Research Within Reach: Science Education

A Research-Guided Response to the Concerns of Educators

Edited by:

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National Science Teachers Association

Research Within Reach:
Science Education

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The Research and Development Exchange

The Research and Development Exchange (RDx) is a federal effort to bring the worlds of educational research and school practice closer together. The Exchange, operated by a consortium of regional educational laboratories and a university-based research and development center, is supported with funding from the National Institute of Education. Currently the R&D Exchange consists of three central support services, including the Research and Development Interpretation Service, and nine Regional Exchanges working through 50 cooperating state departments of education. The Regional Exchanges and their cooperating states are listed below:

Appalachia Educational Laboratory (AEL) P.O. Box 1348 Charleston, West Virginia 25325	Alabama, Florida, Georgia, Kentucky, North Carolina, Pennsylvania, Ohio, South Carolina, Tennessee, Virginia, West Virginia,
Far West Laboratory for Educational Research and Development 1855 Folsom Street San Francisco, California 94103	California, Nevada, Utah
Mid-Continent Regional Educational Laboratory (McREL) 4709 Belleview Kansas City, Missouri 64112	Colorado, Iowa, Kansas, Missouri, Nebraska, North Dakota, South Dakota, Wyoming
Mid-Continent Regional Educational Laboratory (McREL) 470 North Kirkwood Road Kirkwood, Missouri 63122	Illinois, Indiana, Iowa, Michigan Minnesota, Missouri, Wisconsin
Northeast Regional Exchange (NEREX) 34 Littleton Road Chelmsford, MA 01824	Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, Vermont
Northwest Regional Educational Laboratory (NWREL) 300 S.W. Sixth Avenue Portland, Oregon 97204	Alaska, Hawaii, Idaho, Montana, Oregon, Washington
Research for Better Schools, Inc. (RBS) 444 North Third Street Philadelphia, Pennsylvania 19123	Delaware, Maryland, New Jersey, Pennsylvania
Southwest Educational Development Laboratory (SEDL) 211 East Seventh Street Austin, Texas 78701	Arkansas, Louisiana, Mississippi, New Mexico, Oklahoma, Texas
Southwest Regional Laboratory (SWRL) 4665 Lampson Avenue Los Alamitos, California 90720	Arizona, California, Nevada, Utah

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FOREWORD:
Transforming Research Into Practice

The Research and Development Interpretation Service (RDIS) is a project, sponsored by the National Institute of Education (NIE), whose mission is to help bridge the gap between the worlds of educational research and educational practice. The tangible outcomes of RDIS' work—a series of publications called *Research Within Reach*—are developed on a foundation of seven tenets:

1. A corpus of research knowledge exists that can be used by teachers.
2. Teachers need both ''broad'' and ''deep'' knowledge.
3. Those who produce knowledge and those who use knowledge operate from different value structures.
4. Teachers use knowledge to improve performance if they see a connection between the knowledge and their own situations.
5. Knowledge producers and knowledge users use different ''languages'' when talking about knowledge and school improvement.
6. Knowledge needs differ among knowledge users, which may result in knowledge being packaged differently.
7. Users need different presentations of knowledge at different phases of knowledge use.

The knowledge produced through research represents an important resource for the improvement of education. Researchers are investigating literally every aspect of education, from how policymakers arrive at decisions to how learning occurs within individuals. Unfortunately, much of the research that holds potential for improving learning at the classroom level has had little impact. Drawing from the research that gives us the seven tenets described above, RDIS attempts to bring the results of research into teachers' reach.

Teachers work in complex environments and face challenges on several fronts. Not only must they understand educational psychology, including motivation and learning theory, they must also be knowledgeable in the content areas that make up the particular curriculum they teach. In addition, teachers require training in the skills of pedagogy: how to plan and present lessons, how to assess progress of students, and how to meet the needs and strengths of the children they teach.

Of course, teachers do not face these formidable tasks unaided. Curriculum specialists, instructional supervisors, textbook publishers, and school administrators offer specific help as teachers chart the course of learning to be undertaken. Moreover, a veritable army of researchers in universities, educational laboratories, research centers, and in schools themselves, study problems that affect teaching and learning. Nevertheless, it is often the case that research findings have relatively little impact on the actual teaching and learning that occur in schools.

For several years, the federal government has engaged in sponsoring activities that both generate new knowledge and that move research findings into practice. The National Science Foundation; Teacher Corps; categorical programs at the national, state and local levels; Research and Development Utilization projects; the nation-wide Research and Development Exchange (RDx); and federally funded networks of special education, bilingual education, and other "special interest" educators all attempt to help teachers use research knowledge to solve problems.

The results of these two types of federally sponsored activities vary. Research findings in teaching and learning processes, development and sequencing of specific skills (reading, problem solving, writing), organization of social systems, decision-making, and other educational processes have increased the potential for solving educational problems.

Successful demonstrations of moving research findings into practice have been less obvious. We know more theory about how change and improvement happen, but examination of actual practice reveals that those theories aren't being used in many school improvement efforts. The RDIS process, which is built on findings of research, helps move theory into practice.

In the course of helping teachers adapt and implement research findings, Teacher Corps discovered that what teachers do not want is simplistic answers to problems that *they* have not defined, "but the capacity to think about teaching, to define their own problems, and to determine the validity of their own classroom practices" (1). In short, teachers want research that relates to problems affecting them, but the research must be presented in a way that acknowledges the complexity of the teaching/learning process. Moreover, teachers insist on their right to define the problem.

This is often a cause of tension because knowledge advocates, to borrow Gerald Zaltman's term, and knowledge users often do not share common values, and may have different perceptions about accepting an item of knowledge (4). While people who produce knowledge typically value the scientific soundness of research, users may be more interested in the action orientation of the knowledge. This divergence of values is clear when reading research reports. Typically, these end with a recommendation that more research is required. This recommendation is often dismissed impatiently by teachers who want to know how they can use the knowledge on Monday morning.

This difference of values is similar to another difficulty for moving research into practice. Connections between research and practice are often not clearly articulated or immediately apparent. It is not uncommon for teachers to examine regularly research in their own field. However, important research conducted by information processing specialists or psychologists may elude these teachers because they don't read *widely*. Therefore, disseminators "should clearly establish for users the connection between the advocated knowledge and a felt need or concern experienced by the potential use" (4).

Another problem for moving research into practice is that different users need different knowledge. If a school system wants to improve science learning, for example, a disseminator can provide a wealth of research-based information on a variety of issues. It is critically important that the *right* information be provided to the right user. "It's important that administrators not be the only designated target group for such curriculum materials. Training packages suited for school board members, for teachers, for leaders of teacher organizations, and for parents, for example, need to be provided" (2). Zaltman expresses this same idea when he notes that "it may be necessary to design different versions of an item of knowledge to maximally satisfy different user characteristics" (4).

Because conditions differ from place to place, knowledge users need to explore local factors that may affect knowledge use. Herriott and Gross caution against unthinking installation of innovations simply because they have proved to be successful in other schools. The assumption that "it worked there; it will work here" is tenuous at best (3). Knowledge users need opportunities to test the match between their own situations and the research findings, before they can commit to attempting to put the research into practice.

The RDIS Process

The Research and Development Interpretation Service was established with funds from the National Institute of Education (NIE) of the Department of Education. Through its series of interpretive reports, RDIS reviews and presents research findings, along with their classroom implications, to teachers.

RDIS has devised a multi-step process that emphasizes the needs of classroom teachers for current research-based knowledge. This process involves the following steps:

Solicit questions from teachers. While these questions are collected in a variety of ways (telephone interviews, workshop activities, etc.), the important point is that the questions are posed by teachers. They want the answers.

Present questions to consultant panel. For each RDIS project, a consultant panel of experts in the field is convened. The panel's first task is to review the teachers' questions to decide whether or not a research-base exists that can be used in answering the question. Also, the panel prioritizes the questions so that the most important will be included in the interpretive report.

Review the R & D literature. Once the questions are selected, RDIS staff begins accumulating research reports, journal articles, and other documents. These are abstracted and catalogued in annotated bibliographies, which are ancillary products of each project and are available for use in answering the questions.

Prepare interpretive report drafts for review. The interpretive report is prepared, which includes a review of the relevant research, a discussion of classroom implications, and recommendations to teachers for classroom implementation of the research. The drafts are circulated to members of the consultant panel, to a variety of reviewers at schools, to colleagues in educational laboratories that make up the nationwide R & D Exchange, and to researchers in universities.

Incorporate review comments and publish final product. Revisions based on the reviews are made before the final product is printed. Regional Exchange (Rx) programs at the educational laboratories play a key role in the dissemination of the reports, either through workshops or through state departments of education. Further, the professional associations (e.g., International Reading Association and National Council of Teachers of Mathematics) have published and marketed the earlier reports on reading and mathematics to their memberships.

This report, *Research Within Reach: Science Education*, has undergone much the same process as the other publications. The Regional Exchanges have played an important role in the development of this document. This involvement has resulted in a shared sense of ownership of the publication and has enabled RDIS staff to benefit from the expertise of individual staff members at the Regional Exchanges.

Development of This Book

In 1983, RDIS was asked to develop an interpretive report of the research in science education. To emphasize the importance of this task, the directors of Regional Exchange projects at several regional educational laboratories agreed to provide support from their own staffs to help. The Exchanges helped by collecting questions from teachers, by attending meetings of the consultant panel, and by reviewing (and organizing field reviews) of the various drafts. Most importantly, Exchange staffs have actively worked on developing dissemination plans.

How Questions Were Generated

The first task of the Regional Exchanges was the collecting of practitioner questions. Because each Exchange works somewhat differently with the states it serves, the mechanism was left to individual Exchange preference. The approaches varied. One Exchange secured names of teachers in several states, who were interviewed by Exchange staff. The interviews provided important background on the individual and helped set questions into a context.

Another Exchange conducted a two-day workshop on research in science education. After each presentation or activity, workshop participants were invited to record questions or comments in a journal that each person kept. Also in a workshop setting, one Exchange invited practitioners to discuss issues in research and practice. These discussions, then, led to questions.

In all, more than 550 questions were gathered from teachers, curriculum specialists, instructional supervisors, and other educators.

How Questions Were Selected

Clearly, with that many questions, some had to be selected over others. The existence of a series published by the National Science Teachers Association (NSTA) made that task somewhat easier. The four-volume series, *What Research Says To The Science Teacher*, provides research information to teachers on a variety of topics, many of which are not covered in this document. For example, this volume contains no chapter that specifically and exclusively talks about the value of laboratory work. An excellent article on this subject by Gary C. Bates appears in *What Research Says To The Science Teacher*, Volume 1.

The business of choosing which questions to answer was the focus of the first consultant panel meeting. Before the meeting, all the questions were typed, exactly as received. Then participants at the panel meeting reviewed the questions, sorting them by two criteria:

- Was the question of interest to several practitioners?
- Was the question answerable from a research basis?

Once the questions were sorted by these criteria, the panel reviewed them again, placing them into categories. These categories were then examined and questions were selected because they appeared to be of primary importance to teachers, because they were answerable from the available research, and because, taken together, they provided a coherent picture of science education. Finally, participants at the panel meeting suggested research resources that should be considered when responding to the questions.

Collecting the Research

The RDIS staff spent a large part of 1983 collecting resource materials. The books, journals, and micro-fiche were annotated and compiled into a bibliography, which became the first tangible result of the science education synthesis. The bibliography currently includes more than 300 items.

At this point RDIS staff confronted the issue of what constitutes research. We asked: Should we confine ourselves only to primary reports of empirical experiments? Should we include anecdotal reports from practicing science educators who described promising classroom work? Should we include the views of experienced science educators, reviewing long careers in education and commenting on their experiences? In short, we found ourselves squarely in the middle of an epistemological debate that has raged since the days of Plato. We decided to draw from a wide variety of materials that we put under the heading of "knowledge." Some of that knowledge is research in the strictest sense of the word. Some of our sources, however, represent other kinds of knowledge. Throughout the book, we make clear to the reader, either in text or in the citation, what part of the knowledge base is being used.

At the same time that work on the bibliography was progressing, we contacted the science educators who were to become the authors of the chapters of this volume. We hoped to enlist the efforts of educators who were uniquely qualified to describe specific aspects of the research base and who also had demonstrated a commitment to communicating with teachers. We were fortunate in our choices.

By the end of 1983, a sufficiently strong first draft had been prepared to warrant returning to the consultant panel and to RDx colleagues for a review. During a second meeting of the consultant panel, all aspects of the draft were discussed and weak points, needs for further research, and suggestions for improvement of presentation were noted. Lengthy conferences with the writers followed, and a second draft was ready for review during the summer of 1984. Based on the results of that review, final modifications were made in the manuscript.

Overview of the Book

Each chapter is constructed along the same model. The chapter opens with a question posed by a teacher. In some cases more than one question is presented; in other cases several questions were collapsed into one. A discussion of research and practice is then given, which includes examples and implications for teachers and classrooms. Each chapter concludes with a summary and a list of references. The references are numbered and listed alphabetically by author. This number, when found in parentheses within the text, refers the reader to the appropriate citation. All references are brought together and presented alphabetically in a master bibliography, which may be found in the back of the book.

Each chapter is written so that it may be read in isolation. While this creates some repetition, it also allows the reader to read the chapters that are of particular interest in whatever order seems best to the individual.

The two chapters that close the book are different from other chapters. Each of these chapters presents the authors' perspective on aspects of science learning. In the first of these "perspectives" chapters, Wayne W. Welch discusses characteristics associated with science and scientists and relates these characteristics to science learners. The final paper, written by Audrey B. Champagne and Leopold E. Klopfer, offers a look at science teaching from the perspective of cognitive psychologists. We include this paper because the work of cognitive psychologists offers a decidedly different view of learning and the relationship of the learner to a body of knowledge and skills. For readers interested in learning more about this research perspective, we recommend that the work of Lillian McDermott of the University of Washington; James Minstrell, Mercer Island High School, Mercer Island, Washington; Jack Lochhead, University of Massachusetts—Amherst; and Frederick Reif and Joan Heller of the University of California, Berkeley, be consulted. Each of these people has made significant contributions to our understanding of how learners process information.

The remaining chapters of the book are grouped into three sections. Of the two papers in the first section, one looks at what we know about and have learned from the curriculum development projects of the 1960s; the other talks about the goals of science education. Issues of instruction are discussed in the four chapters found in the teaching and learning section. Here we find information about effective instructional strategies and systems appropriate for science classrooms, issues to consider when assessing students' science learning, effects of and activities that promote the integration of science and other school subjects, and the use of the microcomputer in science education. School and home factors that affect learning and teacher preservice and inservice training are discussed in the third section, a Context for Science Education.

Next Steps

This volume brings together some of the questions teachers raised when we began our work well over a year ago. While the questions are answered here, we realize that much more has to happen before research can be applied in classrooms. Furthermore, this book will begin to be out-of-date the day it is finished. Research is progressing on many fronts and new knowledge is being generated, tested, and confirmed. In a sense, this book is a starting point. It should be thought of as a semi-finished product that needs further shaping before its core—the ideas and knowledge—can become finished. That finishing process can only be completed by teachers.

After you have read this book, how can you use it? One way is to discuss the ideas presented with your colleagues. Whether you are an elementary school teacher, who needs to find time in a crowded schedule to teach science, or a secondary school teacher looking for ways to improve your teaching, you will probably find that a discussion of this book with your colleagues will yield new ways of thinking about science education. Another way to use the information here is in inservice education programs, since some aspects of this book can be used for professional development. In addition, a study committee looking at curriculum reform may find useful information here.

You may also want to search out other resources. The books and articles cited in the master bibliography contain much helpful information. Several publications of the National Science Teachers Association can also be recommended. These include *Teachers in Exemplary Programs: How Do They Compare; Centers of Excellence: Portrayals of Six Districts*; *Exemplary Programs in Physics, Chemistry, Biology and Earth Sciences*; the *Focus on Excellence* series; and the previously mentioned *What Research Says to the Science Teacher* series. In addition to these printed documents, human resources can be obtained from the science supervisor of your state department of education, the National Science Teachers Association, the National Science Supervisors Association, and the Regional Exchange that serves your state. These individuals and organizations can provide ideas and information that will help improve science teaching and learning in your school.

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In closing, we thank those educators who posed the questions that lie at the heart of our effort. This book is returned to them and to their colleagues, in the hope that their questions have been answered and that these answers will lead to improved science education in classrooms.

PREFACE

The research on science teaching is sometimes not easily accessible to those who actually teach science. It should be. Such research enables science teachers not only to learn new and effective teaching methods but it also enables them to analyze the methods of the past—it gives teachers a chance to make their teaching as effective as it can be.

At the National Science Teachers Association we have tried to bridge the gap between research finding and practice by publishing the monograph series, *What Research Says to the Science Teacher,* and special columns devoted to research in *The Science Teacher* and *Science and Children.* Now NSTA is proud to present to you this excellent summary of science education research written expressly for science teachers.

If you teach elementary or secondary science, you should find this volume most useful in learning how to supplement and improve your science teaching skills. The topics included in the book are those about which many of you have voiced concern. The format of the book incorporates specific questions which are clearly answered for you chapter by chapter. These questions are not of the "yes" and "no" variety, and their context gives you a strong foundation in good educational practice. In addition to giving answers to current research questions, this book provides you with an invaluable overview of the major issues in teaching science today.

Dorothy L. Gabel
Chair, NSTA Research Committee

CURRICULUM AND GOALS IN SCIENCE EDUCATION

The curriculum used in science classrooms is a primary determiner of what a student is taught. The two chapters in this section discuss the curriculum development projects of the 1960s and the goals of science education.

Curriculum Development Projects of the 1960s

What became of the curriculum development projects of the 1960s? How effective were they? What did we learn from them that will help teachers in today's classrooms?

The scientific literacy of American youth—that is, their mastery of the basic knowledge and skills of communication in science and technology—is a problem of grave national concern. In fact, this problem has been viewed by science educators for some years now as a crisis in science education (18, 29, 39, 52, 56, 59). At the outset of the curriculum reform movement in the 1950s, science and mathematics achievement scores of American students compared unfavorably with those of students in other industrialized nations. Since that time, scores have declined substantially. Almost paradoxically, our understanding of how knowledge and skills are acquired has increased dramatically (49). During this same period of time, we have also formulated a clearer image of what the goals should be for science education as a discipline (57). Thus, we currently have sufficient information to develop an initial concept of what is needed, what works, and what is effective in teaching science. We must now begin to use that knowledge to articulate a sound science education curriculum for all students. It is within the power of our existing educational system to improve the quality of the science education provided students. This enhanced instruction will improve the scientific/technological literacy for both the common and individual good.

As we approach the mid-1980s, it is extremely encouraging to find teachers at all grade levels, science coordinators, and school administrators asking such questions as: What became of the curriculum development projects of the 1960s and early 1970s? How effective were these science programs? Should the "process-oriented" courses have been tossed aside in favor of the "basics"? What are some characteristics as-

William C. Kyle, Jr., The University of Texas at Arlington

sociated with "exemplary" science programs? How can schools improve their science programs?

Recent research clearly provides answers for each of these questions and many similar concerns. This chapter will synthesize and interpret such research findings. First, however, it is important to look briefly at events in the recent past that have led teachers to ask these questions.

A crisis in science education was identified by the mid-1950s and was fueled by the Soviet Union's launching of Sputnik I on October 4, 1957. This event drew attention to the disparity between existing science courses and the rapid advances in science and technology. The educational system was neither keeping pace with advances in science nor with the demands of society. If the country wanted, and needed, more and better scientists then something had to be done regarding the nature of science education in the schools. The launching of Sputnik aroused public interest, awakened a "sleeping giant," and ignited a crash program for curriculum reform in science education. This burst of activity resulted in some of the most current, innovative, and spectacular changes in the history of American public school education. The period that followed has come to be known as the Golden Age of Science Education (1955-1974).

The curriculum reform era was nurtured by a society that demanded improved science education and more rigorous science. The demand was for more scientists, technologists, and engineers who could meet perceived societal needs. Although dozens of "alphabet-soup" science curricula were developed during this era, the following curricula were perhaps the most well-known and widely adopted:

Elementary Science Curricula:

Elementary Science Study (ESS)
Science Curriculum Improvement Study (SCIS)
Science - A Process Approach (S-APA)

Junior High Curricula:

Earth Science Curriculum Project (ESCP)
Individualized Science Instructional System (ISIS)
Interaction Science Curriculum Project (ISCP)
Intermediate Science Curriculum Study (ISCS)
Introductory Physical Science (IPS)

High School Curricula:

Biological Sciences Curriculum Study (BSCS)
  - Yellow Version
  - Blue Version
  - Green Version
Chemical Bond Approach (CBA)
Chemical Education Materials Study (CHEM Study)
Harvard Project Physics (HPP)
Physical Science Study Committee (PSSC)

The new science curricula were similiar in several ways. They were developed by teams that included scientists, educators, psychologists, and teachers. Unlike earlier texts, written by one or two authors, the new curricula benefitted from the combined expertise of people with a variety of perspectives. The curricula that emerged embodied both scientific processes and the nature of scientific inquiry (20, 21, 38, 43).

