading away.

ORGANIZATIONAL STRUCTURES AND SUPPORTS

Even the best educated teachers can be thwarted in their attempts to teach science if the school or school system fails to support them. Just as few teachers know science or feel comfortable teaching it, few principals feel comfortable providing leadership and support for science teaching. Moreover, the recent emphasis on reading and math test scores has led to the neglect of science (as well as social studies). And teachers rarely have the materials they need to teach hands-on science. Few states or school system coordinate science goals with materials, staff development, student testing, and program monitoring. Clearly, the current organizational context fails to support excellence in science teaching.

The body of research on science teaching and educational change suggests that successful science programs require five ingredients:

1. *Clear purposes, outcome measures, and program designs.* The states are in an excellent position to coordinate all the elements of a program: curriculum, instruction, assessment, teacher certification standards, and criteria for the selection of teaching materials. Increasingly, states are exercising their power to harmonize these elements.

2. *Adequate, appropriate resources.* Districts then need to make state-defined programs operational by enabling people at various levels to come together on an agenda for science education. The agenda should include the scope and sequence of the science curriculum, with topics and units of instruction for each grade level; a coherent staff development program for teachers and administrators; a systematic way to provide teachers with the basic facilities, equipment, supplies, and reading materials; and an assessment program that not only promotes good classroom decisions but also tracks outcomes districtwide.

Clearly, the current organizational context fails to support excellence in science teaching.

Teacher assignment policies should also be part of the discussion on resources. Since the opportunity to learn science depends, in part, on teachers who are knowledgeable, enthusiastic, and committed to science teaching, the question of whether to employ science specialists needs careful consideration. Where one teacher on the staff is very knowledgeable about science and inquiry methods, it is probably wise to use that teacher as a specialist who teaches science across the grades. In that case, though, it would be important to structure classes so that the science teacher has time to observe the children in other subjects and to plan closely with other teachers. If common planning time cannot be arranged, teachers know some science, and an inservice training program can be mounted, the best solution may be to have everyone teach science.

3. *A coordinated, coherent, sustained staff development program.* A district that cares about science learning will help teachers develop and refresh their knowledge and skills by offering a staff

development program directly related to the district's science program. The program should include in-classroom coaching and follow-up sessions that promote reflection and collegiality.

4. *Teacher voice in school decisions.* Teachers who help make decisions are more willing to implement them, and the decisions are nearly always better when informed by teachers' knowledge of students, classrooms, and programs. Though states or districts are responsible for setting overall goals and developing curricular frameworks, teachers can best guide decisions about what topics, activities, and materials are most appropriate for children at different grade levels and where science can best be integrated with other subjects.

With strong organizational support, teachers can and do teach the kind of science needed to increase the scientific literacy of future citizens.

5. *Strong and clear leadership.* Research on successful implementation confirms that leaders need to provide clear direction. Program success may depend on school and district administrators maintaining pressure on teachers to give new practices a fair trail, but only if they also provide the assistance and support needed to make them work.

   School and district leaders have the authority to create and retire priorities. When science is a priority, leaders provide release time for teachers to prepare for teaching, plan with other teachers, and attend training sessions. Good leaders announce, and continue to announce, that science is important in elementary school and that children need the opportunity to learn it. With strong organizational support, teachers can and do teach the kind of science needed to increase the scientific literacy of future citizens.

CHAPTER V

RECOMMENDATIONS

The recommendations that follow are intended to reconcile an urgent, national need with the reality of a cherished tradition of local control over education. They are a mosaic of short-term and long-term efforts, of small special-purpose projects and large coordinating projects, of basic research and direct action. Each recommendation is addressed to the governmental or educational level best equipped to carry it out. More specific recommendations for science education specialists, administrators, teachers, and parents will be forthcoming in a series of implementation guides based on the Center's work.

Our recommendations involve changes in:

The separate efforts of states are not likely to be efficiently coordinated unless the federal government asserts leadership.

- The organization and direction of the Federal government's efforts in science education
- Policies of states, school districts, and colleges and universities affecting teachers
- The what and the how of elementary school science education
- The way in which states, testing companies, and school districts assess student learning in science
- The deployment of time and resources at the local level

Although the Federal government's role in the strategy proposed here is small, its purposeful involvement is still crucial. Research questions that cry out for answers are not likely to be addressed unless the Federal government defines the task and provides the funds, nor are the separate efforts of states likely to be efficiently coordinated unless the Federal government asserts leadership. The Federal government is best positioned to convene all the relevant groups and urge them to define policies at each level that will work in harmony.

