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ABSTRACT

A comprehensive reform of the science curriculum and the methods of teaching and assessing science instruction is underway. This booklet shares ideas drawn from research and promising practices in science education. These ideas are addressed specifically to educators, but are important to anybody concerned with science education in elementary, middle, and junior high schools. Each of the following topics is presented on a single page: (1) Science is for all students; (2) Setting science standards provides a valuable resource for improved instruction; (3) Students learn by "constructing" knowledge; (4) Hands-on, inquiry-based instruction is well established as an effective teaching strategy; (5) Exploration, dialogue, and discourse promote understanding; (6) Instruction should focus on the essential key concepts or ideas of science in the overfull science curriculum and on teaching them more effectively; (7) The teacher's role is changing to facilitate student learning, while the student becomes a more active learner; (8) Appropriate staff development brings lasting improvements in science teaching; (9) Assessment must be more closely aligned with the goals of science instruction; and (10) Families and other concerned adults play important roles in promoting science education. (Contains 22 references.) (PR)

State of the Art

Transforming Ideas for Teaching and Learning

Science

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State of the Art

Transforming Ideas for Teaching and Learning Science

A Guide for Elementary Science Education

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The illustrations in this booklet, taken together, represent a transformation of four congruent shapes rotating about fixed points in ten increments to create a new and unified shape.

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Background

When you see. . .
That flowers don't grow when it snows,
That all kites need a wind that blows,
Some birds are red, some blue, some brown,
And a wheel, to roll, must be round.
That's science.

(Evelyn Smith, Kindergarten Teacher,
as quoted in McIntyre, 1984)

Bringing state-of-the-art science instruction to students in grades K–8 is a high priority. There is a greater appreciation of the fact that if we are going to bring quality science education to all students, produce science literate citizens, and meet the national education goal to be first in the world in science achievement, we must begin with the early school experiences of children.

A comprehensive reform of the science curriculum, and ways of teaching and assessing science instruction, is underway. This reform has been characterized as "deep, widespread, and serious." It is systemic, requiring that all parts of the system be partners in change. It is occurring at the national level, in the states, in schools, and in individual classrooms. Teachers, as well as administrators, policymakers, and community members have a vital role to play in furthering reform. To truly change science education, a widespread effort is required.

This reform builds on the experience of the post-Sputnik activities of the 1960's and 70's , with a strong emphasis on development of new curricular materials following a discovery or inquiry approach. Studies have shown that the new curricula were generally more effective than traditional programs in improving student performance on cognitive measures and raising attitudes about science. But they did not get into the classrooms and did not have the benefit of the more recent insight into children's need to make sense of science. Developments in cognitive sciences in the last decade have provided new perspectives on learning that have major implications for instruction and serve as a research base to drive the current reform.

There are some promising new curriculum projects which have been developed to take advantage of recent knowledge of how children learn. For example, the National Science Foundation has recently supported major elementary school materials development programs (National Science Foundation, 1993). Some of these have an interdisciplinary emphasis as well, and some involve technology following a science/technology/society focus. Other promising elementary curriculum programs are under development that encourage understanding of scientific concepts. Museums and other informal science education resources which often include classroom materials are readily available to teachers.

A part of the new approach stresses less coverage of topics to achieve greater depth of understanding. But this approach assumes that science instruction will be prominent in the curriculum of primary and upper elementary grades. It takes time for students to develop understanding in this new way of instruction.

The U.S. Department of Education would like to share ideas drawn from research and promising practice in science education. These ideas are addressed specifically to educators, but we believe they are important to anybody concerned with science education in elementary, middle, and junior high schools. They include families and other concerned adults, as they have an important role in our children's science learning and can provide support at home and in the community for improved science education.

Science is for all students.

Elementary science education is a key to the basics because science promotes the development of the thinking skills, learning processes, and positive attitudes required for lifelong learning.

(Mechling and Oliver, 1983)

A change in the goal of science teaching from preparing a few students with an interest in and an aptitude for scientific professional careers to educating all students in the science needed for today's world has transformed the way we think about science education. All of our children and young adults, not just those preparing to be professional scientists, must have an understanding of scientific ways of thinking and science knowledge in order to function in an information age. Learning science helps develop critical thinking skills and gives practice in use of evidence in decisionmaking. An increasing number of jobs require understanding scientific processes and principles, and most jobs call for problem solving and decisionmaking skills that may be acquired through the study of science. Equally important is the ability for all citizens to make good decisions using a basic understanding of the science and technology behind the various social issues affecting their lives.