The teaching methods and strategies advocated in the teacher guides, and during project inservices, were based upon the most up-to-date theories of how children and adolescents learn. Earlier textbooks contained a mass of disconnected facts and generalizations, presented almost entirely as description, which seemed to require rote memorization (20, 21, 43).

The new science programs emphasized learning by doing while focusing on current concepts in science. Laboratory activities were an integral part of the class routine. Thus, higher cognitive skills and an appreciation of science were emphasized. Traditional science courses had emphasized a knowledge of scientific facts, laws, theories, and applications. Laboratory activities had been used as verification exercises or as secondary applications of concepts previously learned in class (16, 21, 38, 43).

Finally, the new science curricula were organized according to the structure of science disciplines (similar to the traditional science courses of the 1940s and 1950s). The emphasis upon the structure of the discipline was much more apparent, as was the emphasis upon the nature and processes of science. Much time and effort were devoted to identifying the central themes, the conceptual schemes, the unifying ideas, and the patterns of thinking of each of the science disciplines. Efforts were made to distinguish between science and technology. The emphasis was on pure science, doing what scientists do—not on applications of such knowledge (16, 20, 38).

As we entered the 1970s, the United States seemed to have established a preeminence in science education that matched its status in basic scientific research (41). Many people felt that the primary objectives of the 1960s had been met and that the job had been accomplished.

After all, there was now a surplus of scientists and engineers, and the United States had surpassed the Russians in various space projects, including landing the first person on the moon. A small cadre of science educators realized that only part of the job had been accomplished (41). Although science education had achieved its goal of producing more scientists and engineers, science was still not a meaningful and useful subject for all students. The National Science Foundation (NSF) was urged to continue its work in the area of science education.

The early to mid-1970s, however, was a period of disillusionment for science educators. Political, economic, and social pressures were not favorable to science or technology. Society's interest in science education rapidly diminished. Yager notes that "(t)he changes of the 1970s resulted in major problems with respect to public and Congressional support for science education" (53). By the mid-1970s, significant numbers of citizens felt that the continued support for curriculum development and teacher education in science was misdirected and, perhaps, in error (54). Thus, in 1976, all teacher education funds that had been available from NSF were terminated. The second crisis in science in twenty years was underway.

A flurry of activity immediately followed the 1976 cutoff of funds. A new NSF program to support science education was created, and NSF funded three large status studies. The status studies were designed to assess the impact of the 1960s curriculum development activities and to identify continuing needs and possible new directions (6, 54).

One study, directed by Helgeson, Blosser, and Howe, reported on the impact of activity in curriculum development, teacher education, instruction, and needs in science education (14). The second study, co-directed by Stake and Easley, was a collection of case studies designed to provide a picture of the current conditions of K-12 science classrooms (47). The third status study, directed by Weiss, was a demographic survey from which national estimates were made of curriculum usage, course offerings and enrollments, and classroom practices (51).

Also in the 1970s, *The Third Assessment of Science* was undertaken by the National Assessment of Educational Progress (NAEP). NAEP examined science knowledge, skills, attitudes, and educational experiences of precollege students (24).

In 1978, Harms synthesized and interpreted the three K-12 status study reports and the NAEP data. This research effort, called Project Synthesis, examined K-12 science education from five perspectives: biology, physical science, inquiry, elementary school science, and science/technology/society. The research procedure Harms used was to describe a desired state for each perspective and then to compare this ideal state with the actual state. The analysis, then, identifies discrepancies between the two conditions. The major results of Project Synthesis and recommendations for future actions are included in a recent NSTA monograph edited by Harms and Yager (13). This monograph is "must reading" for teachers of science at all grade levels, science coordinators, and school administrators. It provides the most comprehensive analysis of where science education has been, where it is now, and the direction in which it must move.

Finally, in an attempt to increase the scope of the three K-12 status study reports, NSF selected nine professional organizations, with different responsibilities and perspectives, to analyze the studies (27). By 1981, the verdict was in. The three K-12 status study reports, the results of Project Synthesis, and the professional reviews of the status study reports all agreed: a crisis existed in science education.

Yager has synthesized several conditions that illustrate the current crisis:

1. Nearly all science teachers (90%) emphasize goals for school science that are directed only toward preparing students for the next academic level (for further formal study of science).

2. Over 90% of all science teachers use a textbook 95% of the time; hence the textbook becomes the course outline, the framework, the parameters for students' experience, testing, and world view of science.

3. There is virtually no evidence of science being learned by direct experience.

4. Nearly all science teachers "present" science via lectures and/or question-and-answer techniques; such lectures and question/answer periods are based upon the information that exists in textbooks chosen.

5. Over 90% of the science teachers view their goals for teaching in connection with specific content; further, these goals are static, i.e., seldom changing, givens (54).

These conditions are directly contrary to the goals established by the curriculum committees during the Golden Age. However, Yager's findings are similar to those of Goodlad and his associates who recently completed a study of our nation's schools (12). They conclude that students in their sample did not appear to develop any of the abilities commonly listed under "intellectual development": the ability to think rationally, the ability to use and evaluate knowledge, intellectual curiosity, creativity, or the desire and ability to pursue further knowledge. Only rarely did Goodlad find evidence to suggest that instruction goes beyond students' mere possession of information to a level of understanding the implications of that information and either applying it or exploring its possible applications. These findings were true even for science classes. At a time in our history when the development and enhancement of such skills appears to be imperative, they were and are being neglected. Developing and enhancing these higher intellectual processes should be among the primary objectives of the science curriculum.

Fortunately, each finding synthesized by Yager (54) relates to an "alterable variable" (2). Teachers and administrators are convinced that scientific and technological literacy are essential for living in modern society, and that action should be taken to reverse these trends. Cries for revitalizing the science and technology education in the United States are again being heard. Science teachers, science coordinators, school administrators, as well as the public in general, are beginning to realize that the nation that dramatically led the world into the age of technology is failing to provide its children with the intellectual skills necessary for the 21st century. There is a realization that we indeed must return to the basics, but that the "basics" of the 21st century are not only reading, writing, and arithmetic. The "new basics" must include communication and higher problem solving skills, as well as scientific and technological literacy—the thinking tools that will allow our children to understand the technological world around us (26). This goal is so vitally important that the National Science Board Commission on Precollege Education in Mathematics, Science and Technology has stated that, by 1995, our nation "must provide, for all of its youth, a level of mathematics, science, and technology education that is the finest in the world" (26).

Does research indicate that the 1960s curricula were more effective than the "regular" textbook programs? Did student mastery of science concepts and process skills increase? Are the goals of science education the same as in the 1960s? To what extent should societal issues be included in the science program?

During the past ten years, it has become popular to discard the science programs developed during the curriculum development era. At the elementary level, there is evidence that science education is being displaced by an emphasis on "basic skills" (47). Critics of the new science programs maintain that students did not acquire science concepts, that declining enrollments indicated the programs were ineffective, and that basics needed to be stressed over process skills. The critics' contentions are not supported by the research.

A number of recent research syntheses have investigated the effectiveness of the new science curricula. The researchers who conducted these syntheses have integrated primary research results available in the literature through an empirical research perspective called meta-analysis. Glass coined this term in 1976 to describe the process of analyzing the results of a collection of studies on a related topic (10, 11). Translated literally meta-analysis means an analysis of analyses.

Meta-analysis involves calculating a common measurement for each defined variable within a study. This common measurement compares the magnitude of the difference between groups and is referred to as an "effect size." Thus, the effect size measures the difference in performance of two groups on a dependent variable such as general achievement, student attitudes, or problem solving skills.

In the studies reported below, effect sizes have been converted into percentiles. Thus, results are referred to as either percentile points gained (for example, the average student in the treatment group performs 20 percentile points better than the average student in the control group); or, as percentile equivalencies (for example, the average student in the treatment group performs at the 70th percentile of the control group, thus, the student who performs at the 50th percentile of the treatment group exceeds the performance of 70% of the students in the control group).

Shymansky, Kyle, and Alport recently completed a comprehensive review of twenty-five years of research comparing student performance in the new science curricula at all grade levels to student performance in traditional science courses (20, 21, 43, 44, 45). In synthesizing the results of 105 experimental studies involving more than 45,000 students, they report that the average student in classes using the new science curricula exceeded the performance of 63% of the students in traditional science courses.

Strikingly similar results have been reported by Weinstein, Boulanger, and Walberg in synthesizing secondary student performance (grades 6-12) in the new science curricula (50). They report that the average secondary student in innovative courses exceeded the performance of 62% of the students in traditional courses on all learning measures.

If you wish to calculate the effect of research results rather than merely accepting the author's reporting of significance or non-significance, simply subtract the control group's mean score on each variable from the treatment group's mean score for the same variable and divide by the standard deviation of the control group:

$$ES = \frac{\overline{X}_{\text{treatment group}} - \overline{X}_{\text{control group}}}{SD_{\text{control group}}}.$$

Effect size units are equivalent to standard deviation units. Since one standard deviation is equivalent to the 84th percentile of a normal distribution, then an effect size of 1.0 is also equivalent to the 84th percentile. Figure 1 provides a convenient way of visualizing such results as two overlapping normal distributions.

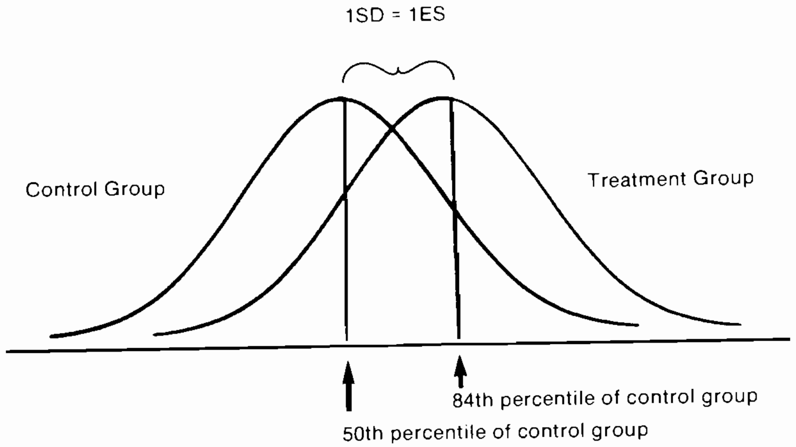

Figure 1
Overlapping Normal Distributions

If, for a given variable, an effect size of + 1.0 was calculated then the average student in the treatment group would be exceeding the performance of 84% of the students in the control group. As you can see, using effect sizes and their percentile equivalents is an extremely powerful way of visualizing the "real effects" of a collection of research results.

Bredderman has also synthesized research that examined K-6 elementary school science programs and found that the average elementary student in the new science programs exceeded the performance of 63% of the students in traditional courses (4). The consistent pattern of positive effects for the diverse performance measures analyzed in each of the above syntheses clearly establishes the superiority of the new science curricula over the courses they were designed to replace.

Table 1 shows that students in the new science curricula performed well at the elementary, junior high, and secondary level on a composite basis. Of special interest are the data for student achievement. Much criticism regarding the new science curricula focused upon the apparent decline of general science knowledge among students exposed to the new programs. At the height of the curriculum reform movement, and even today, the prevailing notion was that the process goals of the new science curricula were being achieved at the expense of the content goals. The data in Table 1 show clearly that students exposed to new science curricula performed better on achievement measures than did students in traditional courses that primarily focused on content. Across all K-12 curricula, the average student in a new science curriculum exceeded the performance of 64% of the students in a traditional science course on achievement measures. Similarly, student attitudes were enhanced, as was performance in areas involving higher cognitive skills (e.g., critical and analytical thinking, problem solving, process skills, creativity, and logical/spatial relations). Further, when students in kindergarten through 9th grade were simultaneously tested for performance in related areas such as reading, mathematics, and communication skills, their performance was also positively enhanced (20, 21, 43, 44, 45).

Kyle also was concerned with the problem of testing bias. One would naturally expect students in new science curricula to perform better than students in traditional courses on tests emphasizing and assessing process skills. Each test, then, was analyzed to determine whether the treatment group or the control group was favored, or whether there was no testing bias. Students in new science curricula performed better than students in traditional courses regardless of the direction of test bias. That is, even when the control group was favored by the testing bias, students in new science curricula performed better (20).

Another quantitative synthesis conducted at the secondary level by El-Nemr studied inquiry teaching in biology (8). Many of the inquiry biology courses in El-Nemr's study used the BSCS materials, so his conclusions are similar to those of Shymansky, Kyle, and Alport. El-Nemr found that the average student in inquiry-oriented biology classes performed at the 64th percentile of the traditional group on achievement

Table 1

Performance Measure Percentile Equivalency of Students in New Science Curricula Compared to Traditional Courses

Grade Level	Composite		Achievement		Attitudes		Process Skills		Analytic Skills		Related Skills		Creativity/ Spatial Relations	
	N	%ile	N	%ile	N	%ile	N	%ile	N	%ile	N	%ile	N	%ile
Elementary (K-6)	138	62	34	64	31	61	19	71	2	52	37	57	15	63
Junior High (7-9)	71	63	13	59	11	72	18	59	14	51	9	75	6	63
High School (10-12)	132	65	83	64	9	67	19	67	19	66	2	41	–	–
All Curricula (K-12)	341	63	130	64	51	64	56	65	35	60	48	60	21	63

Adopted from: Kyle, W. C., Jr. 1982. *A meta-analysis of the effects on student performance of new curricular programs developed in science education since 1955*. Doctoral Dissertation, The University of Iowa.

measures, at the 67th percentile on problem-solving skills, and at the 59th percentile in increased perception of science.

Research also indicates that the kind of science taught has a great influence on students' attitudes toward science. Kyle and Bonnstetter have recently conducted a study of student attitudes toward science in SCIS versus non-SCIS classes. Their work has shown that process-approach science produces students whose attitudes toward science are different from those of students not following a process-approach course. After only one year of this hands-on, inquiry-oriented science curriculum, Kyle and Bonnstetter observed drastic attitudinal differences between SCIS and non-SCIS students. Almost half of the SCIS students chose science as their first or second favorite subject compared to 21% of the non-SCIS students. Only 7% of the SCIS students indicated that science was their least favorite subject compared to almost 20% of the non-SCIS students. SCIS students overwhelmingly wanted more science, desired more kinds of science, and found their school science to be fun, exciting, interesting, and intellectually stimulating.*

In comparison studies, then, the hands-on, inquiry-oriented curricula developed during the Golden Age of Science Education were effective in enhancing student achievement, attitudes, and higher cognitive skills, as well as performance in other areas. The results of student performance in these programs are quite impressive in light of the original goal of that era: the development of an improved and more rigorous science education that would produce more scientists, technologists, and engineers. Ironically, while achieving this goal, the curriculum development activities of the Golden Age, in conjunction with changing societal needs and concerns, actually contributed to the current crisis. With all of their apparent accomplishments, the new curricula failed in bringing about mass scientific/technological literacy among our citizenry (16, 18, 55, 57). Support for science education ceased when change was again most needed. The job wasn't finished—in fact, it should have just begun. Overall, student achievement and interest in science have been declining since 1969 (17, 24, 60). To many, the current crisis is more severe than the crisis of 1957.

Teachers should recognize that the goals for science education have changed. Because society's needs and goals have changed since the 1960s, we cannot simply resurrect the old "new" science curricula. Not

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*Kyle, W. C., Jr. and Bonnstetter, R. J. July 1984. An analysis of student and teacher attitudes toward science in SCIS versus non-SCIS classes. A report submitted to the Division of Planning, Development and Evaluation, Richardson Independent School District, Richardson, TX.

Table 2

Comparison of the 1960s Goals of Science Education With the Goals of the 1980s and Beyond

During the 1960s	During the 1980s and Beyond
1. The demand was to produce more scientists and engineers to solve perceived problems.	1. The needs are related to current social problems rooted in science and technology, e.g., depletion of energy sources, fear of nuclear energy, genetic engineering.
2. Programs were designed to meet the goals of past times in each of the science disciplines. Acquisition of knowledge was still important.	2. There is an urgent need to recognize current societal problems. The knowledge that should be considered important is that which will be useful and relevant to the solution of social problems.
3. Science was taught as a means of advancing knowledge and explanation. Science education was, therefore, preparing future scientists.	3. Science and technology are considered to be a means for improving society. Science education, therefore, should be preparing the future citizens.
4. Science and science education were oriented to the present and immediate past.	4. Science and science education must be oriented to the future in light of its potential impact in helping to resolve societal problems and concerns.
5. Science education concentrated upon the development of cognitive skills.	5. Science education must focus not only on cognitive skills, but upon affective, ethical, and aesthetic understandings as well.
6. Science was viewed as value-free, empirical science.	6. Today's science is more accurately portrayed as value-laden science in which there are moral and ethical dimensions.
7. Science demanded linear thinking and emphasized inquiry skills.	7. Science must be concerned with systemic thinking and emphasize decision-making skills.
8. The goals of science teaching were internal to the various disciplines of science.	8. The goals of science teaching are derived from the interaction of science, technology, and society.

only has scientific knowledge increased since 1960, but society faces problems today—acid rain, nuclear energy, in vitro embryos—that were unimagined then. We must develop science curricula to meet the current demands for scientific/technological literacy, while integrating those successful methods and strategies of the previous era. In Table 2, some useful comparisons between past and present goals have been synthesized from the work of Hofstein and Yager (16). The comparisons can be used to guide our future curriculum development.

Science has always had an impact on society. Science and society have become increasingly interdependent during the past fifty years. Many authors have been urging that a major goal of science education should be to reflect the interaction of science, technology, and society (7, 13, 16, 18, 28, 34, 36, 37, 38, 55, 56, 57). We can use the knowledge that we gained from the curriculum development era as we strive to meet the current societal needs—the educating of a scientifically and technologically literate citizenry.

What are the latest and best programs and materials for teaching science?

The latest and best changes all the time. So while we cannot conclusively and specifically answer the question, we can look to several sources for direction.

The results presented in this chapter and in recent National Science Teachers Association (NSTA) publications provide us with information to develop an initial concept of what is needed, what works, and what is effective in teaching science (3, 5, 13, 22, 30, 31, 32, 35, 36). The National Commission on Excellence in Education has reported that for the first time in the history of our country, the average graduate of our schools and colleges is not as well educated as the average graduate of the preceding generation (25). What should be even more disheartening to science educators at all levels, kindergarten through college, is the knowledge that within the context of the modern scientific revolution "we are raising a new generation of Americans that is scientifically and technologically illiterate" (25). It is apparent that sweeping and drastic changes are necessary in all science curricula if, by 1995, we are to meet the goals for the 2lst century proposed by the National Science Board Commission on Precollege Education in Mathematics, Science, and Technology (26).

It appears that we are about to enter a cycle of educational reform not only for science education as a discipline, but for education as a whole. This reform should rival, in expectations and ideas, the reform era of the 1960s. We must, however, ensure that the 1990s do not become a period of disillusionment and regression as was the 1970s. We must use our knowledge to articulate a sound science education curriculum for all students, especially those who may not become scientists.

In searching for excellence, Penick and Yager note that knowing what works is a considerably more direct route to success than knowing a lot of things that don't work (37). Thus, the 1982 NSTA Search for Excellence in Science Education was a logical next step to the status studies of the 1970s. The goals and the general description of the desired state for each of the five focus areas identified in Project Synthesis were used as criteria in defining excellence in school science programs (13, 37, 58). Fifty-four examples of excellent science programs were identified throughout the U. S. in 1982.

Penick and Yager report that certain characteristics are common to exemplary programs (37). They are all designed to be excellent. Exemplary programs do not simply rely on routine textbook selection. A considerable amount of time is spent on developing the curriculum, on organizing how it will be presented, and on encouraging teachers to work as teams.

There is often a single person who can be identified as providing the methods for the curriculum development. These leaders are able to bring about the desired change by stimulating the active participation of other faculty members. The administration is supportive of such efforts and many teachers receive release time to develop the curriculum. State-level science supervisors, university faculty members, and community leaders are frequently consulted.

In exemplary programs, the teachers are involved heavily in staff development activities. Several years of inservice effort, including extensive summer sessions, have helped in developing and organizing the curriculum.

The courses focus on process skills although content is also stressed. The courses are directed at the majority of students, not just the college bound. The courses are designed with science applications in mind.

Finally, the curricula used in exemplary programs are often locally developed. Many are adaptations of national curricula of the past two decades and/or use activities from a combination of such curricula. Textbooks tend to play a secondary role as resources and references.

Elementary schools are an essential component of a sound science education program. The process of developing a student's understanding of science must begin early. Further, unless children and young adolescents are exposed to science early, often, and favorably, they will not develop the interest or knowledge necessary to be scientifically literate. Penick and Johnson have generalized characteristics of exemplary elementary science programs:

1. Science is taught—and, it is taught more, in terms of time, when compared to national norms. Nationally, schools report an average of 100 minutes of science per week. Exemplary programs average 145 minutes per week, and the teachers maintain that they need even more time. These same schools also spend more time in mathematics and social studies.