RECOMMENDATIONS TO THE FEDERAL GOVERNMENT

1. Relevant federal agencies should support research designed to identify the science knowledge, skills, and attitudes students will need in the job market of the future.

Although most experts predict that there will be an increasing number of jobs in the future requiring more scientific and technical knowledge, not enough is known about the particular kinds of knowledge that are needed today and that will be needed in the future. Before the effectiveness of science education programs can be assessed what children need to know must be clear. Without the development of a shared set of expectations, curriculum will continue to be fragmented and trivial, and assessment will continue to address the lowest common denominator.

2. Relevant federal agencies, or a coalition of state education agencies, should develop assessment exercises and techniques designed to probe the range of understandings, competencies, and attitudes that make up the goals of elementary science education.

In an ideal world, the development of assessment tools would await the results of research programs on what science knowledge is most needed. But the need is too great to await those results. Basic research and the development of assessment tools should be supported concurrently so that they can inform each other. The Federal government should also establish a center or network of science assessment centers. There is a need for ways to document student performance and thinking not now captured by written work or test scores. The federally established centers would collect promising examples of innovative assessment techniques, evaluate their quality and feasibility, and make them available to agencies designing large-scale assessment and to intermediaries who help teachers devise improved, teacher-controlled, assessment tools.

3. The Federal government, in concert with a coalition of science educators and administrators, should support programs for training science education leaders, as well as research on the impact of the current trend toward site-based management of science instruction.

Science leaders should be trained to plan comprehensive science programs, evaluate good science teaching, mount staff development programs that have lasting effects, and skillfully lead teams that include teachers, trainers, and administrators. Also, with the new emphasis on allowing the school, rather than the district, to make educational decisions, a study should be launched now to determine the impact of these new structures on how science is taught in elementary schools.

4. The National Science Foundation and the U.S. Department of Education should create a study panel that will spend no more than 18 months developing a plan to enhance existing dissemination systems, and then implement a system to provide effective services to teachers and local school district administrators to improve science curriculum, assessment, and staff development.

Dissemination and implementation are more costly than research and development. Funds are available through Title II of the Education for Economic Security Act precisely for the implementation of better science programs. These funds should be focused on a coherent dissemination and implementation strategy. Enough is already known about the techniques of effective dissemination and implementation to eliminate the need for further research on how to do it. Lacking is the commitment to, and funding for, the critical task of disseminating and implementing the fruits of the research advocated earlier.

5. The National Science Foundation, in concert with a coalition of science education organizations, should mount a small study project on the quality of problems and exercises included in science textbooks and related teaching materials.

The results of the study would form the basis for a conference of commercial textbook publishers and state education chiefs designed to lead publishers to incorporate better-quality science problems, exercises, and test items in science textbooks and teaching materials

RECOMMENDATIONS TO THE STATES AND LOCAL DISTRICTS

6. States, in collaboration with school districts, should promote and develop comprehensive, coordinated structures at the district or state level to support good science teaching.

These structures should have at least the following elements: (1) common and clear goals and programs for elementary school science; (2) links to teacher certification, employment, and evaluation; (3) teams representing different levels and groups whose members play critical roles in planning and implementing curriculum, instruction, and staff development; (4) comprehensive staff development for teachers; (5) leadership development for those responsible for the support of good science education; and (6) systems to provide teachers with equipment in good repair and the prompt delivery of adequate supplies and materials for science teaching.

Because few such comprehensive structures exist in school districts, models should be established that are known to promote good science teaching. Federal and state agencies, or private foundations, should fund the development and demonstration of such school district structures for at least five years in order to give the models a fair trial. To be useful to other school districts, case studies should be conducted to capture the model development and implementation and provide evidence of effectiveness. Successful structures should then be described in a way that promotes their dissemination and use by other districts.

7. State and regional agencies, in collaboration with districts, schools, and universities, should support experimentation with varying forms of staff development.

Emphasis should be on staff development models that enhance or replace training workshops as the typical mode of staff development.

Instructional techniques should capitalize on children's natural curiosity, but within the organizing principles of a curricular framework, and permit children to develop their growing understanding of concepts in science and technology.

8. State agencies should support university and school district efforts to develop elementary schools that simultaneously demonstrate good science teaching and serve as professional development schools for both novice and experienced teachers to improve their science teaching skills.

Funding for these laboratory schools should be provided for at least five years, and each project should be described and evaluated so that others can benefit from the demonstration.

9. State and local educational agencies should endorse, and make it possible for teachers to implement, those instructional techniques known to promote science learning.