Yet, science has remained a relatively low priority in elementary school for many years, while reading, writing, and arithmetic were considered the basics. A 1990 National Assessment of Educational Progress (NAEP) survey indicates that fewer than one-half of the fourth grade students attended schools that gave special priority to science, compared to three-fourths or more who attended schools that gave special attention to mathematics, reading, and writing. The fact is that science is not taught frequently in many schools. Twenty-eight percent of the fourth graders reported having science instruction about once a week or less frequently, and only about one-half reported having science instruction every day.

The elementary grades are a critical time for capturing children's interest. If students are not encouraged to follow their curiosity about the natural world in the primary grades, waiting to teach science on a regular basis in grade four may be too late. Data show that many children tend to lose interest in science at about the fourth grade. Quality science instruction at the upper elementary grades is also important, for at present these grades are the last time that science is part of the regular curriculum for students.

Setting science standards provides a valuable resource for improved instruction.

American education will be well served by an organized attempt to provide direction on a nationwide basis and to determine some of the important skills and knowledge that all students should master at key stages in their education, without trying to specify a national curriculum.

(National Council on Education Standards and Testing, 1992)

To transform science instruction nationwide, reaching schools in the various districts and states, there needs to be agreement on what students ought to know, how it should be presented, and how to measure the results. The setting of science standards is underway through the work of the National Academy of Sciences through its National Research Council working with the American Association for the Advancement of Science, the National Science Teachers Association, and other professional scientific societies and the broad constituencies they represent. Working groups are drafting standards for curriculum, teaching, and assessment. A consensus process is being followed to encourage broad review and discussion of the products of the groups with a final version planned for late 1994.

Rigorous standards will set the framework for what young Americans should know and be able to do when they leave school. States are making crucial systemic changes to reach these standards, including developing curriculum frameworks, improving assessments, and revising teacher certification and licensure requirements.

Research studies show that children who are in schools with high expectations and challenging curricula learn more than children who are in less demanding educational programs. Most students will work to meet whatever expectations their teachers and families have for them, however high, however low. In science, as in other important subjects, we need a clear consensus on what students should know.

The Statement of Principles on School Reform in Mathematics and Science from the U. S. Department of Education and the National Science Foundation states that "all children should receive a challenging education in mathematics and science based on world-class standards beginning in kindergarten and continuing every year through grade 12."

Students learn by "constructing" knowledge.

Constructivism tells us that people have to build their own scientific knowledge and understanding and that, at each step in science learning, they have to interpret new knowledge in the context of what they already understand.

We cannot teach directly, in the sense of putting fully formed knowledge into people's heads; yet it is our charge to help people construct powerful and scientifically correct interpretations of the world. We must take into account learners' existing conceptions, yet at the same time help them to alter fundamentally their scientific misconceptions.

(Resnick and Chi, 1988)

Research from the cognitive sciences and from science education has transformed our understanding of how children learn. The view of the student absorbing knowledge has shifted to one of the student constructing knowledge, called the "constructivist approach" by being involved in interpreting and understanding new content, and linking new knowledge to existing knowledge in a meaningful way.

Learners come to new situations with preconceived notions; they are not blank slates. As children develop, and long before they enter formal education, they need to make sense of the natural world about them. Thus they begin to construct sets of ideas, expectations, and explanations about natural phenomena. Since these ideas are frequently quite different from the ones held by scientists, we sometimes refer to them as naive conceptions. For example, fifth grade students were asked "What is food for plants?" Most students gave replies of "water," "soil", or "plant food" that can be bought in stores. These students had the idea that food for plants was something similar to food for people, rather than plants' need for light to make their own food through the process of photosynthesis (Anderson & Smith, 1984).

But the students' ideas make sense to them even though they are wrong from a scientific perspective. Naive conceptions are strongly held and must be examined and challenged in the course of instruction for new understanding to develop.

Teaching for conceptual change or "teaching for understanding" as it is called, requires different strategies from those usually followed in the classroom. Teachers continually diagnose student ideas and consider where they are in the process of conceptual change. Students' naive conceptions are addressed through exploration and discussion. Opportunities are provided for testing of ideas, even those that are false. Materials are needed that will encourage the student's exploration of a phenomenon as a way of acquiring new knowledge. While research continues on the implications of constructivism for the curriculum and instruction, there is agreement that traditional didactic teaching is not the most effective way to promote conceptual change because students often remain committed to their alternative conceptions while memorizing new material and doing well on tests, but without any real understanding of new concepts.