2. These programs emphasize hands-on science, inquiry strategies, and student decision-making.

3. Teachers are enthusiastic; they claim ownership of the programs.

4. Teachers read professional journals, attend workshops and conferences, take college courses, and present at professional meetings.

5. Many of these programs use activities from ESS and SCIS.

6. Societal issues are frequently a focus of study; rarely is the classroom a boundary (33).

Thus, the teachers in exemplary programs provide a stimulating environment, promote inquiry, and play a major role in developing the curricula; students actively do science: they identify problems, make decisions, and learn how to learn; administrators are supportive, are involved, and provide resources; and finally, the community recognizes the importance of good quality science programs and supports such programs. These factors are positively related to students developing the scientific literacy necessary to function in the technological age of the future (33). Further, Penick notes that the size of the budget, the school, or the community are not limiting factors (31). He says, initially, the teachers are the most significant factor. Teachers in each of the exemplary programs want to teach science. They are dynamic, thoughtful, young-at-heart, eager to learn with their students, and they are professional educators. He also notes that administrative and community support are essential. While Project Synthesis offered a picture of the desired state for science education, the Search for Excellence provides examples of exemplary programs in real schools.

Are there any quick and easy solutions for designing an effective science program?

Teachers, curriculum coordinators, and administrators are currently struggling with the problem of how to improve the quality of the science education provided all students to ensure a scientifically and technologically literate citizenry in the future. Some commonly asked questions are: Should we increase the amount of time for school science? Should we increase the amount of laboratory work? Should we require more science courses at the secondary level? Should we be emphasizing process skills or science content? Should we be including societal issues in the science curriculum?

Schools will not, and cannot, change overnight. Sigda notes that it takes four to six years to totally develop and revise a program before it can be used in science classrooms (46). Once in place, a program must be constantly monitored and updated. Schools can, however, slowly revise, develop, and update existing curricula—as part of a logical development plan—so that improvements are not delayed until 1990.

Merely increasing the number of hours spent in science classes, the amount of laboratory work, or the number of required science courses, by themselves, will produce neither exemplary programs nor scientifically literate graduates. A well-articulated and well-coordinated science curriculum that balances process skills and content; that provides students with opportunities to identify and solve problems; that enhances higher intellectual processes; that goes beyond mere possession of information to applications; that incorporates societal issues; and that maintains a proper continuum from kindergarten through 12th grade is required.

It must be emphasized that exemplary programs integrate a balance of science processes and content. Finley indicates that students' performance of science processes is dependent upon their knowledge of relevant concepts (9). Laboratory activities are also essential elements of exemplary programs since they enhance the development of inquiry and problem-solving skills. Hofstein and Lunetta note that laboratories assist in the development of manipulative and observational skills, of scientific concepts, of positive attitudes, and of skills in cooperation and communication (15).

This balance between processes and content is also likely to enhance student attitudes toward science. Steinkamp and Maehr note that students are "most likely to feel positively toward science as one actualizes one's ability through science achievement" (48). Thus, as in any endeavor, it is primarily the acquisition of proficiency that leads to positive attitudes.

A substantial body of interesting, imaginative, and educationally sound material was developed by the science curriculum committees of the 1960s; most of these materials are not obsolete (1). The research syntheses of Shymansky, Kyle, and Alport; Weinstein, Boulanger, and Walberg; Bredderman; and El-Nemr support this contention (45, 50, 4, 8). Arons cites two primary causes for the apparent failure of the new science curricula: inadequate logistic support (i.e., administrative support, individuals responsible for the maintenance and re-supply of materials, financial resources); and the lack of properly guided inservice for teachers. The Search for Excellence reports indicate that exemplary programs provide the necessary logistic support, as well as provide and encourage extensive and comprehensive inservice opportunities for teachers (3, 30, 31, 32, 35, 36).

Since 1957, science education programs across the nation have successfully prepared future scientists and engineers for further study and careers in those disciplines. It should be apparent, however, as evidenced by a steady decline in student achievement and attitudes toward science, that science presented in the way it is known to scientists is not inherently interesting to all students (16, 17). For over twenty-five years now, science educators have adhered to a goal that is appropriate for only 3% of the high school graduates. During that time we have failed the majority of the citizenry whose lives and work are affected daily by advances in science and technology. Jackson maintains that science educators should focus on two goals in developing exemplary science programs: more science instruction and a different kind of science instruction. He asserts that science instruction must become "science for all," as opposed to "science for future scientists" (19). In effect, then, new courses should model the previously cited exemplary programs and teach science in a way that brings relevance to daily living and to current social issues. Similarly, Miller states that for scientific literacy to become truly relevant we should not only focus on the traditional understanding of the norms of science and knowledge of scientific constructs, but also foster an awareness of the impact of science and technology on society (23).

Finally, Mary Budd Rowe maintains that a full science program should consist of four interdependent parts: ways of knowing (i.e., What do I know? Why do I believe it? What is the evidence?); actions/applications (i.e., What do I infer? What must I do with what I know? What are the options? Do I know how to take action? Do I know when to take action?); consequences (i.e., Do I know what would happen?); and value (i.e., Do I care? Do I value the outcome? Who cares?). In all but exemplary programs, the primary focus of science instruction is on "ways of knowing"—with most of that attention on what we are supposed to know. Yet, the three missing components "are precisely what are of greatest interest to the majority of students" (40). Exemplary programs of the future must follow the lead of existing exemplary programs and integrate the missing ingredients in order to improve the quality and appropriateness of science instruction.

Summary

Recent research syntheses demonstrate the effectiveness of the hands-on, inquiry-oriented science curricula developed during the 1960s and early 1970s. Evidence shows that students in such courses had enhanced attitudes toward science and scientists; enhanced higher-level intellectual skills such as critical thinking, analytical thinking, problem solving, creativity, and process skills; as well as, a better understanding of scientific concepts. Inquiry-oriented science courses also enhanced student performance in language arts, mathematics, social studies skills, and communication skills.

With information gained through investigation of the effectiveness of the new science curricula and by looking at exemplary science programs today, we can develop a concept of what's needed, what works, and what's effective in teaching science. Educators at all levels are struggling with the problem of how to improve the quality of science education to ensure a scientifically and technologically literate citizenry.

Exemplary programs of the future can examine what we currently know about effective science programs and instruction to improve the quality of science education for all.

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Goals of Science Education

Is there substantial agreement on the goals for science instruction? If so, what are they?

The last major shift in science education goals occurred some twenty-five years ago. Goals espoused then—to meet demands for more scientists—were justified by the social conditions of the time—the Soviet's launched Sputnik I in 1957. Since then, social expectations of schooling and of science have changed greatly. However, the goals espoused by today's science programs are essentially the same. Even in the face of the ''information age,'' a set of goals reflecting current social conditions has not yet emerged.

While there is no agreement on the goals of science education, a consensus appears to be emerging. It is important that the schools of today be responsive to the society they serve and that schools try to anticipate the world in which students will live.

In support of this position, let us examine some current goals of science education and who holds them, the emergence of a new consensus on science education goals, and how school practices can be changed to reflect this new consensus.

In examining some of the current goals of science education, the findings of the National Science Teachers Association's Project Synthesis are particularly illuminating (10). The purpose of the project was to examine the status of science education at the elementary and secondary levels in the 1960s and 1970s and to make recommendations regarding future practices in science education. Four comprehensive data bases were examined to ensure the validity of the recommendations (11, 17, 28, 32). For the purposes of the project, science education goals were divided into four broad categories. Goals regarding individuals' preparation to use science to improve their own lives and to live in an increasing-

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ly technological world were grouped under the category of *personal needs*. Goals pertaining to preparing citizens to deal responsibly with science-related social issues were grouped under the category of *social issues*. Goals pertaining to acquiring academic knowledge of science required by individuals likely to pursue science academically and professionally were included in the third category, *academic preparation*. Goals pertaining to the acquisition of knowledge and utilization of knowledge regarding the nature and scope of scientific and technological careers were included in the fourth category, *career education*. The desired state of science education was described using this framework. The desired state was then compared with the actual state of science education, resulting in a description that could be used prescriptively.

The most striking finding of Project Synthesis was that goals that could be included within the third category, academic preparation, were almost the exclusive focus of science teaching in our schools (10). Goals pertaining to personal needs, societal issues, and career education were largely ignored in classrooms and in textbooks. The reasons for this can be found by examining common school practices, the influence of textbooks, and societal pressures.

Teachers, for the most part, determine the goals of science education pursued in their classrooms. They make the most important decisions about course content and instructional methods (28, 32). Teachers' involvement in the selection of curricular materials far exceeds that of either district supervisors, principals, superintendents, school boards, or parents (32). Even though most decisions about text adoptions are made by representative committees at the school or district level, teachers still have considerable autonomy in the way these materials are used to teach science (28). Within the limits set by the administration, this autonomy may be expressed in teaching style, in selection of text and text supplements, in assignment of grades, and in many other ways.

In day-to-day practice, teachers fail to consider the ultimate utility of the science knowledge and skills they teach (37, 39). Preparing students for specific examinations and later coursework appears to be the primary goal of most science teaching. Little regard is given to preparing students to use science in the personal, societal, and career decision areas (3, 8, 10, 27). Teaching practices are guided by factors that contribute to the socialization of students (e.g., teaching students to learn from books, to attend to directions and lectures, to prepare for later coursework). These practices, for the most part, are encouraged by parents and school administrators, but conflict with the practices encouraged by the science education leadership (16). Such practices may well be caused by the lack of sufficient numbers of properly trained science teachers. They also may be the reason why a majority of students believe the things they learn in science classes are dull, are no fun, and have little relevance to the real world (37, 39).

Interestingly enough, there is a major gap between teachers' stated expectations for their students and their teaching practices. Teachers at all grade levels, when responding to questions posed by John Goodlad and his colleagues, stated that they wanted students "to be able to compare and contrast phenomena, explore the interrelationships among living things, interpret environmental changes, make inferences from data, formulate hypotheses, observe and classify, develop habits of inquiry, and so on" (9). However, observations in classrooms led Goodlad to conclude that "teachers were not able. . .to square their performance with their theory" (9). Other researchers contend that classroom practices reflect neither an emphasis upon inquiry and problem solving nor a concern for technical and societal issues. Further, they find that these practices are not viewed as important by teachers and school administrators (10, 39). Observations by Stallings and her colleagues support this contention (27). They further observe that students in general science courses receive more workbook and reading assignments and interact less with materials than students taking advanced courses. These practices persist despite research findings that suggest that "hands on" activities should precede more abstract experiences and that science taught in this manner is likely to present a distorted picture of science learning. These are but some factors that cause fewer students to take advanced science courses.

Current science teaching is marked by the almost total reliance on textbooks that present science as "fundamental knowledge" (37). Stake and Easley found that teachers rely on textbooks at least 90% of the time and that the typical method of lesson presentation is "assign-recite-test-discuss" (28). The reliance on textbooks is also verified by student responses to affective items, which were part of the National Assessment of Educational Progress (NAEP) in 1978 and included in a survey administered by Hueftle and her colleagues (13, 17). Students believe that the textbook is the major determiner of content studied. In other words, the curriculum infrequently ventures beyond the boundaries set by textbooks. Stake and Easley further suggest that reading is the primary mode of science learning in our schools. Parenthetically, it may be useful to think about the impact on poor readers of this reliance on the textbook. Because poor readers are unable to process the information printed in the science book, they are "punished" twice for the lack of reading skill.

Several analyses of textbooks have been conducted. Since the textbook is central to science education *practice*, it is interesting to note what is included—and excluded—in widely used texts. The textbooks most frequently used in all science disciplines at all levels are, for the most part, devoid of the characteristics representative of any goals other than academic preparation (16, 23, 37). For example when the most widely used biology textbooks were examined, possible learnings about insects that seem particularly useful in peoples' everyday lives (e.g., damage done by insects, ways of controlling harmful insects) were not included. Similarly, activities that would reflect the societal relevance of insects (e.g., economic impact of insects on food supplies, necessity for the use of insecticides in agriculture) were not evident. Likewise, learnings to foster career awareness (e.g., job description of insect exterminator or entomologist) were not found (16). Taxonomical information, the description of insect body parts, and the behavior of social insects represent the breadth of information presented in most biology textbooks.

The insect example appears to be representative of the content found during reviews of most other secondary school textbooks (2, 33). In these reviews, places in the textbooks where information or activities pertaining to the other goals could be easily and logically integrated were noted.

Elementary textbooks fitting the categories "widely used texts," "NSF funded curriculum," and "new generation texts" were also reviewed (23). The general description of the "widely used texts" matches that for biology textbooks described above. The textbooks included in the categories "NSF funded curriculum" and "new generation texts" emphasized the goals of personal needs, societal needs, and career education better than elementary textbooks widely used (23).

Personal, societal, and career education goals seem, then, to be given little consideration by authors and publishers when developing science textbooks. The scarcity of information and activities found in science textbooks at all levels relevant to these goals is evidence of the low priority that is given to learning experiences that will help prepare students for the problems they will face in the future.

Textbook authors and publishers cannot be held responsible for the lack of information and activities pertaining to the personal, societal, and career education goals. They respond to the market: what teachers want to teach and what the public believes should be taught. Our national concern for "keeping up with the Russians" and "meeting the industrial challenge of Japan," has recently been reflected in several documents that report on the status of education (19, 24, 29). Among the recommendations are calls for at least three courses of high school science for all students, more time for the teaching of science at the elementary grades, and more rigorous content in textbooks and other curriculum materials. Unfortunately, increased rigor is being interpreted in much too narrow a fashion, namely as science that concerns itself with only the concepts, laws, and theories of science. This current interest in improving science education seems to be founded on the wrong premise; it does little to foster the goals of personal needs, societal issues, and career education.

In concert with the mood of these recent reports, parents and school personnel recognize the need for minimal competencies in science; however, these competencies are given low priority when compared to reading, spelling, writing, and mathematics (10, 28). The decline in financial support for education in the sciences and the diminishing time allocated to science in the early grades suggests that funding agencies and the public place little value on science education. Conferees at the Exeter Conference on Secondary School Science Education contended that this is because the public sees what is being taught in science classes as not relevant to today's problems (22). However, some science courses are given high priority; for example, chemistry and physics for brighter students are protected tenaciously by teachers responsible for those courses and these courses are viewed by the public as necessary for preparing future scientists (37).

In summary, then, the school practices in science education that are most evident today reflect goals that were established in the late 1950s. The primary goal of that time was to produce more students who would pursue further studies in engineering and science when they went to college. The future engineers and scientists, then, would help regain America's position of prominence in scientific applications. The other three goal areas we have indentified—personal needs, social issues, and career education—were largely ignored in classroom practices, in textbooks, and by society, except as they fit into the national press for more scientists.

However, as early as 1962, the Educational Policies Commission published this statement:

> The schools should help to realize the great opportunities which the development of science has made apparent in the world. They can do this by promoting understanding of the values on which science is everywhere based. Although no particular scientist may fully exemplify all these values, they characterize the enterprise of science as a whole. We believe that the following values underlie science:
>
> 1. longing to know and to understand,

2. questioning of all things,
3. search for data and their meaning,
4. demand for verification,
5. respect for logic,
6. consideration of premises, and
7. consideration of consequences (5).

Clearly, if these values were imbedded in the science curriculum studied by all students, we would expect to see educational objectives similar to those reported by teachers to Goodlad. Moreover, we would expect to see practices related to the values enumerated by the Educational Policies Commission.

Nevertheless, science as general education shows no sign of either being considered as one of the "basics" or of gaining substantial public support (11). "The low amount of time (allocated for science) in the elementary schools and relatively low percentage of teachers in the secondary schools suggest some lack of certainty about the importance of science as a field of precollegiate study" (9). However, the leadership of science education as a profession has consistently worked to overcome this perception of science as an elitist subject. While there is no unanimity of form or content in the goals statements that have been articulated by various groups and individuals who constitute the national leadership, there is clear evidence of a growing consensus. Consider, for example, this statement by Paul D. Hurd about the goals of science education. He identifies four large purposes of science education:

- sensitizing students to expect and anticipate change;
- recognizing that the future of human beings and the quality of life are not capricious;
- enhancing students' self-concept so that, as individuals, students can use knowledge of science to make decisions that can lead to a more desirable world; and
- helping students to acquire capacities to cope with changes, as well as to shape changes (14).

Hurd wants to see science taught as preparation for life in a changing world. More specifically, he wants schools to prepare children for life in a democratic society in a changing world.

Simpson and Anderson, in a textbook intended for use in university classes preparing students to be teachers of science, offer a description of the "scientifically literate person." This description can easily be converted to goals statements congruent with those of Hurd and of the Educational Policies Commission.

The scientifically literate person:

- has knowledge of the major concepts, principles, laws, and theories of science and applies them in appropriate ways;
- uses the processes of science in solving problems, making decisions, and in other suitable ways;
- understands the nature of science and the scientific enterprise;
- understands the partnership of science and technology and its interaction with society;
- has developed science-related skills that enable him or her to function effectively in careers, leisure activities, and other roles;
- possesses attitudes and values that are in harmony with those of science and a free society; and
- has developed interests that will lead to a richer and more satisfying life and a life that will include science and life-long learning (26).

Does research give us a picture of the current thinking about what today's goals for science education should be?

As identified by the National Science Teachers Association's accomplishments and needs study, the appropriate setting for any consideration of science education is the interdependence of science and society (21). As a young discipline, science education should be concerned with the relationship between science and society, with interpreting science to society, and with interpreting and studying the effects of science on society (34, 35, 38).

Part of the emerging consensus, then, suggests that the most significant influence upon science teaching at all levels should be current societal issues and problems. From such a frame of reference, values, goals, and objectives of science education can be formulated to meet the needs of our society and of students.

Science process skills and general inquiry processes are essential and generalizeable intellectual procedures. Students need to have the opportunity to experience science as inquiry, as well as to learn about the products of inquiry (33).

Goals need to be generalized in the area of problem solving. Problem solving should not be restricted to solving problems that are bound by specific science disciplines (35). Problem solving, in a more general sense, should involve the use of scientific knowledge in making decisions in a real-world context (3, 13). In such a context, problem solving shifts from uncovering correct answers to discipline-bound problems to investigating less-than-perfect alternatives to science-related problems. Students then make choices that will increase positive outcomes and minimize negative side effects. Students need practice using problem-solving skills in the context in which these skills are likely to be used; they cannot be expected to transfer problem-solving skills learned in a restrictive scientific discipline to new situations that demand both scientific information unknown to the students and problem-solving skills different from the ones they know (18).

Career awareness needs to become an integral, rather than incidental, component of science learning (6, 35). Career awareness activities can provide opportunities for students to learn about scientific and technological careers that will be in demand in the future. The biographies of historical people do not adequately represent current career opportunities; thus, they are of little benefit to students in making career decisions.

Science education has traditionally emphasized its value-free concepts and activities. However, students need to learn that science and applications of science influence social issues that are value laden. Of necessity, thinking about and studying value laden, moral, and ethical issues must be a part of science courses (4, 7, 30, 37).

This need, of course, cannot be met by prescriptive, dogmatic presentation of the "answer" to complex issues about which reasonable people disagree. In fact, the inclusion of societal issues in science courses will lead students to an understanding of the limited but important help that science provides in forging solutions to important societal issues.

Perhaps the most extensive and necessary change in the goals of science education is the addition of attention to the relevance of scientific knowledge to societal issues and human needs (3). Goals pertaining to the nature and structure of the discipline must be balanced by other premises for selecting the content to be included in science courses (10). More attention must be directed toward the impact of scientific and technological advances on a variety of societal issues, including human engineering, use of natural resources, environmental quality, and energy availability and use.

Attention must also be directed toward preparing individuals to use science and technology to improve their lives and to adjust to changes taking place in the world around them (35). This can be done by organizing science programs around themes like the human being, human potential, human advances, and human adaptation (3, 34).

In sum, those goals that reflect the emergent consensus contribute to the development of scientifically literate citizens: citizens "who understand how science, technology, and society influence one another and who are able to use this knowledge in their everyday decision making" (20, 36). Such a citizen is the foundation of our democracy.

To be sure, widespread debate is to be expected and welcomed before the goals of science education are established in a definitive way. Redefinition will only come about "through the involvement of science teachers, other educators, scientists and technologists, and the public as a whole" (3).

How must school practices change to reflect current thinking about the goals of science education?

The application of science to problems of personal and societal relevance must be a common theme at all levels of science education. Concern for personal and societal relevance is not likely to evolve from a science curriculum that treats personal needs and societal issues as problems to be solved by others. Nor is concern likely to evolve when personal needs and societal issues are not regularly included in science programs or when they are treated as things to hear about rather than as things to be acted upon. The solution is rethinking what is important and relevant to the student.