These techniques include recognizing the importance of children's prior knowledge and their need to reconstruct and refine their knowledge of the world through active, hands-on study. Instructional techniques should capitalize on children's natural curiosity, but within the organizing principles of a curricular framework, and permit children to develop their growing understanding of concepts in science and technology. Rather than merely reading about science, children need to learn by doing and by collaborating with other students and the teacher to find solutions to questions that have personal meaning to them.

10. State and local agencies should adopt a curriculum for elementary science and technology informed by major organizing concepts.

We suggest the adoption of the concepts recommended by the Center. Whatever organizing principles are chosen should meet the following criteria:

- They should apply to both science and technology.
- They should have application beyond science and technology.
- They should be teachable, in some appropriate form, to children of all ages.
- They should be powerful, explanatory concepts.

When there are clear indications from states and localities about the substance of the curricula and instructional techniques to implement them, textbook publishers will perceive a market large enough to justify the development of kits, readings, and laboratory materials that support the curricula.

RECOMMENDATION TO ACADEMIC DEPARTMENTS IN COLLEGES AND UNIVERSITIES

11. Academic departments in colleges and universities must create the necessary rewards and incentives for excellence in undergraduate curriculum and teaching so that prospective elementary teachers are equipped to teach science with understanding.

Significant improvements in the nature and quality of lower division science courses are not likely to occur until the criteria for tenure and promotion are revised to recognize good teaching or until more departmental funds are diverted from research to the development of excellent, hands-on science courses for prospective teachers.

RECOMMENDATION TO EDUCATIONAL POLICY BODIES

12. Concurrently and reciprocally with state efforts to develop model structures, national policy bodies in education and science education should establish a broadly based group to identify state and local laws, policies, and procedures that inhibit good science teaching and recommend changes that will facilitate it.

Specifically, the group needs to study state statutes, state education agency mandates and programs, district mandates and programs, school procedures, the role of the principal, university tenure criteria, teacher certification requirements, and policies and procedures affecting the selection of textbooks and other learning materials.

This group should consider how to implement the Center's recommendations in one or more small-scale pilot projects (for example, in several districts of a single state), focusing specifically on needed changes in policies and procedures. Implementation strategies should be thoroughly documented and disseminated to assist others in making policy changes for better science education in the elementary grades.

RECOMMENDATION FOR A NATIONAL ASSISTANCE CENTER FOR SCIENCE EDUCATION

The special-purpose research projects, demonstrations, and collaborative efforts recommended above are essential to progress. Nevertheless, these efforts must influence one another and ultimately be harmonized into a whole. The magnitude of the task for improving science education calls for unique dissemination system. The goal of such a system would ultimately be to provide good science instruction to all American children. To achieve this goal, federal and state agencies need a mechanism for reaching national academic organizations institutions that educate and train teachers, school districts, teacher unions, and classroom teachers.

13. A consortium of agencies, institutions, and organizations concerned with science education should create a National Assistance Center for Science Education that will put in the hands of agencies serving teachers, science educators, and policymakers the very best that is known about effective science education.

The National Assistance Center for Science Education would:

- Package information and materials, recommendations, and models that flow from research centers and special groups created to address the need for better science education. It could build on the National Science Resources Center and draw from such national efforts as Project 2061, the exemplary programs identified by the National Science Teachers Association and the National Diffusion Network, the NSF-funded elementary curriculum development projects, and the work of the assessment center(s) proposed in this report.

- Formulate the most effective strategies for training expert teachers and local science leaders for the science-related training of other school or district staff, for awareness sessions for parents and school board members, for manuals for teachers and principals, and for policy briefs for superintendents and local and state legislators.

- Develop and endorse delivery systems by identifying existing organizations, agencies, and networks, interacting with them, and fostering cooperation among them.

- Coordinate ongoing services to school districts and teachers, and establish quality controls that monitor the soundness of the services and the equitable distribution of information, materials, and services.

- Provide information to policymakers, researchers, developers, and service agencies about how teachers and administrators experience new programs and services and about what they believe they need to reach the goals.

No feature of the National Assistance Center for Science Education should displace or duplicate the work already being done by others. Instead, the Assistance Center would enhance the work of others and build on their efforts. Every function of the recommended dissemination and implementation system should serve multiple constituencies through multiple channels. A more detailed discussion of the system including the proposed functioning of the Assistance Center is available from the National Center for Improving Science Education.

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International Association for the Evaluation of Educational Achievement (1988). *Science Achievement in Seventeen Countries.* A Preliminary Report. Elmsford, NY: Pergamon Press.