Hands-on, inquiry-based science instruction is well established as an effective teaching strategy.

Hands-on science means just that—learning from the materials and processes of the natural world through direct observation and experimentation. Professional scientists develop hypotheses and then test these ideas through repeated experiments and observations. They cannot simply "know" that something is so; they must demonstrate it. The education of children in science must also provide for this kind of experience, not simply to confirm the "right" answer but to investigate the nature of things and arrive at explanations that are satisfying to children and that make sense to them.

(National Science Resources Center, 1988)

Hands-on learning activities used appropriately can transform science learning by engaging the student in the process of science. Unfortunately, these activities are not widely used. It could be because so few teachers have had opportunities to develop skills needed for hands-on instruction. Another factor is that "hands-on learning takes time—and the pressure to get on with the overstuffed curriculum discourages many teachers from taking that time" (Rutherford, 1993).

In hands-on science instruction the teacher engages the students in questions that require them to think about and apply what they are doing to new situations. The "minds-on" part of instruction comes with dialogue, discussion, and exploration using the hands-on materials. Experiences with a particular science phenomenon must be concrete, relevant to the students, and varied.

All hands-on activities include materials. The student learns by doing, using materials such as plants, batteries and bulbs, or water, or instruments such as the microscope, meter stick, or test tube. But instructional materials must be sequenced to facilitate students' construction of meaning. Giving students sets of activities without connections drawn among them leads to isolated bits of knowledge or skills which do not promote understanding but rather the forming of naive conceptions. Therefore, rather than presenting students with bits and pieces of information and leaving it to them to piece these together, the teacher needs to help students see the interconnections among scientific ideas.

In practice, however, despite the emphasis on "doing science" with the use of instructional materials, textbooks have defined the curriculum. In drawing a comparison one science educator commented: "Teaching with hands-on activities is demanding, but everyone is involved, eager, and active, and participants remember what they have done... I never saw a textbook do that "(Rosanne Fortner, as reported in Haury and Rillero, 1992). While textbooks may have a place in the curriculum as a support to inquiry and experimentation, a more experimental base is needed at all levels involving use of instructional materials and equipment and thought-provoking questions and dialogue.

Other material resources are needed to support student's exploration of scientific ideas. Children's trade books and magazines are valuable resources to engage students and enrich their understanding of the natural world. Many of these resources are reviewed and evaluated periodically and an annotated bibliography published as a guide for users. Relevant films, videos, and computer resources are also important resources for the classroom. In addition, technical support is needed to supply teachers with science equipment and materials and to maintain and manage these resources.

Exploration, dialogue, and discourse promote understanding.

As Socrates well understood, learning is more likely to change through dialogue and reflection than through lecture and imposition.

(Kober, 1993)

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.

(The National Center for Improving Science Education, 1989)

Learning is interactive and occurs in a social context. The vision is to transform the classroom into a learning community where ideas are shared, evidence is used to strengthen ideas, and there is willingness to change ideas through exploration, dialogue, and discourse.

Teachers should provide students with many opportunities to explore scientific phenomena, using examples from their everyday experience. Exploration allows students to "play" with materials and ideas in open discussion with others. Through exploration students apply their naive understandings and develop explanations by experimenting. It is also a way for students to confront their misunderstandings.

Teachers organize the classroom and set the social norms of discourse to help students develop understanding from experience with materials in the classroom as well as from their out-of-school experiences. As one science educator described it: "There must be opportunity for independent exploration, as well as guided group activity, for quiet reflection and for animated discussion. Small group work enables every individual to participate fully in activities and discussion, and allows children to develop leadership skills, to learn from one another, and to take intellectual risks" (Bird, 1992). Research on cooperative learning indicates several positive effects of small group, student involved or led, hands-on science lessons. However for small group cooperative learning the teacher must carefully plan the learning environment; " . . . it takes time and practice for teachers to become skilled in its use" (Blosser, 1992). Large group work brings students together to share a variety of ideas similar to professional scientists collaborating on an investigation. Through a combination of large group and small group work the teacher designs the classroom environment to promote experiential learning.