A useful way to begin a consideration of relevance is offered by Mary Budd Rowe. She has proposed a list of questions that adolescents ask themselves and those around them. These questions are:

1. What kind of country is this?
2. What values control activities?

3. Where do I fit in?

4. Do they expect me to succeed or fail?

5. How much effort do I need to make?

6. Is success worth the effort?

7. Can I get help?

8. Do I have the energy and endurance?

9. What happens if I do not make the effort?

10. What am I up against? What is the competition?

11. What difference can I make?

12. Do I care? Does anybody care? (25)

While the questioning process described by Rowe may not be overtly conducted by adolescents, it seems clear that much adolescent behavior can be understood with reference to this search for meaning. If we compare these questions to the school curriculum, do we find a match? In what ways do school practices help adolescents answer these questions?

In order to use science to resolve personal and societal problems, students must understand the problems and how science is related to them. Furthermore, students must have a chance to learn appropriate methods of problem solving. Producing student outcomes such as these is possible by using one of at least two general curriculum designs. In one, science would be presented in the context of personal needs and societal issues (15). Using these themes as organizers, the curriculum may vary from location to location, reflecting community desires (12). The second alternative would be to organize science courses around the structure of the particular science discipline, but with content energized by frequent reference to relevant personal and societal problems (2). This new curricular focus would emphasize the utility of science knowledge in resolving persistent real-world problems and would "provide students with opportunities to participate actively in such applications" (10).

Teaching basic science knowledge should also be considered a common theme of science programs at all levels (3, 37). A basic understanding of the knowledge of science products and processes is necessary not only for those students intending to pursue careers in science and engineering, but for all students. Such basic science knowledge is necessary to enhance the general societal welfare and to meet the future personal needs of students. Moreover, the need to understand the knowledge of science products and processes can be enhanced through knowledge of science-related issues (3). Only when students reach the point of using knowledge of science can more and better acquisition be expected.

Specific changes in the science practices at the elementary, middle school/junior high school, and high school levels must also come about if a new consensus on science education goals is to be realized (10). At the elementary level, science outcomes must be valued and considered worth pursuing by teachers, principals, and parents. Misconceptions that inquiry has been tried and does not work and that discovery-learning, hands-on demonstrations, and field study are unproductive must be dispelled. Many of the barriers to a successful elementary science program stem from a lack of support from school administrators and the community. These barriers must be overcome. In many instances, available elementary curriculum programs could be implemented to match the goal shifts suggested by the new consensus.

The primary goal of science education at the middle school and junior high school level must shift from the preparation of a few students for future coursework to education of all students for future life. Science learning that could be defended only because of its "utility in advanced courses or in specialized fields" would be given lower priority (10). In conjunction with this shift, problem-solving skills and laboratory activities that make clear the implications of scientific principles and technological developments for problems faced by individuals and by society would receive increased emphasis (1).

At the senior high school level, general science education courses as well as college-preparatory courses would be offered. The physical science and introductory biology courses—because they are taken by the majority of college bound and non-college bound students—would stress topics of personal and societal relevance (35). Emphasis would be placed on the human species and how the human species interacts with the physical and living world. In addition, new courses would be offered that would not stress the structure of a particular science discipline but, rather, would focus on the applications of science and technology to daily life and would prepare students to participate more effectively in the affairs of a scientific and technological society. Such courses would offer attractive options to students who now take no science beyond introductory biology.

Academic college-preparatory courses in biology, chemistry, and physics would continue to be offered at the senior high school level. However, intertwined with the principles, facts, and processes required for further study would be learnings designed to emphasize the relationship of scientific and technological advancements to life and problems of the future.

Summary

Science education programs are under considerable pressure for a change in the direction of the utilization of knowledge. Analyses of existing programs reveal that discrete knowledge, in and of itself, continues to be the emphasis of all programs. While advocacy groups of the past have urged that science course content be revised and updated, it is now the basic goals of science education that are being reassessed. Using the interdependence of science and society as a frame of reference, the goals of science education can be reformulated to meet the needs of our changing society. The new science curriculum would be a demonstration of the realization that scientific knowledge is made concrete when it influences career choices, helps to solve social problems, and results in a richer life for the individual. It is this mixture of goals—for academic, personal, social, and career applications—that appears to define the new consensus.

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TEACHING AND LEARNING IN SCIENCE EDUCATION

Teachers feel a great sense of responsibility for seeing that their students learn. Chapters included here provide information about instructional strategies and systems, evaluation, the integration of science and other school subjects, and microcomputers.

Instructional Strategies in the Science Classroom

What can teachers do to increase their effectiveness in the science classroom? Are there methods and instructional strategies that are more effective than what teachers currently use?

The current crisis in science education in our nation's elementary, middle, and secondary schools has received widespread publicity throughout 1982 and 1983. The crisis is made more apparent by the results of three National Science Foundation (NSF) studies conducted in the late 1970's that characterized science teaching practices (6). These NSF studies and other reports describing science teaching practices, relatively unchanged since the 1950s, indicate that:

1. The predominant method of teaching observed was recitation (discussion), with the teacher in control, supplementing the lesson with new information (lecturing). The key to new information was the textbook.
2. The secondary school science curriculum was ordinarily organized with the textbook at the core. The textbook determined the course content, mode of instruction, and evaluation. The most significant curriculum decision that teachers made was their choice of a textbook. Once chosen, teachers attempted to cover all the content in the book, mostly in the order determined by the sequencing of the textbook, with instructional aids provided or suggested by the teacher's guide.
3. The next most frequently observed activity, the demonstration, was conducted in two out of five classes once a week or more.

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4. Student reports and projects were used once a month or more in half of the classes. Other teaching techniques were used infrequently or not at all.

5. The textbook's dominance of the curriculum tended to discourage the use of inquiry techniques that require students to do more than look up information in the text and then to recite or record it. Students were found to engage rarely in activities for which the answers were not provided by the textbook or the teacher. Many activities in science classrooms were nothing more than workbook exercises in following directions and verifying information given by the textbook or teacher.

6. A principal justification for science at every level was the preparation it provided for the next level. The goals of instruction were commonly limited to specific knowledge and specific processes. Evaluation of success in science emphasized definitions and knowledge dimensions.

7. Time spent in various instructional arrangements did not differ significantly for the various grade levels. Approximately half the time, the entire class was arranged as a group; one-sixth of the time, it was divided into small groups; and about one-third of the time, students worked individually (11, 22, 23).

These characteristics continue to be present in many classrooms today. Wise and Okey analyzed current research reports to give us a description of the typical or traditional classroom (21). In such classrooms, students are not aware of the instructional objectives. Most questions asked in the classroom are posed by the teacher, are primarily fact-oriented, and do not reflect any preplanning on the part of the teacher. Students usually have few opportunities to manipulate materials or plan activities that interest them. The teacher generally follows the book, is in control, and utilizes the lecture and discussion method. Any evaluation or testing is summative in nature for the purpose of reporting student progress. Formative testing (feedback-oriented) for the purpose of determining progress or performance to date is rarely used. On the whole, the typical classroom reflects very little planning on the part of the teacher, apart from the sequencing of the textbook. Input from students appears to have little impact on class planning.

This view of a typical or traditional science class is reflected in what students have to say about science teaching and science teachers (24).

From *The Third Assessment of Science* by the National Assessment of Educational Progress (NAEP) conducted in 1978 and from a replication reported in 1983, we find that student perceptions, opinions, and interpretations regarding science classrooms, their study of science, and their teachers provide a corresponding view of current practices.

Student perceptions of their role in determining instructional practices are most revealing. Most students perceive that they have limited, if any, input into determining the content to be studied. They also feel that they have no choice in the way they learn the science the teacher selects, the order of topics considered, when assignments are due, or when tests are to be scheduled. Most students feel that the textbook is always or often the only determiner of the order of the study of science. Students feel that they are encouraged to state their own opinions in less than half the science classrooms, and that they are actually discouraged in such actions in nearly a third of the classrooms. Nearly half the science teachers are perceived by students as seldom or never admitting that they do not know "everything" related to a given topic of study. Students feel that science teachers value students' ability to think for themselves; however, few science teachers are perceived as taking interest in their students. As many students feel that they are seldom or never encouraged to be creative as do those who feel their teachers always or often provide such encouragement.

In summary, there is little student satisfaction with science classes. Students generally see science class as dull, no fun, and a place where they do not wish to be. Students do not like the typical or traditional science classroom.

In order to increase their effectiveness in the classroom, science teachers need to realize that they do have choices about which methods and instructional strategies they can use. Science teachers must also be aware that they can make decisions based upon research to improve the instructional effectiveness of their own particular context, if they want their programs to succeed.

Through a series of case studies in science education, Stake and Easley found that teachers "feel imprisoned," as if no choices or decisions are open to them (18). Stake and Easley also found that many teachers feel they have little power to change things, see little more they can do themselves, and are resigned to the status quo. One is given a textbook; the textbook guides the course. Rarely do teachers attempt to alleviate this feeling of powerlessness by making instructional decisions based upon research evidence of what might be more effective.

The findings of current practice and the comments from students themselves reveal that what science teachers do in the classroom presently does not reflect the decision-making power available to them.

Realizing that choices are available and making decisions based upon research evidence are first steps toward increasing the instructional effectiveness of the science classroom.

From a number of research studies, a picture of a more effective science classroom is emerging. In this classroom we find instructional strategies and instructional systems that yield greater effects on learning outcomes than do typical or traditional classroom practices. In this chapter, we will examine research related to instructional strategies and instructional systems so that implications can be made for an emerging, effective science classroom in which teachers have choices and make decisions.

Does research tell us anything about the effects of various instructional strategies on student achievement?

In this chapter, the generic term "instructional strategies" will be used to cover instructional strategies, teaching techniques, and methods. One may view instructional strategies as a limited aspect of a more complex teaching plan that describes either the teacher's or student's role in the instructional process. By contrast, an instructional system is a general plan, encompassing many aspects, for conducting a course over an extended period of time. In this chapter, we will discuss instructional strategies and then consider instructional systems. We will conclude with implications for an effective science classroom.

Instructional strategies may be classified in a number of ways (16). Strategies in which the teacher has direct control are referred to as "teacher-centered." Common examples include lectures, demonstrations, teacher-led discussions, and questioning. "Student-centered" strategies allow students to play a more active or self-guided role. Common examples are laboratory activities, use of learning activity packets, and student-planned activities. Instructional strategies may also be classified as "direct" or "deductive," or as "indirect" or "inductive," each encompassing both aspects of student and teacher-centered instruction. The use of direct strategies implies that science is being communicated by the teacher to the student. The teacher is in control. Indirect strategies suggest the teacher plays the role of facilitator, guide, or catalyst. Science is being communicated through the materials to the student. The use of different strategies may require shifting role relationships and responsibilities for both teachers and students.

Research on the quality of instruction is extensive, diverse, complicated, and often appears to be inconclusive. Reviews of hundreds of studies have resulted in disappointment on the part of many reviewers who perceive a lack of substantive research in the quality of instruction and its influence on student learning (18). Often, attempts at research synthesis, based on the qualitative character of the research, give rise to differing views on the summative findings in a given research area. Long narratives citing study after study provide little basis for objective comparison and accumulation of results. If study characteristics and outcomes could be quantified, research synthesis might gain a new precision and objectivity, providing a finer measure of what is known, as well as giving a better picture of the gaps and flaws in the accumulated research (4).

A technique that allows quantitative synthesis of a large number of research studies is meta-analysis (9, 10). Meta-analysis is proving useful in translating the results of numerous studies on a particular topic into a concise form that is understandable to those who may be in a position to apply the results. (For a fuller discussion of meta-analysis, see Chapter 1.)

From the results of recent meta-analyses of instructional strategies, some clear directions can be indicated for constructing a working model of effective classroom practices. The first major meta-analysis of instructional strategies was conducted by Boulanger (4). The purpose of his study was to synthesize quantitatively the published science education research conducted during 1963-1978 with students in the 6th through 12th grades. Through a simple count of independent variables (instructional strategies), he identified from fifty-one studies six instructional clusters that related to cognitive outcomes.

The instructional cluster that produced the most significant gains in improving student conceptual learning was the use of preinstructional strategies such as behavioral objectives, advanced organizers, or set induction. These studies compared the effects of using a preinstructional strategy with a comparable instructional treatment, where no preinstructional strategy or placebo was used.

Preinstructional strategies may take any of several forms. A teacher may communicate the behavioral objectives to the class prior to beginning instruction. Set induction strategies prepare students for learning by directing or focusing attention on what is to be presented or learned, by frequently motivating students to attend to the lesson, and by encouraging students to become interested. Set induction strategies may take the form of questions that interest the student and can be answered later in the lesson. Advanced organizers allows the teacher to relate what is to be learned to what is already known. For example, this might be done by comparing the circulatory system to a hot water system prior to a presentation on the circulation of the blood. Advanced organizers relate the unfamiliar to the familiar. Use of any or all of these preinstructional strategies can improve student conceptual learning, especially when used with other instructional activities by classroom teachers.

Boulanger also found that greater realism or concreteness of supporting instructional materials was associated with greater cognitive achievement. Instructional materials may be placed on a continuum from concrete to symbolic: manipulatives are more concrete than are pictorial stimuli, which, in turn, are more concrete than printed text material. Similarly a student's lab experiment is more concrete than is a teacher's demonstration, and the teacher demonstration is more concrete than a lecture. All the studies Boulanger looked at showed that greater realism or concretness in supporting instructional materials led to greater cognitive achievement. When given a choice, those teachers who utilize manipulatives, pictorial stimuli, or hands-on experiences in appropriate instructional situations will be more effective in producing cognitive achievement.

A second large meta-analysis was conducted by Wise and Okey as part of the University of Colorado Science Meta-Analysis Project (21). The purpose of this study was to synthesize findings concerning the effects of various teaching strategies on science achievement. Through analysis of 160 studies, twelve categories of teaching techniques or instructional strategies were identified. All the categories represented a variety of means researchers have used to bolster science achievement by altering one or more aspects of the instruction situation.

The average impact of the teaching strategies analyzed in this report was an increase in achievement of about one-third of a standard deviation, or 13 percentile points. The most pertinent categories (those greater than one-third standard deviations) will be discussed here to identify their contribution to an emerging effective science classroom.

The most significant category identified is wait-time. Wait-time occurs when a teacher pauses from three to five seconds after asking a question and again after the student response is given. When teachers employ wait-time, researchers have found the length of student responses increases, the failure to respond decreases, the incidence of speculative thinking increases, student-to-student interactions increase, and more questions are asked by students. Wise and Okey found that use of wait-time strategies increases cognitive outcomes, critical thinking, creatively logical thinking, and affective measures by .90 standard deviations (21).

Another category of instructional strategies that proved highly significant was the use of focusing techniques. Focusing occurs when students are alerted to the objectives or intent of instruction before, during, or after instruction. General examples include providing students with objectives, reinforcing objectives at various points during instruction, or using advanced organizers. Focusing strategies help students focus their attention on what is to be learned, much the same as the preinstructional strategies discussed earlier.

Another category Wise and Okey created is one that corresponds to Boulanger's cluster of realism or concreteness. Wise and Okey refer to this as manipulation. Manipulative activities require students to handle, operate, or in some way work or practice with physical objects as part of the instructional process. Being involved with concrete manipulatives is much more effective in producing large effects in achievement than having students observe someone else performing an experiment, or merely reading about it.

Wise and Okey reported a number of other categories in which large effects in science achievement were shown (21). In all cases, teachers had altered some aspect of the instructional situation. For example, by modifying or revising instructional materials, teachers contributed to increased achievement. Materials were rewritten for a specific reading level or were annotated. Directions were presented orally, pictorially, or by audiotape.

Another attempt to alter the instructional process was through the use of questioning strategies to improve achievement. By varying the levels of questions asked or the positions of questions asked during instruction, teachers can help increase student achievement. For instance, attempts might be made to ask more questions requiring comprehension, application, or analysis skills instead of relying on knowledge-level questions. Or, teachers may ask questions during films, or before, during, or after assigned reading. The use of questioning strategies represents a deliberate attempt on the part of the teacher to involve students in the instructional process and helps call the students' attention to significant facts or concepts.

Another category of effective strategies related to using tests to improve achievement. Usually this involved a change in the frequency of testing, the purpose of testing, or the level of test items. Examples of effective use of tests include formative testing, immediate or explanatory feedback, diagnositic testing and remediation, optional testing, and testing to mastery.

Two categories produced smaller achievement effects (around one-third standard deviations). The inquiry-discovery category included teaching techniques that were more student-centered and less step-by-step teacher-directed learning experiences. When teachers utilized inquiry lessons, guided discoveries, or inductive laboratories, improvements in achievement were noted. A similar category called "teacher-direction" included variations in the extent to which the learning task was spelled out for the student. Examples include situations in which students conduct experiments or activities given only sketchy direction, or when students select specific objectives and assume responsibility for learning those objectives.

What is important about the results reported by Wise and Okey is that a deliberate attempt was made by teachers to alter some aspect of the instructional environment to produce gains in achievement. The categories discussed above have resulted in successful teaching and learning.

The Wise and Okey study offers support for other recent research reviews that have concluded that direct teaching strategies have greater impact than indirect ones (14). The large effect sizes of wait-time and focusing are related to direct instructional strategies. The relatively smaller effect sizes of inquiry-discovery and teacher direction are related to indirect instruction.

While the results of these two meta-analyses are not definitive and specific toward a particular instructional strategy, they do provide an overview and suggest some directions for future research. A number of implications can be drawn upon which to build a picture of the effective science classroom, which we will discuss later. Upon closer analysis, these quantitative results agree fairly consistently with the qualitative summaries of research on instruction that have been reported in the science education literature (13, 17).

Inquiry-teaching and learning have been prevalent aspects of the science education literature of the past quarter century. The results of four meta-analysis studies point to positive results from inquiry teaching (2). Separate meta-analysis studies of elementary and secondary science curriculum projects found the use of curriculum materials developed with an inquiry philosophy to be more effective in enhancing student performance than most critics were willing to admit. Student achievement scores, attitudes, and process and analytic skills were either raised or greatly enhanced by participation in the new science curricula. Wise and Okey, in their analysis of instructional strategies, found an increase in cognitive outcomes when the inquiry-discovery strategy was used in science classrooms (21). In a study of the effects of inquiry teaching compared with inductive and deductive teaching approaches, positive support was given to inductive teaching strategies (12).

While the support for inquiry teaching and learning is not significantly conclusive, inquiry teaching appears to be a viable strategy that science teachers need to consider in any attempt to increase their effectiveness.

What is an instructional system? Are some more effective for science teaching than others?

While instructional strategies may be viewed as a component part of a more encompassing teaching plan, an instructional system is a general plan often encompassing many aspects of a course over an extended period of time. Consideration of instructional systems is necessary because they provide a framework that can accommodate a variety of instructional strategies. Many instructional systems like team-teaching, programmed learning, individualized instruction, contract learning, and audio-tutorial systems have been in existence for a long time. Others, like computer-linked instruction, mastery learning, and personalized systems of instruction, are new arrivals. Instructional systems can provide a coherence to various arrangements of instructional strategies.

A meta-analysis was conducted to determine the effects of different instructional systems used in science teaching (20). In the analysis of 130 studies, two instructional systems generated significant results that set them apart from the other instructional systems examined. The two are mastery learning and personalized systems of learning (Keller Plan). Compared with conventional instruction, both mastery learning and personalized systems of learning were 0.64 standard deviations better on all learning outcomes. (Specifically, both systems were 0.50 standard deviations better on cognitive outcomes, 0.52 standard deviations better on affective outcomes, 1.24 standard deviations better on measures of scientific methods, and 0.89 standard deviations better on measures of critical thinking). In contrast, instructional systems of individualized instruction, media-based instruction, audio-tutorial learning, computer-linked instruction, programmed learning, team teaching, and self-directed study operate at a level only a little higher than the conventional instruction they replaced.

The instructional systems mentioned above all represent a departure from the day-to-day conventional teaching practices described earlier. In all cases, teachers involved with instructional systems have made commitments to alter significant aspects of their courses (how content is presented, sequencing, testing, grouping, the materials of instruction) as part of a total package. Teachers have invested time and effort in preparation and have sought out the details of how to operate in whichever system is chosen.

For example, the personalized system of instruction (Keller Plan), mostly found on the college level, contains the following features: learning is self-paced; learning materials are divided into small modules, each of which must be mastered before going on to the next; students are used as graders and tutors; there is a lack of reliance on live lectures, with printed materials being the primary form of communication; and a detailed study guide is available. A key factor to the success of the personalized system of instruction is frequent testing with immediate feedback (20). This feature is also found in mastery learning and may explain why these two systems of instruction have been more successful than the others reported here.

Because mastery learning is a term often heard in educational circles today and because its results were so significant in the meta-analysis study of instructional systems, it is important to examine what mastery learning is and what research is associated with its effectiveness.

Mastery learning may be viewed both as an instructional system and as a technique of instruction that can be applied to many different instructional situations. While the term "mastery learning" is often associated with learning of material that is "mastered," it is also important to note that mastery learning can be viewed as a rubric or heading under which a number of features of successful or effective instruction can be grouped.