The results of science tests administered to 10-year olds, 14-year olds, and students in the final year of secondary school. Ten-year old U.S. students placed 8th; 14-year olds and 12th graders placed among the lowest-scoring countries.

Mullis, Ina V.S., and Jenkins, Lynn B. (1988). *The Science Report Card. Elements of Risk and Recovery.* National Assessment for Educational Progress. Report No. 17-S-01. Princeton, NJ: Educational Testing Service.

Report of the most recent assessment of science learning of U.S. students conducted in 1986. Comparisons are made among different population groups and with performance in previous assessments.

Murnane, Richard J., and Raizen, Senta A., Ed. (1988). *Improving Indicators of the Quality of Science and Mathematics Education in Grades K-12.* Committee on Indicators of Precollege Science and Mathematics Education, National Research Council. Washington, D.C.: National Academy Press.

Discussions of how to select educational indicators and assess the following components of educational quality: student learning, student behavior, teaching quality, curriculum quality, and financial and leadership support.

NAEP (National Assessment of Educational Progress) (1987). *Learning by Doing.* Report No.:17-HOS-80. Princeton, NJ: Educational Testing Service.

Manual discussing and illustrating eleven hands-on tasks for assessing a variety of laboratory and thinking skills in science. Equipment needed, question sheets, and appropriate student responses are given for each task.

Oakes, Jeannie (1986). *Educational Indicators: A Guide for Policymakers.* OPE-01. Santa Monica, CA: Rand Corporation.

An explication, written in non-technical language, of the uses of and problems with educational indicators.

Raizen, Senta A. (1987). "Assessing the Quality of the Science Curriculum." In Audrey B. Champagne and Leslie E. Hornig (eds.), *The Science Curriculum.* Washington, D.C.: American Association for the Advancement of Science.

Factors to consider in evaluating the several components of a science curriculum.

Raizen, Senta A., and Jones, Lyle V., eds. (1985). *Indicators of Precollege Education in Science and Mathematics.* A Preliminary Review. Committee on Indicators of Precollege Science and Mathematics Education, National Research Council. Washington, D.C.: National Academy Press.

Reviews and critiques the data available on quality and quantity of teachers, quality of curriculum content, instructional time and course enrollment, and student attitudes and achievement in science and mathematics.

Teacher Development and Support

Carnegie Forum on Education and the Economy (1986). *A Nation Prepared. Teachers for the 21st Century.* New York: Carnegie Corporation.

Reporting on the current state of teachers and teaching in America's schools, this report makes a set of recommendations aimed at upgrading the teaching profession. Among them is the establishment of a national standards board that certifies teachers at different levels, accommodating the need for different roles for teachers, particularly in making decisions about the operations of classrooms and schools.

Crandall, D.P. and Associates (1982). *People, Policies, and Practices. Examining the Chain of School Improvement*, Vols. I-X. Andover, MA: The NETWORK, Inc.

A set of ten reports of the Study of Dissemination Efforts Supporting School Improvement, which examined federal, state, and local efforts to improve schools using a variety of strategies. Surveys and case studies focused on classroom and school implementation, external assistance, and government support to determine factors that influence the success of change efforts.

Fullan, M. (1982). *The Meaning of Educational Change.* New York: Columbia University, Teachers College Press and Toronto: OISE Press.

This book is a synthesis of the research and literature on educational change, with special emphasis on how each component of the education system responds to change and can influence its success.

Holmes Group (1986). *Tomorrow's Teachers: A Report of the Holmes Group.* Lansing, MI: Author.

A report of a consortium of major research universities in the country, this report profiles the current state of teacher education and calls for a restructuring effort that includes new roles for teachers, professional development schools, longer preparation programs, and collaboration between universities and schools.

Joyce, B. and Showers, B. (1988). *Student Achievement Through Staff Development.* New York: Longman.

This book describes an approach to changing teachers' classroom behavior that results in increased student learning. Training that takes place over time and is reinforced by coaching is further enhanced by school and district expectations and support.

Loucks-Horsley, S., Harding, C., Arbuckle, M., Dubea, C., Murray, L., and Williams, M. (1987). *Continuing to Learn: A Guidebook for Teacher Development.* Andover, MA: The Regional Laboratory for Educational Improvement of the Northeast and Islands.

This guide synthesizes the research and literature on staff development, outlines how to build effective school and district systems to support professional growth, and profiles 12 different approaches to staff development that go beyond the traditional inservice workshop.

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.

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