Discussion among a small group of students or between student and teacher, and the framing of ideas and arguments to support a particular point of view, is an important strategy for developing students' conceptual understanding. Every effort should be made to have children ask questions and then use their questions to further their investigation. By posing questions, teachers may assist children to confront their assumptions and lead them to follow new paths of inquiry.

Instruction should focus on the essential key concepts or ideas of science in the overfull science curriculum and on teaching them more effectively.

Curricula must be changed to reduce the sheer amount of material covered; to weaken or eliminate rigid subject-matter boundaries; to pay more attention to the connections among science, mathematics, and technology; to present the scientific endeavor as a social enterprise that strongly influences —and is influenced by—human thought and action; and to foster scientific ways of thinking.

(American Association for the Advancement of Science, 1989)

A transformation in science curricula is occurring from coverage of a large number of facts and terminology on many topics to more indepth study of fewer, major concepts. Major scientific ideas or concepts and thinking skills need to be emphasized while somewhat less attention should be paid to specialized vocabulary, memorized facts, and procedures. Both Project 2061 of the American Association for the Advancement of Science and the National Science Teachers Association's Scope, Sequence, and Coordination project recommend that instruction cover the main ideas of science and the interrelatedness among various phenomena within the disciplines. The goal is to provide a greater depth of understanding.

There are different schemata for organizing science content around topics and relating units often taught in elementary grades to the larger ideas of science. Project 2061 identifies common themes that pervade science, mathematics, and technology (such as systems, stability and change, and scale) and suggests that science curricula should be centered around these themes. A conceptual approach to science would suggest science concepts (such as diversity, variation, order, structure, function, and change) as a way of integrating diverse topics. Other reports suggest different organizing principles, but the common element from research and studies is that the curriculum highlight major ideas, concepts, or themes, "the big ideas," so that detailed information about science becomes connected, becomes meaningful, and contributes to successful problem solving" (*Elementary School Science for the '90s*).

More time can be spent on developing understanding of the major concepts illustrated by the topics. An illustration of how a unit on seeds can build understanding of a major idea is found in the Life Lab Science Program. The first grade theme of this curriculum is diversity and cycles. A unit on investigating seeds would compare and contrast seeds, monitor germination, and begin to predict the outcome of simple experiments. Other units on a study of soil and the diverse plants and animals living in it will continue the theme drawing upon the life, physical, and earth sciences and the connectedness among the sciences around this major idea.

The teacher's role is changing to facilitate student learning, while the student becomes a more active learner.

The role of the teacher. . . requires much skill and effort. The teacher needs to identify projects that will interest students, monitor their work by asking questions that will further the work, help them learn how to work together. We need to allow students to be the children they are, to allow them to play and explore phenomena of interest. We need to avoid or reduce a fear of being "wrong," and encourage their delight at the unexpected. Children's curiosity, whetted by the clever teacher, needs to become the impetus for much of their work on science projects.

(Trumbull, 1990)

The role of the teacher is being transformed from one of primary dispenser of knowledge to one of being a facilitator of learning. This is a more demanding role in many ways. The teacher provides information in the context of a rich learning environment, in which the student is an active learner. Rather than the teacher telling the students what they are to learn, the teacher sets up an environment where the student can be active in acquiring knowledge, mainly through the process of experimentation and discourse.

The teacher engages students in problem solving by asking probing questions, promoting inquiry, and guiding discussion with use of hands-on materials. Facilitation also takes being well acquainted with resources whether they be curriculum materials, technology, community members or professional colleagues with special expertise, or institutional resources such as museums or science centers, and a capacity to draw on these resources as the need develops. "When students' investigations lead them down an exciting but unexpected path, having experimental materials or reference tools at hand or having a knowledgeable colleague to call on can turn a 'teachable moment' into a lifetime of understanding. Good teachers are accustomed to responding to children's short and long-term intellectual and emotional needs, but to do so in the context of scientific inquiry requires a special kind of preparedness and sensitivity" (Bird, 1992). It takes a deep understanding of basic science concepts and a willingness to not always be the "authority" to be comfortable teaching science in an experimental mode.

For teachers to be successful facilitators of children's science learning a great deal of support must be made available to them both within the school and from the broader professional community. They cannot do this without support from professional colleagues. They must have opportunities to exchange ideas and experiences with other teachers and with colleagues from the science and education community, to reflect on their teaching, to read research and contribute to it as part of a research team.

Appropriate staff development brings lasting improvements in science teaching.