Bloom formulated the modern conception of mastery learning as a teaching strategy that could enable most students to achieve at high levels (3). His conception has been refined and elaborated on by others over the past several years. Essentially, mastery learning is an instructional technique for the teaching and learning of *hierarchical*, *sequential* material. The content areas compatible with mastery learning procedures appear to possess several common characteristics. They require a minimum of prior learning, are sequentially learned, emphasize convergent thinking, and possess a finite set of ideas and cognitive behaviors. A large portion of our middle and secondary school science curriculum matches these characteristics.

In the science classrooms using the mastery learning approach to instruction, the material to be learned is subdivided into natural units or steps, covering from one day's lesson to several weeks' lessons. Next, student performance is specified and a level at which mastery is to be attained is determined. This is called the criterion level, usually set at 80%. The science units are taught using group instruction, laboratories, and the other usual activities that occur in science instruction.

Next occurs the most important feature of the mastery learning approach. Students are given help when and where they are having difficulty. This step is frequently called the diagnostic remediation cycle. Frequent diagnosis is given through formative testing (progress tests) throughout the unit of instruction to identify learning difficulties and provide positive reinforcement for those who master the material. The progress tests reflect the objectives communicated to the students at the start of the unit of instruction; mastery is judged according to the criterion levels specified. The diagnosis is followed by feedback to the student and may or may not be accompanied by remediation. Remediation may be either teacher- or student-managed. The student may reread the text, do laboratory work again, use programmed materials, have private tutorials, etc. Importantly, additional time is provided for students to learn material they missed or did not learn the first time through the unit. The diagnositc remediation cycle—use of testing, followed by specific recommendations for improvement and additional time if needed—is the single most important feature of the mastery learning approach.

The mastery learning approach emphasizes the achievement of all students for a given science unit, and eventually, the science program. The purpose of mastery learning strategies is to help practically all students attain a level of achievement now reached by only a few students. Most students can be successful with mastery-based instructional approaches. Mastery learning does not advocate lowering standards so that fewer students fail, but rather giving students more appropriate opportunities to learn material, which results in fewer failures (8).

Many researchers have found mastery learning procedures superior to non-mastery methodologies (3). Other researchers are investigating various aspects of the strategy to improve its effectiveness with students and to enhance its appeal to teachers. For example, Yeany and Miller determined through a meta-analysis of diagnostic/remedial instruction on science learning that it makes little difference whether remediation follows feedback (25). Apparently, in the absence of prescribed remedial activities, science students attend to their own remediation when provided feedback from the diagnosis of achievement deficits. Providing only diagnostic feedback to the science student is far simpler and less demanding than following up with complex remediation schedules and cycles.

In another study, conducted by Dillashaw and Okey, the effects of a mastery learning strategy modified to limit diagnosis to two cycles per unit of instruction were tested with high school chemistry students (7). The results were significant. The study indicates that high school science teachers may be more willing to spend time constructing formative or progress tests and using remediation activities with the knowledge that only two cycles of diagnosis and remediation can increase student achievement.

When mastery learning techniques, particularly diagnostic/remedial cycles, are utilized in other instructional systems, a notable increase in achievement occurs. Aiello and Wolfle conducted a meta-analysis to compare the effects of different types of individualized instruction methods (1). They then tried to determine the effectiveness of programs that incorporated mastery learning features into their instructional formats. It was found that a category labeled "combination of methods" increased achievement 0.36 standard deviations. When mastery learning techniques were incorporated into the "combination of methods" category, achievement increased to 0.67 standard deviations.

From the results of research into instructional systems, mastery learning emerges as a powerful instructional strategy or system when used alone. In combination with other techniques, its power is increased. These are results that are difficult for science teachers to ignore.

What does the research say about how an effective science classroom looks?

The effective science classoom is one in which instructional objectives are formulated and communicated to the students prior to the start of a unit of instruction. The objectives are carefully planned by the teacher and may have criterion-performance levels identified that are needed for mastery. Throughout the process of instruction for each unit, students receive feedback about their progress toward those objectives.

Teachers use set induction and advanced organizers to direct or focus attention to the lesson and provide connections between new learning and previous learning. These may take the form of questions that interest the student and that can be answered later in the lesson, or they may be short activities, demonstrations, or the presentation of familiar ideas that are related to what is to be learned. In effect, students are prepared for instruction either at the start of the unit or daily as a result of deliberate planning and actions taken by the teacher.

Students interact physically with instructional materials whenever possible through handling, operating, or practicing. Efforts are made by the teacher to provide greater realism or concreteness with the materials of instruction. Greater efforts are made by the teacher to incorporate use of manipulative and pictorial stimuli along with printed matter.

Teachers alter instructional materials or classroom procedures when they think that these alterations will increase the impact. For example, materials may be rewritten for clarity or reading level. Alternative reading materials may be provided for those students who have reading difficulty. Directions may be presented in other than written forms. Alterations occur as the result of deliberate action on the part of the teacher.

Greater attention is given by teachers to the types and placement of questions asked in the classroom. Attempts are made to ask fewer knowledge-level questions and to ask more questions requiring students to show that they comprehend, can apply, and can analyze what they have learned. Questions may be asked to cause students to hypothesize about what might happen, to make inferences about what is observed, or to apply what they have learned in a different context. The teacher asks questions throughout the lesson at appropriate times so that students attend to the instructional process. Yet, a barrage of questions is avoided. Questioning is part of the instructional plan. Teachers give students more time to respond to questions and wait longer before they act on a student's response. This action increases the length of student response, decreases the failure to respond on the part of students, increases the incidence of speculative thinking, promotes more student-to-student interactions, and causes more questions to be asked by students. In effect, the teacher bases verbal interaction with students on a plan that is formulated to yield desired results.

Greater use of formative (progress) testing techniques is made in conjunction with immediate or explanatory feedback, with possible remedial activities. Students select from a "menu" of remedial activities. Whether mastery learning has been adopted totally or not, some of the features of mastery learning will be utilized as part of a plan to assist students with their learning.

The effective science classroom reflects considerable teacher planning. More thought and care are given to maximizing learning outcomes. Teachers are aware of ways to utilize the time available in the classroom to increase the amount of academic engagement time (time-on-task) on the part of their students (5). Classrooms in science are better managed by the teacher. All of this reflects considerable effort and planning on the part of the teacher with the aid of the students.

Will science teachers still use lectures and recitation? Probably so. Will the textbook still be the key to new information, determining the sequence of instruction and what is learned? Probably so. But not to the extent revealed in studies of current practice. Lectures will be shorter, more interesting and meaningful; discussions more involved. A portion of the textbook will be read very carefully. The students will learn more and will find greater satisfaction in science classes.

The picture of an emerging effective science classroom is a vivid contrast to the typical or traditional classroom described earlier. In order to achieve it, science teachers need to realize that choices are available in terms of possible actions to take. Science teachers must make decisions in light of their own particular instructional context about how to proceed to implement an effective science classroom based on research evidence. The teacher is still the most important variable in the classroom (6).

Summary

A probable cause for students' failure to achieve in science classes is the use of teaching strategies that are text-based rather than learner-centered. Meta-analyses have shown that several teacher practices are associated with increased achievement. The use of pre-instructional strategies (set-induction, advanced organizers), the use of thoughtfully altered materials, and the use of more concrete experiences all lead to greater cognitive gains.

Research also indicates that the diagnostic remedial cycle, and the increase in time for learning, that is a feature of mastery learning leads to increased learning. Thus, specific strategies for teaching an instructional management system that permits feedback to students will lead to improvements in students' learning.

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Evaluation of Student Progress

I spend a great deal of time designing a variety of activities for use with my science classes. However, I'm not sure how to assess my students' progress. How can I tell if my students are really learning from my science classes?

Science has become a major focus in our lives. Increased attention is paid to showing the public the role of science in everyday life. Weather forecasters on television and radio explain the causes of weather patterns and the consequences of shifts in wind or temperature. Recent medical discoveries are explained and health advice is presented from the perspective of the consumer. Space exploration reporting has made many complex phenomena understandable to a wide audience. Today the public is "doing science" or watching scientific history being made to a greater degree than ever before.

Teachers want their students to have positive attitudes toward science and to value science's contribution. Teachers know that not every child who studies science will become a scientist. Most teachers don't develop their lessons so that all students will consider a career in science. However, they would like their students to act like scientists and to conduct active research in their classrooms. They teach science in ways that help students become interested in science and learn how a scientist thinks. Science teachers want students to learn that scientific research must proceed according to a specified set of rules, but that there is room for creativity, originality, and excitement in science. They would like their students to gain insights into that excitement. By structuring lessons to provide "hands on" time and "messing around" time, teachers hope to stimulate students' understanding of science as a process of discovery and not just a body of facts. They want to develop scientific literacy so that their students will begin to think like scientists and understand how scientific theories are constructed and tested (2). Many teachers have been skillful at creating interesting lessons and at

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allowing students to experiment, and to work independently and actively. Naturally teachers want to assure themselves that their lessons are having an impact on students. They want to measure the effectiveness of their lessons, especially lessons that are activity-based and not derived from textbooks. However, many teachers are troubled that what they teach isn't measured by many of the tests available to them. They would like to measure a broader array of student skills than is possible with many traditional tests.

Measuring what students have learned is not easy. It is difficult and time-consuming to assess how well students can generate hypotheses on their own or how adept students are at writing operational definitions. Few teachers have been thoroughly trained in testing and evaluation. Many lack familiarity with the basic testing tools that permit the measurement of many facets of students' science knowledge. With careful curriculum analysis and careful planning, teachers can measure students' knowledge of science facts and their ability to reason scientifically.

Evaluating science learning is similar to teaching a good science lesson: it takes thorough planning, skillful execution, and careful review. Techniques for evaluating students' science learning are available and can be adapted to meet most science teachers' specifications.

One of the first steps in developing a good science evaluation program is to develop an evaluation plan. An effective plan for evaluating students' science learning takes into account all the goals and objectives of the science curriculum, stressing the skills and knowledge the teacher will emphasize during instruction. Once the curriculum is analyzed, teachers need to choose an appropriate evaluation strategy, or several strategies; test students; analyze the results of testing; and study the implications of test data for future instruction. Each step is important. Unfortunately, teachers often skip over or combine one or more steps. Then students complain that tests don't really test what they've learned, or teachers express concern that they can't relate students' test performance to their day-to-day classroom performance. By carefully planning the match between curriculum goals and evaluation strategies, teachers will be able to assess students' progress more accurately and design additional instruction specifically targeted to students (1, 6, 8, 31).

Why is it important to review the goals and objectives of my curriculum when creating an evaluation plan?

Not all science courses are alike. Some are based on textbooks that stress basic facts and terminology. Other texts present a history of science and are designed to give students an overview of the major milestones. Some texts encourage teachers to present demonstrations of significant scientific experiments or to conduct experiments that convey key ideas in science.

In recent years many science programs—not based on textbooks—have been developed with the goal of encouraging students to re-create scientific experiments and to share the results of those experiments with other students (9, 22). Innovative programs like Science—A Process Approach, the Individualized Science Project, the Intermediate Science Curriculum Study, Elementary Science Study, and others were planned as alternatives to conventional textbooks (38). At the elementary school level, these programs emphasize students' learning how to think as scientists do. Students were encouraged to observe, record, analyze data, and consider the meaning of the data. The goals of the innovative projects included developing students' ability to infer, to generate hypotheses, and to evaluate experiments. Not only do these science programs differ from conventional text-based courses, they also differ from one another. Just because two programs are described as innovative does not imply that they share the same goals, use the same strategies, or build the same skills. Indeed, the same program taught by two different teachers may lead to different results in students' learning. One teacher may stress students' mastery of the techniques of data collection, while another may stress the inferences students draw from the data. Different programs and different instructional approaches will yield differences in students' scientific knowledge. Different evaluation strategies may be the only way to measure what each group of students has learned. In any case, a wide range of information and skills can be evaluated. For example, among the skills science educators can measure are:

- *Acquisition of basic science facts.* Do students learn the technical terms, special vocabulary, and basic information?
- *Recall of facts.* Can students memorize and recall information?
- *Application of basic facts.* Can students use the basic facts to analyze a situation and tell how it is similar to another one they learned about? Can students read about a situation and supply missing information?
- *Understanding the generation of scientific theory and its relation to subject areas.* Can students identify an operational definition? Can

they distinguish between cause, effect, and accident? Can students read about scientific discoveries and understand the processes and products that result?

Activity-based or process-approach science programs, stressing the way scientists think, emphasize other skills in addition to basics. These programs are predicated on the notion that scientists handle objects, analyze the properties of those objects, and examine the relationships among objects. Analyzing a curriculum to see which skills are emphasized will help teachers develop evaluation tasks matching instruction. While different curricula stress different skills (and even call the same skill by different names), the following skills are important:

- *Naming*. Given an object, a student should be able to tell what it is. For example, "That is a large, round brown sponge."
- *Comparing*. Given two or more objects, a student should tell how they are alike. For example, "Both the red one and the yellow one are round."
- *Discriminating*. Given several objects, a student should tell what sets one or more of them apart. For example, "Only the green circle is big."
- *Analyzing*. Given a situation, a student should be able to tell which are the relevant variables and which are irrelevant. For example, "The black beads are not all the same weight but all the large beads weigh the same."
- *Designing*. Given a problem, students can design an experiment that will test hypotheses. For example, "To test which beads weigh the same, construct a balance beam and weigh the beads alone and in combination."
- *Evaluating*. Given a report, students will study it and tell what could have been done differently. For example, "Instead of just planting seeds and watering them, the class should have checked the effect of different kinds and amounts of light. Maybe the seeds received enough water but not enough light."
- *Predicting*. Given information about relations among variables, students will be able to predict if a situation will follow the pattern of other situations. For example, "Grass usually doesn't grow under trees. Since there are many trees in a forest, I wouldn't expect to find much grass in the forest."

These cognitive skills are but a few that can be developed by science instruction. Their acquisition and use is important if scientific thinking is to occur. Taxonomies of cognitive skills are available and can be a valuable guide to teachers assessing their science programs (5, 9).

Once teachers have decided which skills are fostered by their programs, they can match their evaluation strategies to those skills. But teachers must be careful. Not all evaluation strategies are equally appropriate. For example, it would be inappropriate to use a true/false test to assess students who have been following a curriculum like Biological Sciences Curriculum Study or Physical Science Study Committee. Students who have been taught to analyze, compare, and evaluate would not use those skills to answer the question "Whales belong to the class *mammalia*. True ___ False ___ ." They would call upon those skills, however, to answer the question "Whales are similar in some ways to man and in some ways to fish. Write an answer defending that statement." The strategies of thinking that have been fostered by the program should be evident in the answer. If not, either the student hasn't learned or the student knows the answer and is unable to express it. In either case, some additional instruction would be appropriate. The important point to remember is that there are many strategies for testing students' skills. Some are more appropriate for one curriculum than another and some will be easier for students than others. Some typical strategies are:

- *Short-answer tests* (true/false, multiple choice, completion). Short-answer questions are best used to assess students' knowledge of basic facts and their ability to make simple discriminations.

  Examples: Whales are mammals. True ___ False ___

  The largest planet is:
  (a) Pluto
  (b) Neptune
  (c) Mars
  (d) none of these

  Sponges belong to the phylum ________________ .

- *Essay questions.* Essay questions can test basic factual information, students' ability to compare and contrast, or students' ability to do higher level critical thinking and problem solving. However, caution should be exercised when using essay questions. Teachers often reward writing skill as well as scientific knowledge on such tests. The teacher needs to ensure that the test measures what it sets out to measure.

  Examples: What indicators do weather forecasters use to predict changes in the weather?

  Which is more important in conducting scientific experiments, recording data carefully and accurately or relying on hunches?

  If you landed on a remote star in the solar system, what clues could you use to tell its history?

- *Practical tests.* Practical tests are usually more appropriate for testing students' ability to think critically and to predict outcomes by means of problem solving.

  Example: Do tulips need light or heat or both to bloom? Design a simple experiment to answer the question.

- *Projects.* Projects can help students acquire basic facts as the basis for making inferences or can allow them to do original problem solving.

  Examples: Collect information on the vegetation of rain forests, deserts, and mountains. Analyze the data and compare the results.

  Collect leaves from deciduous trees and from evergreens. Compare.

  Can robots think? Define what you mean by thinking and then see if you can design a thinking robot.

- *Oral Reports.* Oral reports can be used to communicate facts. Students can apply their knowledge and draw conclusions from the information.

  Examples: Present a brief biography of Charles Darwin and state his major contributions to science.

  Discuss recent science events and tell how they affect our lives.

- *Lab Reports.* Lab reports can be used to help students practice rudimentary record-keeping. They can be used to help students draw inferences from the data.

  Examples: Summarize the major points of today's experiments (goals, procedures, equipment, etc.).

  Contrast the results of this week's experiment with the results of last week's experiment. Discuss why the results of the two experiments differed.

These applications are but a few of the ways to assess students' learning. Discussions of science evaluations and other types of program evaluations are resources for such strategies (1, 3, 6, 19, 34, 39). The important point is that there should be a match between what has been taught and how, and what is being measured and how. If texts emphasize facts, teachers can write multiple-choice items, which measure students' ability to recall facts; if a program encourages students to compare and contrast objects' properties, then multiple-choice items, which test students' ability to make those comparisons, can be written.

Students' skills also are affected by the way teachers present the curriculum. A teacher who consistently shows the relation between facts, who explains why whales are like man and like fish, will likely receive high-level answers to essay questions. A teacher who teaches facts in isolation will receive essay answers that parrot information, but fail to integrate it into a coherent whole. The key to successful evaluation is to decide what students need to learn, how the information will be presented, and how an accurate assessment of students' strengths and weaknesses can be obtained. Differences in implementation of science programs in different classrooms is to be expected and occurs (31). Some teachers emphasize group instruction regardless of the content; others prefer to have students working independently regardless of the skills or content to be mastered. While group tests are always appropriate to measure how well one student's progress compares with another, group tests shouldn't be used to the exclusion of other forms of assessment. If students often work on their own in class, they ought to be assessed on the basis of their work in that setting. If students habitually do group projects, then an evaluation of those projects is appropriate. Relying exclusively on group-administered standardized tests when students often work under other conditions conveys only a partial picture of students' competence.

To match instructional strategies to evaluation procedures, the suggestions in Figure 1 might be useful.

When planning for assessment, knowing how the information will be used is as important as analyzing the curriculm's goals. For example, teachers can use test results to help answer these questions:

- *Do students need more instruction in this topic before we go on to another chapter?* If teachers say "yes" to this question, then they might want a more informal assessment that lets students comment on where they think they need more help. This formative type of evaluation allows students to pinpoint their own weaknesses and ask for additional help.

- *Am I going to give this test to assess how much students have learned and then go on to the next topic?* If teachers say "yes" to this question, they will want straightforward, summative evaluation of students' knowledge. They will want to touch on all the major points of instruction. They will probably want a comprehensive test that is easy to administer and easy to score.

The purposes of formative and summative evaluation have been discussed by evaluation specialists. Reading their rationale for choosing assessment strategies helps to define the goal of evaluation strategies (1, 9, 31).

Whether teachers adopt a formative approach, and use tests to tailor subsequent instruction to students' needs, or a summative approach, and use tests to measure how much students have learned, they should be aware of constraints on students' understanding. Students will learn according to their level of conceptual development and their ability to integrate what they already know through untutored primitive scientific discovery and the formal rational instruction provided in science classes (26, 27).

Figure 1
Examples of Evaluation Procedures

	Evaluation Process		
	Oral	Written	Demonstration
Instructional Strategy: Individual	A student can be called on in class to give a brief summary of basic information discussed in class that day. A student can be asked to critique an experiment conducted by a fellow classmate or critique a published study.	A student can be asked to write a review of a science program shown on television. A student can be asked to write a brief report of research he/she conducted.	A student can take responsibility for studying an experiment and presenting a demonstration of it to the class.
Instructional Strategy: Group	Students can collaborate on presenting a summary of the key concepts studied in a unit. Students can conduct a roundtable discussion of an important topic.	Students can collaborate on producing a bibliography of important books or articles.	Students can share the responsibility for preparing and presenting an experiment or discussion on an interesting topic to the class or school.
Instructional Strategy: Class	A class might conduct an assembly on a topic of interest or concern to the entire school.	A class might keep a log of their science experiments and provide written comments and critiques of each other's work.	A class might dramatize an important event in the history of science.

Once I have decided on a plan for evaluating my students' science learning, what resources are available for selecting tests?