Staff development programs that result in meaningful changes in teachers' behaviors have certain common characteristics. Among other things, they allow for intense study of and engagement with the new knowledge or skill over time, with time to practice and work through with others the problems of implementation. This combination of theory and application, time to reflect and practice, self study and cooperative learning, rarely is found in the more traditional inservice workshops, college courses. . . .

(Loucks-Horsley and associates, 1989)

The teacher is key to improved instruction. Since teaching for understanding demands a role that the teacher's preservice training often did not model, opportunities for inservice training are essential in transforming science instruction. In addition, teachers are often minimally prepared in science content, particularly elementary teachers who must teach all subjects. While very capable, teachers often have not had a college program that provided a basic background in the physical, life, and earth sciences and the ways to teach science to promote understanding. Elementary school teachers do not need to be experts in every aspect of science; in fact most scientists are experts in only a narrow specialty. But they do need a general background in science content.

It is most important that the inservice instructors model the teaching strategies they wish teachers to use. In addition, time for the teachers to practice new teaching behavior and continue to work with mentor colleagues is also a part of a good inservice program. Further, teachers will need to have regular opportunities to plan and collaborate with their fellow teachers at professional meetings such as national and state science teachers' meetings.

Teaching for understanding takes not only time to learn but also support from other colleagues and the school administration. Meaningful change in teacher behavior may take years. Teachers experimenting with new strategies and programs need the time and resources to try new techniques to determine what works best. They also need to exchange ideas. In short, they need to use the same methods to learn to teach science as the students need to learn it.

The most effective staff development activities:

- are continuous and on-going;
- model the constructivist approach to teaching that teachers will use with their students;
- provide opportunities for teachers to examine and reflect on their present practices and to work with colleagues to develop and practice new approaches; and
- provide good support structures within the group, among the group and the instructors, and from the school.

Assessment must be more closely aligned with the goals of science instruction.

Perhaps the most compelling reason for developing performance assessments is that they can provide an opportunity to appraise what society currently values, but is having difficulty measuring with multiple choice tests. Whether one reads a science journal or the *Wall Street Journal*, there are pleas for educating students who have both the mastery of subject matter knowledge and the more general abilities to think, solve problems, communicate, and collaborate.

(Baron, 1990)

A view of assessment as the servant not the master of curriculum is transforming assessment practice. Assessment and instruction are closely linked. Since teachers experience pressures to teach to the test, the prevalence of assessments that don't test for conceptual understanding or are limited to isolated facts has led to a curriculum that focuses on factual knowledge and vocabulary. In this way students learn discrete pieces of information and unconnected facts.

A new link between assessment and instruction is being forged through the reform movement. By using more authentic assessments such as performance-based or portfolio assessment or multiple choice tests that require thought beyond recognition and recall, more higher order thinking skills can be assessed, and students can learn through the process of assessment itself. Children must be offered many different options for communicating what they know and understand, and for raising new questions about a subject. Occasions to demonstrate ideas, quantify results, and make written, oral, or visual presentations of findings and hypotheses are essential. The important consideration is that the assessment measure progress toward the goal of the instruction.

Families and other concerned adults play important roles in promoting science education.

Informal science education resources also can provide a strong foundation for learning science. Like many of you, I have always enjoyed visiting zoos. As a youngster, I didn't visit zoos to learn about animals. I went simply to see animals and to have fun, but I learned about animals in spite of my nonacademic motives.

(Druger, 1988)

The rise in informal science education opportunities and the strong influence of the family and other adults on children's science learning has the potential to transform science learning. Families and the community can encourage children's study of science both in school and in out-of-school, informal science education activities. They can do this by supporting children in their homework, carrying out science activities at home, and participating in the growing number of informal science activities at zoos, museums, nature centers, national parks, and community organizations such as 4-H clubs. If families view science as an important subject for all students, they will more likely promote science activities for their children both in school and out of school. Often parents and other members of the community can bring their experience to enrich the curriculum.

The availability of informal science education activities for young people has increased dramatically in the last few years. They vary in format from *Science By Mail*, a program produced by the Boston Museum of Science, to the "Voyage of the Mimi" televised science program. Other programs help adults and children work together on science in out-of-school activities. The Family Science Program from the Lawrence Hall of Science at Berkeley encourages fun with science as a family activity. The U.S. Department of Education has published the book *Helping Your Child Learn Science* with many excellent opportunities to engage children in science.

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