Unless they must restrict themselves to school district-approved tests, science teachers have a wide range of options. Even teachers whose district or state department of education require using approved tests will want to conduct periodic assessments of student learning for their own purposes. Weekly or monthly checkups or spot quizzes, classroom observations, or lab-book checks are assessment tools that every science teacher can use to keep track of how well students understand their science. Given the number of published and unpublished science tests and the number of ways to observe and record students' performance, teachers can easily check students' skill development and students' knowledge of concepts and technical terms (4, 7, 9, 24, 25, 30, 36, 37). Samples from formal testing programs like the College Board can be obtained (7). The National Assessment of Educational Progress (NAEP) periodically measures students' science knowledge (29). From time to time NAEP releases samples of items used in previous testing. By sending for sample items, teachers can review the typical science items used by NAEP. Teachers can compare what students in a class or school know with what the national NAEP results show. However, in making those comparisons, teachers should remember that differences in curriculum, teaching strategies, and type of student will mean that the students tested may differ widely from the national group. The use of test items from NAEP or similar groups should never be done as a summative assessment. Such testing should only be done to answer the question: "How are my students performing on these questions compared to the national sample?" If the test results are unsatisfactory, you might want to review your curriculum, or your teaching strategies, or both.

State- and locally-mandated tests exist, and students' performance on those measures can be analyzed for clues about what students have learned and what needs to be taught. However, in administering those tests, teachers should remember that many are designed to test "minimum competencies," the lowest level of skill or information students should have mastered. Those tests should not limit instruction. Teaching to the tests by drill-and-practice methods usually reduces the amount of time available for learning other, equally important information and skills not featured in the tests. So teachers shouldn't review test items, survey the skills and information tested, and say: "Well, if that's all they're going to test, that's all I'm going to teach." The average science course is much richer in content and skill development than any test or set of tests; teachers should use as many strategies as they can to evaluate students.

Many of the paper and pencil tests I've seen seem limited to measuring how much science students know. I'm more interested in tests that can tell me how my students are thinking. What types of measures are available?

When the innovative science curricula were being evaluated, tests designed to measure the unique features of those programs were developed. The Test of Logical Thinking (TOLT) is one example of an instrument that measures students' ability to translate theory into practice. Items like the following are part of the test:

> Which of the following would be an appropriate measure of the size of a spot of light from a flashlight pointed at a screen?
>
> 1. diameter of a flashlight
> 2. size of battery
> 3. size of screen
> 4. radius of spot on the screen

To measure students' proportional reasoning, items like the following were written:

> Four large oranges yield six glasses of juice. How many glasses of juice would be produced by six large oranges?
>
> 1. 7
> 2. 8
> 3. 9
> 4. 10
> 5. Other

These tests, developed by Karplus and his associates, as well as similar tests not only measure students' knowledge but also help teachers understand the way students think about relations among variables and the students' ability to make inferences (17, 18).

The Test of Integrated Process Skills (12), the Basic Science Processes Test (4) and the Understanding in Science Test (35) also measure students' ability to respond to a relatively novel situation, apply the principles they've learned to specific situations, and think like a scientist. However, these tests, and other tests developed as part of the innovative movement in science education, should be used with caution. In many cases, the standard psychometric procedures that characterize good test construction and that mark standardized tests as different from other teacher-made tests were not followed (15). As a result, we don't know how well these tests predict future success in science. Since the tests were not administered to a wide range of students, we don't know how well the tests discriminate between students who know science and those who don't. As a result, the tests might be appropriate for formative evaluation, where teachers want to assess topics in which students need additional instruction, but might not be appropriate for summative evaluation. Teachers might like to adapt one or more of these tests to their own needs.

Alternatively, teachers might decide to construct their own test to measure the specific objectives of their own curriculum and/or lessons. They also might like to design tests for lessons based on conventional textbooks for which commercial tests seem inappropriate. Teacher-made tests can be among the best means of assessment since, when properly constructed, they reflect the unique content and processes that students and teachers bring to the lessons. Caution is advised; care should be taken in the construction of teacher-made tests (1, 6). They must be both valid and reliable (15). A recent survey of teacher-made tests showed that many are weak, since they did not reflect the level of difficulty of the concepts taught. Others did not measure what the teacher intended them to measure. Inspection showed many tests contained ambiguous items; others failed to discriminate between students who knew the skills or concepts and those who didn't. Teachers should make sure the tests measure what the teacher intends to measure (validity) and that a student who receives a high score on the test one day would receive an equivalent score on that test or a similar test on a subsequent administration (reliability). Since many teacher-made tests don't hold up to scrutiny when checked for ambiguity of items, the results of those teacher-made tests should be interpreted cautiously.

Tests can be put to more than one use. One technique allows students to read sample test items but, instead of answering them, commenting on what they think is being tested. This allows teachers to discover whether or not students have missed the point of a lesson. It allows teachers to gain insights into the reasons why students might be having difficulty learning concepts or techniques that Karplus, McDermott, and Minstrell, among others, have cited as a major issue science teachers must undertake in assessing students' science knowledge (26, 27, 31).

Other types of evaluations, classroom observation schedules, questionnaires, and checklists also can be adapted from instruments designed for classroom use (3, 9, 25, 31, 32). Many instruments, although not specifically developed for use in science classes, would be suitable for evaluating some of the typical instructional processes used in teaching science.

Once I've evaluated my students' performance, what is the best use I can make of test score information?

Once teachers have assessed students' learning, they can use the information to decide whether the lesson goals have been met. By reviewing assessment results, teachers can ask themselves if, having set goals for students, those goals have been met. They can ask:

- Have the major concepts been understood?
- Do students understand the special vocabulary and the scientific terms? Can they apply them appropriately?
- Do students understand the relation between the new information they learn each day and what they learned a day, week, or month before?
- Can students apply to new situations the scientific procedures they have learned?

Teachers should be the first ones to analyze students' scores since they will need to think about the implications of students' test performance for future instruction. They will want to know: "Did all the students master the topic?" and "Are there any students who need additional time or practice before they move on to another topic?" Assessments for each of the following purposes can be made:

- *Diagnosis.* By using both pretest scores and posttest scores, teachers can judge what students knew when they started working on a topic, what they have learned over the course of instruction, and what they still need to learn for optimal understanding. A teacher might say: "I was going to teach students how to compare and contrast different objects before teaching them about the plant kingdom, but since they already know about those comparisons, I will go directly into the unit on plants."

- *Comparison.* By comparing the scores of all students in a class, teachers can ask if one group of students achieves at a higher level than other groups. A teacher might say: "The higher-ability students know more of the basic concepts but the lower-ability students really profited from our use of the three-dimensional models and our reviews of the technical vocabulary. With another review they should be able to master most of the information in this unit."

- *Prediction.* By relying on test information, teachers can tell students how well they are progressing. Reviewing a student's test performance the teacher might tell a student: "Unless you study harder you will have difficulty with the next unit. The work in that unit builds on what we are studying in this unit and you will need a better understanding of the concepts and vocabulary than you have shown on this test."

The instruments that teachers use for these objectives should be considered carefully. A true/false test might yield easily scored answers but might not give a complete picture of a student's understanding (or lack of understanding). Essay tests, or lab work, might give teachers more opportunity to assess students' knowledge. The myth that essay tests or lab work cannot be quantified should be dispelled. If a teacher knows what concepts and skills are being tested and devises a grading system to analyze the students' work, then essays or lab work can be quantified, and quantified consistently, from student to student.

Having decided which purposes should be met, teachers should communicate test results and the consequences of testing to students. In doing so they need to consider how they are going to communicate the testing results. If teachers plan to report back to students and only to students, they have a wide range of choices. They can comment directly on the student's work. They can write a critique or give suggestions for improvement. Alternatively, they might simply assign a letter grade or a number grade. Then they should explain their criteria for assigning each grade. If scores are to be reported to parents, fellow teachers, or principals, teachers will want to make sure that the audience understands what has been measured, what standards were used for assigning grades, and what followup is planned. Students who need special help should be identified and students who have made a special contribution should also be noted.

Whatever choices a teacher makes, it is important that those choices be governed by a match between instructional goals and assessment methods. It is also important to realize that teachers have some control over what they measure and how they measure it. Finally, it is important that students (and parents and principals) receive comments on the assessment results. It is important not to let students fall farther and farther behind in their work as the school year progresses. If teachers explain carefully the reasons for evaluating students' work and help students prepare for their tests, then all students will show some progress. If teachers explain the purpose of testing—that it is designed to help the student learn—then students will come to view testing as a way to help themselves and not as a process designed to frighten or frustrate them.

I want to measure more than students' achievement. How can I assess students' interest and their attitudes toward science?

Measuring students' science achievement is not the only way to evaluate students. Attitudes and interests play a major role in students' learning (14, 21). Currently there is concern that girls' science and math achievement is not as high as boys'. Fewer girls take advanced science and math courses and elect careers in science (13).

Concern has also been expressed because students' knowledge of science and scientific processes differs from scientists' perceptions (13). Preconceptions are not easily changed, and gifted, creative students who perceive science as a series of sterile, rote memory tasks may be deterred from choosing science as a career.

Surveying students' attitudes and interests plays a major role in creating a climate where good science teaching can take place. In surveying students' attitudes toward science, the following topics should be included:

- perceived usefulness of science;
- confidence in learning science;
- perception of science as a male domain;

- perceptions of parents' interest, attitudes, and support of science and science careers;
- perception of science ability;
- liking for science; and
- anticipated success in science or science-related careers.

Several student attitude/interest surveys have been developed (7, 20, 23, 24). Attitude is even more difficult to measure than achievement (1, 6, 28). Discussions and sample attitude surveys are available for teachers to review (1, 6, 25). However, researchers and practitioners question the values of those surveys and advise caution when interpreting the results (1, 28). In spite of careful development, it is not clear that current attitude surveys are valid, that is, they may not measure what they purport to measure. We don't know if current attitude surveys measure students' attitudes or if students are responding because an answer seems to be socially acceptable. We also don't know how today's scientists would respond or how they responded when they were students. Sometimes, in answering that type of survey, students often deceive themselves. For example, not knowing that scientific careers can be intellectually challenging, a talented student might circle "strongly disagree" to the question: "Would you enjoy a career in science?" Since words have different meanings for different people, two students, each with different attitudes and values, might circle the same answer.

Because we can't be sure what attitude surveys measure, teachers are advised to interpret survey results with the same caution they would use in interpreting teacher-made tests. Whatever the method of assessment chosen, and whether its intent is to help students learn more effectively or measure what they've learned, teachers should remember that the goals of evaluating students' science knowledge and ability are to help students recognize their level of science literacy and to help them learn the power of science and scientific training.

Summary

Evaluation of science teaching and learning can be conducted in a variety of ways for a variety of purposes. In order for students, teachers, and administrators to benefit from evaluation data, it is important that evaluation of science learning be planned and conducted as carefully as are the science lessons themselves.

Many educational decisions depend on evaluation data. Are students learning the skills and knowledge presented? Can a course be restructured to allow emphasis on different topics? Do students know the requisite skills that will allow them to be successful in this class?

A sound evaluation plan will capture a large sample of the skills and knowledge taught. Thus, a number of evaluation strategies will be required, depending upon teaching methods, course structure, and learning objectives and goals. Many science tests have been published and can be adapted. The key, of course, is in adapting the test to the particular situation.

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Integration of Science and Other School Subjects

Is there a relationship between science and other subjects taught in schools?

Science has always been given little attention in elementary schools; it has even been omitted from the curriculum of many. There are several reasons for this unfortunate state of affairs. One is that elementary teachers lack the requisite knowledge and background in science content (9, 10). Another is that elementary teachers generally harbor negative attitudes toward science and science instruction (9, 10). In addition, many people, including teachers, feel that science at the elementary level is a frivolous, superfluous subject and should be excluded from the instructional day.

Few people view science at the secondary level as frivolous. In fact, biology, chemistry, and physics are viewed by many as the springboards to future occupations in medicine, engineering, and agriculture, occupations important to a healthy and prosperous America. However, science at the secondary level is taught in a manner that, for the most part, depicts the structure of the discipline, not its usefulness to future citizenry. Teaching as they were taught, secondary teachers don't know how to blend science with other subjects.

Because of these attitudes, science education has experienced a steady decline for a number of years at the elementary level and has become further removed from reality at the secondary level. Results from the science assessments conducted by the National Assessment of Educational Progress (NAEP) reveal a continuing decline in science achievement scores (80). Attitudes toward science also have become progressively more negative over time. John Slaughter, former director of the National Science Foundation, underlines the danger of this trend when

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he says, "The decline in student achievement in mathematics and physical sciences at the precollege level has reached a point where this country's strength in science and technology may be affected" (23).

Neuman proposes that highest priority be given "to those subjects and activities that clearly provide students with unique opportunities for intellectual and emotional strengths" (78). He points out that science develops useful attitudes and knowledge that enable students to make informed decisions as adult citizens in a democracy. Scientific activities develop rational thinking skills, as well as communication skills. These process skills (e.g., observing, comparing, classifying, inferring) are required for survival and success in life's pursuits.

There have been several attempts to combine science with other disciplines within recent years. Ost states that these changes in the school's curriculum at all levels are a reflection of the "needs of society" (90). Many of these curricular attempts at combining science with other disciplines are described using various terms such as interdisciplinary, integrated, unified, correlated, coordinated, and core (90). While there are subtle differences in the use of these terms, the main point is that science is taught in some combination with other disciplines.

The integration of science with other disciplines (e.g., language arts, social sciences, fine arts, mathematics) has potential for improving both the quantity and quality of science instruction and learning. Cohen and Staley say that:

> . . .integrating science in the general curriculum can help reflect the relationships between science and other disciplines, increase or sustain student interest in science, increase teachers' confidence in their abilities to understand and teach science, increase students' science achievement, and increase students' awareness of the role of science in everyday life and the role of scientists in society (23).

Many concepts, process skills, and problems found in science are also part of and central to other disciplines. For instance, concepts such as interaction, system, interdependence, and interrelation are important to science, as well as to the humanities and the social sciences. Integrating science with other disciplines gives students a more realistic view of science. Its separation from other disciplines presents science as an isolated subject and fosters incorrect perceptions of its true nature. Teaching science as an integrated or unified subject with other disciplines is a desirable goal (24, 66).

This chapter explores the relationship of science with other school subjects. Two kinds of information are presented. In the reading and mathematics sections, research is cited to show that the integration of science with these subjects has produced positive effects on student learning. In the social studies, health, and fine arts discussions, activities or curriculum materials are described that can be used to integrate science with these subjects. In these sections, no claim for increased student achievement is made. Integration in these subjects is more philosophically based. That is, students develop greater appreciation of and increased awareness of science's relationship to society, health, and music and art.

What can teachers do to integrate science with language arts programs?

The current emphasis on teaching the basic skills of reading and writing combined with state mandates for minimum competencies in these areas have reinforced school administrators' and ~~teachers~~' inclination to stress language arts instruction. Because science has not been identified as a basic skill, science programs have received less emphasis. However, research indicates that a strong experienced-based science program, one in which students directly manipulate materials, can facilite the development of language arts skills (124).

What is the relationship between reading and science?

Reading and activity-oriented science emphasize the same intellectual skills and are both concerned with thinking processes. When a teacher helps students develop scientific processes, reading processes are simultaneously being developed (75, 110). Furthermore, science instruction provides an alternative teaching strategy that motivates students who may have reading difficulties (124).

Processes and content are the concerns of both reading and science. Content can be thought of as specific concepts, the accumulation of detail, and generalization of particular learnings. The reading skills and scientific skills necessary to acquire and apply the content constitute the process (118).

The hands-on manipulative experiences science provides are the key to the relationship between process skills in both science and reading (71). Science process skills have reading counterparts (17). For instance, when a teacher is working on "describing" in science, students are learning to isolate important characteristics, enumerate characteristics, use appropriate terminology, and use synonyms. These are all, of course, important reading skills, too. Furthermore, when students have used the process skills of observing, identifying, and classifying, they are better able to discriminate between vowels and consonants and to learn the sounds represented by letters, letter blends, and syllables (78). Children's involvement with other process skills enables them to recognize more easily the contextual and structural clues in attaching new words and better equips them to interpret data in a paragraph. Science process skills are essential to logical thinking, as well as to forming the basic skills for learning to read (7).

Do we know whether teaching science enhances reading readiness?

Reading readiness is defined as a skill-complex by Guszak (42). As a skill-complex the component skills of reading readiness are, therefore, teachable. Of the three areas within the skill-complex, two can be directly enhanced by science process skills. The two are physical factors (health, auditory, visual, speech, and motor) and understanding factors (concepts, processes) (7). When students see, hear, and talk about science experiences, their understanding, perception, and comprehension of concepts and processes may improve (7, 8).

Evidence suggests that early experiences in science help children of all socioeconomic levels in language and logic development (118). For example, studies by Kellogg and by Renner and his associates found that experiences gained by first graders when involved in the Science Curriculum Improvement Study (SCIS) unit "Material Objects" improved children's scores on the Metropolitan Reading Readiness Test (MRT) (59, 100, 101). The scores on all subtests except copying exceeded those obtained by other first graders who used commercial reading-readiness programs (99).

Other studies that evaluated the effectiveness of SCIS units used to promote reading readiness report similar findings. Experiences with the SCIS first-year program greatly enhances children's ability to conserve quantity, an essential indicator of reading readiness (100, 101). In another study, Maxwell used measures from MRT and the Marianne Frostig Developmental Test of Visual Perception to assess the effect of selected SCIS activities on reading readiness (73). Maxwell provides evidence that SCIS activities produce significant, positive effects on kindergarten children's reading readiness scores (73).

Neuman also argues persuasively for providing inner-city kindergarten children opportunities for experiences with natural phenomena to improve reading (86). Using the MRT to measure the effectiveness of the experiences, Neuman found that science activities provide opportunities for manipulating large quantities of multisensory materials. This manipulation promotes perceptual skills (e.g., tactile, kinesthetic, auditory, and visual) (86). "These skills then contribute to the development of the concepts, vocabulary, and oral language skills (listening and speaking) necessary for learning to read" (124).

Other studies have tested the effectiveness of Science—A Process Approach (SAPA) on reading readiness. Ayers and Mason investigated the influence of SAPA, Part A, which emphasizes observation and communicating with others, on kindergarten students (6). They found that kindergarten students who used SAPA outgained those who didn't. Ayers and Ayers concluded that the SAPA affected students' reading readiness by enhancing their ability to perform six conservation reasoning tasks (5). The conservation tasks performed were number, liquid amount, solid amount, length, weight, and area. The work of Ayers and Ayers substantiated the earlier finding of Almy that the ability to conserve is an important factor in beginning reading (1, 5).

These studies and others clearly indicate that the nationally-funded science curriculum projects, as well as other science programs that emphasis hands-on manipulative experiences, enhance the development of process skills in young children (88, 102, 105, 112). The attainment of process skills developed by such science experiences are positively correlated with the development of reading readiness.

Can science instruction increase reading skills in the intermediate and upper elementary grades?

Improving reading skills through activity-oriented science programs is not limited to preschool or primary-grades. When testing the effectiveness of SCIS on 5th graders, research conducted by Webber and by Renner and his colleagues found that SCIS was effective in developing the science process skills of observation, classification, and communication, which enhance reading skills (100, 122). Using SAPA activities for one hour a day for a period of twelve weeks, Esler and Anderson found significant improvement in 5th graders' ability to identify story outcomes, as measured by the California Test of Basic Skills, when compared with students not using SAPA (29).

Other studies, by Campbell, Kraft, Olson, Quinn and Kessler, viewed cumulatively, suggest that science instruction at the intermediate and upper elementary grades does improve the attainment of reading skills (15, 63, 89, 95). The findings reveal that students have derived benefits in the areas of: "vocabulary enrichment, increased verbal fluency, enhanced ability to think logically, and improved concept formation and communication skills" (124).

How can teachers use science activities to enhance reading skills?

Reading is a means to extend our own experience. Through reading we experience—albeit indirectly—things that are not present in our immediate environment. An obvious answer to the question, then, is to read about science. Library books can serve as a valuable science resource. In keeping records of the books children checked out from the school library, a librarian in Rochester, New York, found that science books were the second most popular category (40). Science books were surpassed only by fiction books, many of which were science fiction or in science fields (40). Library books also increase the possibility that materials at the reading levels of students will be used.

Teachers can integrate reading activities in their science classes to augment students' hands-on experiences. After students have experienced hands-on manipulative activities, words and terms can be "invented" for what they have been doing. "Operational definition" is the term used to describe the new words or terms that evolve from students' experiences (117). As students handle materials, they invent new words or terms to describe what is happening, such as "evidence of interaction." Follow-up activities, presenting the same concept in new situations, can then be used to reinforce the concept. For example, when dropping an Alka-Seltzer tablet in water a teacher could say: "The bubbles are 'evidence of interaction' (new invented term) between the Alka-Seltzer tablet and water." Next, another activity could be performed using interaction—mixing colors, pasting a collage, or conducting a small group discussion. Students could then be asked to identify the similarities and the differences in the original task and the others.

Textbooks also can be used to enhance students' hands-on, manipulative experiences. There are many ways that science textbooks can be used to expand an activity-oriented science program. They are a reliable resource of science facts, concepts, and principles. In using textbooks, it is important that the textbook matches students' cognitive levels. To ensure that each student gets the maximum benefit from using science textbooks, individualizing textbook assignments may be necessary (77). In addition, helping students learn to locate and organize information from science textbooks provides them with study skills (127). Reading can be used as one of science's processes to find and share other people's information and to check the validity of students' own findings (16).

Do science experiences enhance oral and written communication skills?

As with all process skills, only through actual practice does competence in oral and written communication develop. The learning of discrete grammatical facts and practice at giving speeches are insufficient.

Involvement in activity-based science programs provides learners with a multitude of experiences to draw from when they think and write (110). Teachers can exploit science experiences that occur as a result of activity-based programs by encouraging students to write. A written record can easily become the culmination of almost any activity-based science experience. This written record can, of course, take several forms. First, students can be taught to use the styles and forms used by working scientists when they prepare lab reports. Teaching the special conventions of scientific reporting will lead to an increased understanding by students of the influence of subject, audience, and purpose for writing.

Students can also write their science experiences in more anecdotal forms. Short stories in the form of science fiction, journalistic reports of class activities in science, and students' own reflections about a science class, recorded in a personal journal, are all ways to record the outcomes of a science class while simultaneously providing practice in writing. With all the natural conjunctions between writing and science, it is surprising that a recent survey of teachers reveals that teachers of science seldom use writing to stimulate or to reinforce creative thinking. More than teachers of any other subject, secondary science teachers rely on writing only for testing how well students have mastered content (3).

Studying the relationship between creative writing and science experiences, Jenkins notes that, when children write their own reading materials, their writing scores improve significantly (57). The major things they write about are science and social studies. One study revealed that 40% of the words beginning writers chose to use were related to science experiences. Furthermore, Knight found that science demonstrations presented as stimuli prior to student writing sessions resulted in significantly more creative writing than other stimuli (62). The reason for such findings, suggest Mechling and Oliver, is that learners are motivated to write about things they know and like (75). Realizing that the words they are using are not found on their spelling list or in their reading book seldom hampers the creative efforts of elementary students (75).

Guidance in selecting science-related topics about which students can write may be obtained from many sources. The more than thirty theme ideas to foster creative writing suggested by Reid and McGlathery range from "sluething" to "visit to another planet" and can be adapted for use at the elementary or junior high school level (98). Additional suggestions for stimulating creative writing based on the science topic "machines" are presented in an article by Cacha entitled "Children Create Fiction Using Science" (18).

Strenski suggests that teachers present a ready-made data set of science facts from which four or five bits of information can be chosen and pulled together into a paragraph. As part of Project Write, which uses this approach, a list of science-related writing activities was prepared for use in grades K through 12. Some of the suggested writing activities included: keep a journal of class experiences, criticize a science news article, and investigate and report on a science-related career (32). Having students construct narratives to be recorded on cassettes to synchronize with film strips is another way to stimulate science-related creative writing (68).

The interpersonal communication between teacher and student can also be improved through science-related writing. Stulp suggests using index cards as communication tools when it is difficult to personally talk with each student each day. By communicating in writing on the index card, students can benefit from practice in written communications and the teacher can find out more about students who may avoid oral communication in science class (115).

Work with children from inner-city schools by Bethel and by Huff and Languis found significant gains in children's oral communication skills when they participated in SCIS and SAPA activities (8, 53). In tests of language output; vocabulary; sentence structure; and classifying, transmitting, and receiving oral communication skills, children who were exposed to SAPA out-performed students who were not (53). A similar finding was reported by Rodriguez and Bethel. Bilingual students who participated in hands-on inquiry activities scored significantly higher on the Test of Oral Communication Skills than students who did not (103).

In studying spontaneous and student-initiated speech, Rowe discovered that spoken language in science classes exceeded that in language arts classes by more than 200% (106, 105). She also noted that when teachers paused for between three and five seconds after asking a question and following students' responses to the question, language and logic development were enhanced (107).

Does involvement in science experiences enhance the language development of students with special needs?

Research has shown that science can enhance the language development of children of limited English proficiency, of children from other ethnic backgrounds, and of physically handicapped children. American Indian children scored higher on Stanford Achievement Tests after being exposed to the process skills of Elementary Science Study (ESS) (64). Other studies have shown that Spanish-speaking first graders experienced an increase in their ability to form complete sentences, in their attention span, in auditory discrimination, and in listening ability after exposure to SAPA (51, 114).

Science experiences also help students who are physically handicapped. The oral communications skills of deaf children were found to improve when involved in ESS and SCIS (14). When exposed to SCIS and SAPA units providing hands-on manipulative experiences, visually-impaired students developed science process skills and concepts (69, 70).

Deficiency in the acquisition of categorical systems that underlie language was also found to be eliminated when deaf students were involved in inquiry lessons structured toward the development of classification skills, and based on the physical manipulation of objects (13).

Several science programs designed specifically for physically disadvantaged students also stress hands-on manipulative experiences vital for the attainment of science process skills and concepts. The Lawrence Hall of Science of the University of California, Berkeley, with federal support, has produced a science program for the visually impaired called Science Activities for the Visually Impaired (120). It was developed by many of the original SCIS team and reflects many of the original SCIS ideas. Other programs for the physically disadvantaged are Adapting Science Enrichment for the Blind and Science Enrichment for Learners with Physical Handicaps.

A language development program that includes active science experiences serves a dual purpose (52). The science experiences appeal to students' curiosity, and they provide something concrete and stimulating to read, write, and talk about.

What is the relationship between science and social studies?

Many of the decisions concerning the societal problems that we face today require a basic understanding of science and technology. Science and social studies are clearly related. Both have a specific mandate with regard to the development of an informed citizenry, which is the *sine qua non* of a democracy.

Studies of secondary students and their science experiences reveal little to no growth in science concept mastery over the secondary school years. Indeed, factors other than school contribute significantly to students' science knowledge (76). In investigating students' attentiveness to science, Miller and Voelker found that 90% of the college-bound high school students and 96% of the non-college-bound high school students were unattentive to science (76, 121). Responses to surveys of public awareness reveal that a majority of 13- and 17-year-olds have no understanding of the relationship between science, technology, and society in the areas of energy, food production, population growth, and environmental problems (80). Similarly, fewer students than ever understand the functioning of the U. S. Congress, know that the Senate must approve the appointment of all Supreme Court justices, and are able to explain the basic concept of democracy (79).

These results cannot be viewed with much optimism. They suggest that science and social studies educators are not preparing students capable of making informed and responsible decisions regarding social issues, science, and technology. Further, questions arise concerning the students' future participation in democratic processes. The discrepancy between current societal issues and the knowledge and attitudes of students helps to delineate the educational crisis and to illuminate the needed direction of change.

Science and social studies educators alike have made an impressive case for the extensive infusion of science-related social issues in the general education of students. Both groups are critical of the controversial curriculum patterns that isolate the study of science from the study of society; both groups stress that students must be taught to understand, appreciate, and appraise the impact of science and technology on society (20, 25, 56, 111). Pollution, drug use, euthanasia, biological and chemical warfare, weather control, and many other areas are seen as integrative themes around which instructional activities could be developed (37). Moreover, both educator groups see common goals in the broad areas of knowledge, values, and beliefs, and in decision-making skills' development (37, 81, 83, 92, 111).

Are there programs available to assist teachers who are interested in dealing with science-related societal issues?

Several science programs have been developed that attempt to teach values clarification in conjunction with science content. Biological Sciences Curriculum Study (BSCS) has developed junior high and senior high school programs that explore human sciences and genetics and that emphasize values clarification regarding politics and issues that have been raised by scientific and technological advances (11, 54, 55, 74). Curriculum materials and instructional films have been developed with funding from the National Science Foundation Ethics and Values in Science/Technology Program. These materials present basic ethical theories and help students develop and defend their ethical positions (108).

Three programs that help students think about the environment and science-related social issues are Project Learning Tree, Project WILD, and Project SCATE, or Students Concerned About Tomorrow's Environment. Project Learning Tree activities place the use of natural resources in a cultural context, providing opportunities for students at all levels to explore the historical and present-day effects of these resources on people and people's effects on them (2). Issues concerning people's interaction with their environment are also a part of Project WILD. The materials help students acquire the knowledge, skills, and commitment to act responsibly in decisions concerning wildlife and habitat, "beginning with the recognition that the earth is home for people and wildlife" (125).

Project SCATE was designed as an environmental investigation/political participation program for use with Iowa students (45). Investigations force students to consider both the ecological and social ramifications of a variety of problems (e.g., thermal pollution of the Des Moines River) in proposing solutions.

The National Science Teachers Association (NSTA) is one of several groups sponsoring the development of curriculum materials to assist students in clarifying their values about the use of energy (31). Another is BSCS, which has developed a nine-week instructional unit in which high school students learn about decision-making skills and energy issues (11). During the course of the unit, Energy and Science: Investigations in Decision-Making, students discuss basic information about energy, explore some possible consequences of energy decisions, and select an energy-related research problem to investigate (49). Through consideration of empirical data and through examination of personal and community values, students attempt to arrive at energy "recommendations" for their community (11).

An innovative program for elementary students that teaches decision-making skills regarding societal issues is Man—A Course of Study. The program presents an intensive study of man in society—as culture-builder, ethical creature, tool-maker, and dreamer (30). The Netsilik Eskimos of the Canadian Arctic are studied in-depth, because their society is small and technologically simple, yet the problems it faces are universal.

A more recent attempt to identify still other programs that foster the science and technology in society theme is the NSTA Search for Excellence in Science Education. The national search was for programs in five areas, each of which focus on one aspect of science education: elementary science, biology, physical science, inquiry, and science and technology in society. In looking for exemplary efforts that deal with the interaction of science, technology and society, programs were identified that used either energy, population, human engineering, environmental quality, use of natural resources, national defense and space, sociology of science, or the effect of technological development as the integrative thread to link learnings in science and social studies (92, 94). Ten such programs were identified as exemplars of the science-technology-society focus (93).

Whether these exemplary programs are used or not, incorporating the science-technology-society theme into the curriculum is relatively easy in many elementary schools, since the same teacher is responsible for teaching both science and social studies. In schools where the same teacher is not responsible for both courses, teachers can team teach (104) or, at a minimum, plan their courses together. Such team planning allows teachers to coordinate the curriculum by identifying common skills and concepts that advance the science-technology-society theme. Then these common skills and concepts are stressed in both classes (61).

How can teachers use science experiences to teach health?

The traditional approach to health education has consisted largely of a list of "don'ts" that quickly become tedious. "Don't drink;" "don't smoke;" "don't use drugs." Today that list has been expanded: "avoid caffeine;" "limit cholestrol intake;" "add more fiber to your diet;" and so on. While it is true that each of these rules has some health benefit, the poor impact of this approach to health education has been well documented (44).

Further contributing to the shortcomings of health education today is the way that topics of health are taught. At both the elementary and secondary levels, these topics are presented by textbook reading or lecture only (123). Moreover, students report that the same topics are studied year after year (50). It is no wonder that students assert that health is boring and repetitious.

Health courses need not be boring and repetitious. By developing an acceptable scope and sequence for health concepts and by reinforcing health concepts through science manipulative experiences and laboratory activities, students will see the relevance of health education to their lives.

Health is obviously a sub-set of science. A great deal of the content that one normally associates with health is also the content of science. Health topics such as food and nutrition, human genetics, health and diseases, and human body systems are common to all elementary science and biology programs (123, 128). The distinctions between the two disciplines become hazy when such topics are considered. The important point is not whether this commonly-shared content is taught in science or health class, but whether it is taught in an educationally sound manner (75).

The content that is common to science and health can be taught in either science or health class. Involving students with science processes and teaching them thinking and decision-making skills applicable to their own health makes the common content more than an exercise in reading or listening.

Curriculum materials that take the perspective outlined above are being developed for elementary and secondary students. One such program is the Teenage Health Teaching Module (12). Another, being developed by BSCS, is a comprehensive health education curriculum for students kindergarten through 8th grade. The curriculum materials being prepared will emphasize individual responsibility for health, improved health decision-making, and attitudinal and behavioral changes regarding health-promoting lifestyles (12).

A third example, designed to help students sharpen their science process skills and practice their thinking and decision-making skills applicable to their own health, is Health Activities Project (40). Developed in the late 1970s, the program involves elementary, middle school, and junior high school students with their own health and safety through discovery activities. Students learn how their bodies function, what their bodies can do, and how individuals can make changes in the way their bodies perform.

Is it possible to integrate science and the fine arts?

The relationship between science and the fine arts is not as well described in the literature as that between science and other subject areas such as mathematics, social studies, and language arts. Nevertheless, obvious relationships do exist between science and the fine arts, particularly art and music. The literature indicates that when science and the fine arts are integrated, both curricular areas profit (43, 75).

How can art be used in science classes to enhance learning?

Science and art share common learning experiences and procedures. Manipulating, describing, and demonstrating are integral to the process of learning in both disciplines. In both science and art, a body of information exists that is presented and comprehended primarily through the "student's own participation and production" (43).

Integrating science and art has several specific benefits for students. It facilitates learning about the importance of mental concentration and careful observation involving all the senses. It helps students to recognize that there is beauty associated with science. Furthermore, the integration is another demonstration that information learned in science is relevant beyond the confines of the science classroom and the school building, or that learning in one subject can be used in another subject area.

The practice literature—teachers writing from their own experience—describes the integration of science and art, not as a contrived and unnatural overlapping of disciplines, but as a beneficial partnership. For example, Chetelat describes how science and art can be integrated at the elementary level (21). Karen describes a program that integrates biology and art so that both courses retain their individual integrity (58). Matray and Knorr describe how biology and art can be incorporated into an existing curriculum using a team-teaching approach (72). Their effort resulted in the preparation of attractive, accurate renderings of animals and plants. Another benefit of the integration was the enhanced student awareness of career possibilities in biological illustration. These teachers' efforts not only demonstrate how art and science can be integrated, but also represent efforts by teachers to construct learning experiences appropriate for their students.

Aside from the programs designed by teachers at individual schools, few large scale programs have been developed that integrate science and art. One such program, designed for the elementary grades, is Outdoor Biology Instructional Strategies (OBIS). In one OBIS activity, children create "animals" by painting vegetables to camouflage them. They then hide them in the school yard for others to find. In another OBIS activity, students use clay, pipe cleaners, construction paper, and other materials to "invent" plants, which are adapted to certain environmental conditions.

Another resource for teachers is a volume presenting a series of laboratory science and art lessons for mainstreamed classes in kindergarten through 6th grade (43). The lessons presented in the volume are appropriate for use with deaf, blind, or emotionally disturbed children of normal intelligence, as well as with children without learning difficulties. Throughout the volume "match boxes" serve to help the user relate science and art learnings (43).

What are some activities to show the relationship between science and music?

The study of vibrating systems offers an opportunity to emphasize the relationship between science and music. By using simple musical instruments made from paper drinking straws, rubber bands, string, or soda bottles the relationship between physical and musical vibrating systems can be demonstrated (75). Investigations using a hacksaw blade or rules fastened to the edge of a table top, a swinging pendulum, or an electronic sound synthesizer can be used to demonstrate physical vibrating systems that are "damped" or "sustained" (126). With the knowledge gained in the investigation, elementary and secondary students classify musical instruments as either damped or sustained according to the vibrations produced by playing the instrument.

Other experiences that relate science to music can be found in ESS (27, 28). Two ESS units afford elementary students the opportunity to create vibrations and sounds and to alter the pitch and intensity of sounds they create. These units also provide directions for constructing musical instruments from a variety of commonly found materials.

Does integrating science and mathematics enhance the learning of mathematical skills and concepts?

Science and mathematics are integrally related. One cannot speak of a viable science curriculum without considering the integral role played by mathematics, and vice versa. Mathematics, to a great extent, is the language of science (84). The development of skills in logical mathematical reasoning and problem-solving is a goal of both science and mathematics instruction (82, 85). In the learning environment, science and mathematics reinforce each other, thereby facilitating better cognitive development (1). Through the use of mathematics in investigations, students gain better insight into scientific concepts and principles.

Mathematics is a discipline based on abstractions. Integrating science and mathematics experiences is commonly recognized as a means of helping students learn abstractions by relating abstractions to meaningful experiences (65).

Reports of individual teachers' attempts to integrate science and mathematics in their classrooms have appeared in the literature for some time (26, 60, 91, 96). These and later attempts to integrate science and mathematics were based on the intuitive assumption that such an arrangement would produce better learning outcomes. However, other than an inconclusive investigation by Gorman in the early 1940s (39), no attempts to empirically test the intuitive assumption of enhanced learning outcomes through science and mathematics integration were undertaken until the 1970s.

In 1976, Kren studied the abilities of 4th and 5th graders to interpret and construct linear graphs and to construct and measure angles to empirically establish the efficacy of the integration of science and mathematics (65). Using lessons drawn from SAPA and from Modern Mathematics: Structure and Use (1976 edition), Kren's study indicated that the integrated science-mathematics curriculum was as effective as the traditional mathematics curriculum in teaching the construction and measurement of angles. Furthermore, it was found that the skills of constructing and interpreting linear graphs can be taught with equal effectiveness using either the science curriculum, mathematics curriculum, or the integrated science-mathematics curriculum. The results of Kren's study suggest that science activities are just as effective in teaching selected mathematical skills as mathematics instruction alone. They do not, however, conclusively prove whether science and mathematics should be taught separately or as integrated subjects.

In a related study, Shann evaluated the effectiveness of Unified Science and Mathematics for the Elementary School (USMES) on the learning of selected mathematical skills and concepts (109). Her findings suggest that using USMES to supplement a traditional mathematics program results in students learning more mathematical skills and concepts than students not using USMES. Shann hypothesized that the cause of the difference in performance was that mathematical skills and concepts had more meaning for those students whose mathematics program was supplemented by USMES.

More recently, another investigation to empirically establish the efficacy of science and mathematics integration was undertaken by Friend and others (33). The investigation attempted to determine how integrating science and mathematics in a 7th-grade physics unit affects students' attitude toward science and their acquisition of specific physics facts and principles. Their results indicate that students, whose standardized mathematics scores classified them as being at least two years above grade level and who were taught the physics unit integrated with selected mathematical skills, scored significantly better on the Test of Physics Facts and Principles than similar students who did not have such integration between disciplines. No significant difference in attitude toward science was found between the groups.

The results suggest that enhanced learning outcomes can be realized when selected science and mathematics topics are integrated.

Does teaching science enhance achievement in mathematics?

Research has demonstrated that a variety of science experiences can facilitate the transition of students from one level of cognitive development to the next (1, 5, 6, 34, 99, 113). A relationship between science and mathematics is suggested by the fact that one's achievement in mathematics is related to one's level of cognitive development.

Oblivious of Piaget's research, many elementary teachers assume that if students can count, they are conservers of number and should be able to add and subtract. However, this is not the case; knowing the meaning of "number" is a quantum cognitive leap from being able to count. Preoperational children who can count are doing nothing more than repeating a memorized sequence of names.

One of the first indicators that a child can engage in operational thinking is when an understanding of number is demonstrated. To attempt to involve children in experiences requiring an understanding of number prior to having learned the significance of number through working with objects is a futile exercise (4). Involving students in "hands-on" science activities, where they count and manipulate objects, provides experiences that contribute to their understanding of number. In addition, science experiences contribute to the development of other operations basic to the study of mathematics. Some of these operations are: conserving substance and length, one-to-one correspondence, ordering, seriating, and classifying (16).

The contribution of science experiences to the development of operations basic to the study of mathematics is substantiated by research. In studying the relationship between students' ability to conserve number and quantity and mathematical performance, Almy found that students having the ability to conserve experience greater success in learning mathematical skills and concepts (1). In a subsequent investigation, Almy tested the effects of the Greater Cleveland Mathematics Program, alone and in conjunction with either SAPA or SCIS, on students' ability to perform a series of conservation (e.g., number, weight, class inclusion) and transitivity tasks. Her results indicate that students who had mathematics-science programs performed better on the conservation and transitivity tasks than did those who received only mathematics instruction (1).

Other studies substantiate the findings of Almy. Renner and Stafford found that SCIS caused significant gains in conservation of number and length and other related operational abilities among kindergarten and first grade students (99, 113). Further study by Kellogg revealed that the "Material Objects" unit of the SCIS program was the main cause of the increase in operational abilities noted by Renner and Stafford (59).

In another study, Ayers and Mason found that kindergarten students using curriculum materials from SAPA scored significantly better on the number section of the Metropolitan Readiness Test than kindergarten students not using SAPA materials (6). A similar study done with kindergarten students from the Appalachian mountain region concluded that the operational abilities of the students were significantly improved by using SAPA curriculum materials (5).

Research further indicates that science experiences not only enhance the operational abilities of kindergarten and first grade students, but also facilitate the transition from one level of cognitive development to the next among older students and among adolescents with hearing difficulties (34, 116, 119). In studying the effects of certain inquiry-oriented science curricula on formalistic reasoning, Froit found that the Introductory Physical Science; the Earth Science Curriculum Study; and the Time, Space, and Matter programs caused significant gains in the number of students capable of performing tasks of formalistic reasoning (34). Further substantiating the effect of science instruction on formalistic reasoning, are the findings of Tipps. Studying 5th through 8th grade students, Tipps found that, other than age, the strongest predictor of formal reasoning was achievement in science (119). Studying the effects of science learning on students' formal reasoning abilities is important because formal reasoning is a precursor for adequate student performance in many forms of higher mathematics, including algebra.

The effect of science instruction on the cognitive development of hearing-impaired adolescents was reported by Sunal (116). The dramatic difference in cognitive development noted between hearing-impaired adolescents and peers of normal hearing ability seems to be significantly reduced by sustained exposure to science instruction characterized as high in activity, variety, and amount of feedback.

What is the relationship between science and mathematics regarding problem-solving skills?

Research suggests that one of the skills considered essential for achieving success in science-related problem solving, especially at the secondary level, is mathematical aptitude (35, 36, 67). Work by Champagne and Klopfer resulted in a causal model of students' achievement in physics courses (19). The model suggests that mathematical aptitude is a factor that significantly influences problem-solving skills. Components subsumed by the mathematics aptitude variable include mathematical calculation and manipulating skills, and mathematical experience.

Research has also shown that science can be used to broaden the current approach to teaching problem solving in mathematics (22, 109). Replacing contrived problems with real-world science problems has the potential to enhance the problem-solving abilities of students, while promoting a greater appreciation of the usefulness of problem solving in a multitude of circumstances.

Studies suggest that the innovative elementary science programs developed during the 1960s and 1970s enhance the mathematical problem-solving abilities of elementary students. Coffia studied the effect of SCIS on 5th grade students' ability to solve mathematical problems (22). He found that students who had been taught science using SCIS for five years significantly outperformed students who had been taught science using a traditional textbook approach in their ability to apply scientific knowledge in a problem-solving situation.

In a related study, Shann tested the effect of USMES on the mathematical problem-solving abilities of elementary students (109). Her findings reveal a significant difference in problem-solving ability, favoring those students whose mathematics program was supplemented by USMES.

Research also suggests the benefits of science instruction on the problem-solving abilities of older students. Gabel and Sherwood studied the factors that facilitate problem solving in high school chemistry (35). Their findings indicate that supplementing problem-solving activities with less mathematical, more visual activities will enhance the performance of mathematics-anxious students on problem-solving tests.

Further research by Gabel and others clearly shows that few students use reasoning skills in solving problems of an algebraic nature (36). Most high school students rely exclusively on algorithms and frequently try to make algorithms fit problems in inapplicable situations. Offered as a solution to help students overcome this "algorithmic mode" is involvement in science exercises whereby the concepts upon which a problem is based can be understood before the problem is quantitatively presented. High school chemistry and physics courses afford students many opportunities to qualitatively solve problems and, in so doing, prompt the identification of systematic problem-solving approaches (i.e., including the units next to each measurement). Such approaches have proven to be invaluable to students in solving quantitative problems (36).

What can be done to foster the integration of science and mathematics?

Science and mathematics educators favor the integration of the two disciplines. They agree that one of the primary justifications for teaching both science and mathematics in the schools is their usefulness in enabling students to solve real-world problems (82, 85). Too frequently, however, the approaches used to teach mathematical problem solving are narrow in focus or restricted. Often, the selection of problems has been limited to story problems, where the solution lies in choosing the appropriate operation and then performing the computation. Most real-world problems involve more. For example, many real-world problems involve formulating the problem to be solved, ignoring irrelevant data, or collecting new data. Moreover, efforts to compartmentalize mathematical problem-solving skills have, in effect, minimized their potential usefulness in solving real-world problems (41).

Through science experiences, students can apply mathematics to real-world problems (75). One example is when students are provided with a variety of materials to determine which are better insulators. The students are responsible for deciding the steps included in the procedure, the instruments to use for measuring the insulating quality of the materials, and the conclusions. These are but a few of the processes students use to solve such a problem.

Integrating science and mathematics in the curriculum is possible. In a number of instances, integration is made easy because considerable overlap exists between a number of concepts taught in science and mathematics classes. At the elementary level, since the same teacher is responsible for teaching both science and mathematics, coordinating the two subjects is easily accomplished. For example, the teacher can provide hands-on science activities that facilitate the learning of abstract arithmetic concepts such as number sequencing, regrouping, and fractions (75). Activities in ESS, SAPA, SCIS, USMES, and Minnesota Mathematics and Science Teaching, or MINNEMAST, can be used and can serve as models for the development of additional activities by teachers interested in integrating science and mathematics at the elementary level. Among the specific activities that provide mathematics learning experiences are: light and shadows, tangram, and measuring from ESS; material objects, populations, and relative position and motion from SCIS; and using space-time relationships from SAPA (97).

At the secondary level, where the same teacher is not responsible for teaching both science and mathematics, little integration of related concepts can be accomplished without interdepartmental cooperation. Cooperative course planning between science and mathematics teachers is a way to avoid duplication and to ensure consistency. Teachers considering interdepartmental planning would be wise to consult the summaries of work describing similar efforts of science and mathematics educators in England (46, 47).

Along with the work being done in England, the secondary science programs developed with funding from the National Science Foundation during the 1960s and 1970s warrant a close examination. While such programs such as Harvard Project Physics, Chemical Education Materials Study, Biological Sciences Curriculum Study, and Chemical Bond Approach were not specifically designed to foster interdepartmental planning, their developers recognized the utility of mathematics to science. To them, mathematics was viewed as the language of science. Consequently, mathematics became an integral part of these programs.

Summary

The integration of science and other school subjects can improve both the quantity and quality of science instruction and learning. This integration increases students' interest in science, teachers' confidence in their ability to understand and teach science, students' achievement in science, and students' understanding of science's relationship to everyday life.

The concepts, processes, and methods found in science are used in other disciplines. Many science-class activities are predicated on students' reading and writing skills. Students read textbooks, read directions for conducting experiments, and write their own reports of observation. Science's integration with mathematics also requires little effort, since the development of logical mathematical reasoning and problem-solving skills is a goal of instruction in both disciplines. Many decisions concerning societal problems require a basic understanding of science and technology.

Relationships between science and the fine arts and science and health are not as well described in the research literature. Opportunities for integration exist, however. Integrating science and art helps students learn the importance of mental concentration and careful observation involving all the senses. Science activities also can be designed to demonstrate the relationship between science and music. Teaching health concepts through science manipulation experiences and laboratory activities helps students sharpen their science process skills and practice their thinking and decision-making skills applicable to their own health.

Integration of science with other school subjects benefits all curricular areas. This integration demonstrates the value of each discipline area, as well as provides students with examples of the interdependence of knowledge.

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Computers and Science Teaching

What role do computers and other technological advances play in science teaching?

Classroom teachers have always employed technology to initiate and expand teaching and learning. The root of the word technology indicates an art or skill relating to a human behavior. A formal, dictionary definition, drawn from the 1971 edition of the Random House Dictionary of the English Language, states that technology is "the sum of ways in which a social group provides themselves with material objects of their civilization." American educational institutions, constituting a primary "social group" in modern society, have historically done just what this definition suggests: surrounded and provided to the schools the material objects of the society's efforts in technology. Some previous innovations, such as the introduction of the printed page, provided a source of distilled expertise on topics to be addressed in the classroom. Meanwhile, the bound text tended to limit somewhat the application and generalization of knowledge (one tends to believe what one reads). The introduction of a more current technological tool, the microcomputer, may provide a means of overcoming the relative rigidity of a textbook. Opportunities exist for the introduction of many different instructional applications of the microcomputer in science education, although current uses appear to center mainly around simulation-type exercises (2, 7, 36, 53). Overall, computers show great promise as a means of augmenting the classroom instructional process, under the guidance of the teacher.

Research that specifically addresses microcomputer applications in the science classroom is not abundant. In addition, the reporting done in most of these research efforts may be anecdotal in nature, or so nar-

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row in focus as to be questionable when attempts are made to apply the information to specific teaching situations (4, 9, 25, 28, 34). It is important to recognize that the microcomputer is one tool in a rank of technological resources that a teacher might use in science education. In order to integrate responsibly so powerful an instrument as the microcomputer into the curriculum, teachers require information from current and reliable sources regarding such integration. This chapter addresses some basic issues surrounding educational computing in the science classroom. Issues discussed include: computer literacy for science teachers and their students; the effects of current technologies on curriculum and the need for reform; the effectiveness of the microcomputer applications in science classrooms; and the implications for the future of microcomputing in science education.

What does "computer literacy" mean to science education?

A large body of information on the topic of computer literacy may be found in journal articles, magazines, newsletters, and books (24, 33, 46, 53). Material on the subject is widely available at whatever level the professional educator requires. Many journals and microcomputing magazines have published entire issues devoted to the subject of the introduction of microcomputers into the schools. Many of these articles do a good job of outlining key terminology and concepts in language that is familiar to educator audiences. Lipson cites several professional publications for principals and administrators (34). Technology-based magazines, such as the *Instructional Innovator*, a journal of the Association of Educational Communications and Technology (AECT), are particularly useful. Many people in a variety of institutions have outlined their own definitions of computer literacy and the impact that the information will have on the schools (32, 46, 55, 60, 42).

Teachers, when asked what sort of information was needed when establishing microcomputers as a method of instruction, responded that resources in the following were needed:

1. how to use computers in a content area;
2. how to increase the use of computers in the school;
3. where to obtain help in using computers in instruction; and
4. where to obtain information about computer systems and instructional software (11).

All of the above influence a teacher's role; each should be addressed by anyone considering use of the microcomputer as an instructional aid. As with similar questions, the level of understanding and sophistication of the questioner will influence the kind of response that will be helpful. The depth of the information sought by the teacher and student also depends on what role the microcomputer is filling in the classroom. As experience with the technology increases, more meaningful information on microcomputers and science education will become available (1, 29, 51, 57). This is as true for individual users as it is for a society of users. Attitudes of teachers and students toward microcomputers can influence the degree of literacy acquired as well (5, 7, 18, 31). It is important to eliminate the reluctance to include microcomputers as learning tools.

What is the significance of microcomputers in the science curriculum and what are the implications for change?

The significance to students of becoming "computer literate" is greater in many respects than the average educational institution supposes. Schools require much more of students today than they required during the back-to-basics movements of the past decade. Literacy now includes many factors other than the ability to read and interpret print, or to perform mathematical computations. Students must now be able to sort, analyze, and synthesize vast amounts of information in a variety of media (print, video, radio and computer). The traditional skills necessary for access to information and the ability to use that information effectively are still components of literacy. Technological literacy is a step above simple literacy, including the "necessary abilities to engage in complex thinking, i.e., the possession of an appropriate fund of knowledge and the skills to tap a continuously changing information base" (19).

For a science classroom to be technologically impoverished is to invite "factual obsolescence," (59) particularly in the areas of applied science and engineering (19, 40, 50, 59). A nation of individuals who cannot read or write well and who have little control over a technological study will be ill-equipped to deal with competitive groups in trade and defense. According to Clifton Wharton, the "educational infrastructure must accommodate this economic reality" (59).

In response to reports such as the 1983 report of the National Commission on Excellence in Education, *A Nation at Risk: The Imperative for Educational Reform*, congressional and local school efforts are currently being directed toward the improvement of science, mathematics, and computer science curricula. Rather than developing a new set of standards for schools, the science and mathematics reform movements consist, more often than not, of an add-on type of change in curricular approach. The traditional liberal arts programs have not stressed higher-level academic skills (those centered on process, rather than content), and are deficient in teaching logic and critical thinking (12, 32). These deficiencies become obvious in light of reports of declining student achievement in all tested areas. It is a widely accepted view that technological illiteracy is symptomatic of an overall lag in teaching and instructional content in all areas of the curriculum, not just in mathematics and science (15, 18).

The National Science Foundation (NSF) was formed in the late 1940s as a coordinating group for research, development, and improvement of educational programs in mathematics and science. Further prompted by the Sputnik revolution, federal money was allocated on a large scale for curriculum development in these areas. The outpouring of funds for the formulation of new science curricula was not sufficient, however. Teachers received inadequate training on new materials, and were overburdened with too-large classes and too-full teaching schedules. This combination of concerns resulted in the "discovery" two decades later of a math and science problem in the schools (10, 13, 22, 44). The NSF has funded projects recently that have been more successful in pointing out areas of change that could affect science teaching. Project Synthesis explored five topic areas in relation to needs and recommendations for science education improvement: biological sciences, physical sciences, elementary school science; science and technology; and the effects of science education on society (16). The project explored the relationships between the actual state of science education in the schools and the desired models of instruction. The status and needs of the science and technology linkage were discussed in the context of elementary and secondary education practices. Another report, a synthesis of three NSF studies, (17) revealed additional links between science education practices and the potentials of technology. The learner outcomes in the projects studied are described in relation to the impact on curricular content on students' academic achievement, as well as their career selections. The need for changes in teaching methods and materials also is highlighted in a 1983 report delivered at a hearing organized by the Federation of Behavioral Psychological and Cognitive Science for the National Science Board Commission on Pre-College Education in Mathematics, Science, and Technology (15). Major advances and recommendations for uses of technology were discussed in the report, including areas that might be addressed, if adequate funding should become available. Gaining consensus on locating funding for the most effective

means of improving curriculum and instruction in science is a current concern at both national and local levels. More than two dozen bills dealing with science, mathematics, and training in technology are currently before Congress. However, efforts of funding agencies would be best directed toward encouraging *total* school effectiveness, rather than toward upgrading criteria only in science and mathematics as a means of increasing overall student achievement and literacy (18). In brief, computer technology cannot be expected to solve all the problems associated with education that were identified in the reports mentioned above.

What are the effects of computer applications in science classrooms?

One major role—perhaps *the* major role—of classroom computers is to allow students and teachers to work with content in ways that are not possible with conventional means of instruction. Practical examples of abstract concepts (mathematical probability, or chemical reactions, for example) can be demonstrated over and over again, in endless combinations. Students are free to explore a topic as thoroughly as they like, with no time limits or need for constant teacher-intervention. Critical thinking skills (those skills on a higher order than rote memorization or simple generalization of concepts) can be introduced through the use of microcomputers (41).

Several pieces of commercial software that are currently available can help in developing higher-order thinking skills. "Rocky's Boots" teaches logic and organization; "The Factory" promotes complex relational thinking skills; "Gertrude's Secrets" and "Gertrude's Puzzles" introduce deduction and inference; and "Taxman" helps in the construction of numerical strategies and sequence.

Teachers can get help in the process of both hardware and software selection. Numerous articles and reports available through journals and abstracts describe student achievement in relation to use of the microcomputer as a learning tool. Sources of evaluations for software used in general curricular areas include MECC (Minnesota Educational Computer Consortium), MicroSIFT (Northwest Regional Educational Laboratory), and EPIE/CU (Educational Products Information Exchange/Consumers Union). More specific evaluations of science software exist. However, these reports are not common in the literature and tend to be content-oriented. Doyle and Lunetta describe three different areas of computer applications in science education and their relative effectiveness as compared with traditional methods (8). They also outline problems in hardware/software selection, and the prospects for the future of microcomputing in science education. Mandell suggests that the powers inherent in microcomputers (rapid calculation, word processing, data storage capabilities, graphics, color, animation) can be used effectively in a variety of instructional modes (37).

Three instructional uses to which microcomputers are often put in science education are general computer-assisted instruction (CAI); simulations and games (a type of CAI, geared toward student-described outcomes); and specific problem-solving activities. Literature on computer-assisted instruction (CAI) is abundant in current research on classroom computing practices. The process of introducing the computer into the science curriculum, and the effects on student achievement and literacy, along with different methods of applying the computer's capabilities to the teaching of science content, are areas of study that are receiving attention in the research community (11, 36, 38, 43, 56). Simulations and games are an increasingly popular application of microcomputers in science education (6, 12, 30, 45, 47). A simulation is a dynamic display that is based on a model or a simplified version of the actions and reactions of a system over time (48). A simulation can be a powerful teaching tool, because many daily experiences are formulated mentally in much the same manner as simulations are designed. Aside from the realism of simulated experiences, the advantage of computerized games and displays is the ability of the microcomputer to increase the difficulty and complexity of a task (35). Problem-solving skills are the third area of computer application to science education. Cox and Berger reported that students could learn problem-solving skills through the use of the microcomputer and group dynamics techniques (7). Advances in science curriculum reforms that focus on applications of techology include the use of technology to teach systems logic and problem-solving skills. Microcomputer-directed lessons are a natural avenue for the support of such learning schemes (39). A useful discussion of the role of classroom instruction and the integration of problem-solving activities in science instruction is found in *What Research Says to the Science Teacher*, Volume 4 (61). Hurd links science and technologies as factors relating to the changes in science education curriculum (21). Priorities for knowledge acquisition are approached from both a historical and a futures perspective. Student adaptability and problem-solving skills necessary for coping with information overload and rapid advances in both good and bad technological influences in the classroom, are discussed.

One positive direction in science education that is beginning to receive attention is the potential of the microcomputer for teaching the handicapped student. Researchers have given attention to science education for handicapped students, highlighting the serious gaps in existing science curricula that can be remedied by microcomputer integration (3, 20, 23, 27, 54). Science educators can become familiar with the philosophy of mainstreaming handicapped students in science, as well as with the concept of using an individualized education plan or program (IEP) as a tool for responding to students' needs. Lazar outlines appropriate uses of IEPs and classroom techniques that allow the science teacher to apply the most useful elements of the existing science curriculum to the student's program (31). Lazar's recommendations on learner needs assessments, task analysis, choice of instructional materials, and management objectives met and/or levels of achievement, could be applied to a microcomputer management system. Methods of instruction for the handicapped student (particularly physically handicapped) have also been explored using the microcomputer. Extensive work with LOGO programming and communications devices for physically disabled and educationally impaired (blind, deaf, autistic) children has been reported (43). Goldenberg has prepared one of the definitive resources on the subject of special education and computer technology (14).

What are the implications of microcomputers for science education and the future?

Computers represent an enormous resource for the enrichment of science education practices. The use of microcomputers may change the relative emphasis on and importance of certain skills. For example, more emphasis may be placed on problem solving than on memorization of sequences and formulas for computation. More emphasis may also be placed on the students' verbal skills and the precision of language used in science classes, since students need to be accurate when communicating with a computer. Simulations will create an important role for microcomputers to fill, but they will probably never fully replace the real-life laboratory (12). Sparkes outlines uses for the microcomputer that will give this technology a leading role in the classroom of the future (52). Electronic blackboards for distance transmission of images, notes, simulations, and other graphic data presentations, represent a way to expand teacher capabilities and to provide advanced instruction to sites that normally would not be able to access such information (13, 52). Other computer-managed functions such as data analysis and transmission; management of student materials and records; and applications of computer-assisted instruction (CAI) may also play a role in future science education settings. Discussions of new and future directions for computers in science instruction are found in recent literature (22, 26, 49, 58). Links between industry and schools would involve employees of business in the classroom. This resource-sharing could involve scientists and engineers from industry and the university system in planning and implementing educational programs in the public schools (16, 17, 22, 49).

Alternatives exist for enhancing instructional practices in the science classroom through microelectronics. Students are facing an increasingly complex education process that, it is to be hoped, will prepare them for an increasingly complex workplace. Educators can take part in introducing students to this technological boom in communication and learning. In recent months the U. S. system of education, from kindergarten through higher education, has come under rigorous appraisal from federal, state, and local groups. Dynamic developments in electronic communications and microcomputer technology are rapidly altering what teachers do and how they do it (50). According to the U. S. Office of Technology Assessment:

> The so-called information revolution, driven by rapid advances with communication and computer technology is profoundly affecting American education. It is changing the nature of what needs to be learned, who needs to learn it, who will provide it, and how it will be provided and paid for (42).

Strategies are being developed to deal with the future-oriented science curriculum. Issues to be addressed include computer-assisted instruction and similar techniques, as well as management of student progress and records. Teacher training is essential for understanding and effectively applying new techniques in the classroom. Future-oriented curriculum content in all areas of instruction (not just science); administrative policies concurrent with growth and advancement to meet societal transformations; instructional practices and training in appropriate skills for teachers and students; and links between school and the community, home, and other educational agencies are essential for the successful implementation of a science education system of the future.

Summary

The development of low-cost, relatively easy-to-use microcomputers enables schools to prepare students for their future in the information society. Unfortunately, the potential of this new technology is blemished by problems. First, the development of hardware and software has been unequal. While hardware is relatively sophisticated, instructional software is often of poor quality technically and/or pedagogically. Technology users in schools need to think of themselves as pioneers, forging a trail into often uncharted lands. Some evaluation and anecdotal literature exists and should be consulted. However, in many cases the teacher using technology would be well-advised to function as a researcher discovering, hypothesizing, and testing ideas for computer applications in his/her own classroom.

It is important to realize that many current applications of microcomputers are answers to *old* problems. The potential of microcomputers to solve problems of which we are only vaguely aware or to extend our capabilities in new ways is great. While microcomputers can help science students simulate natural phenomena in controlled settings, this technology has much broader and deeper applications for all aspects of education.

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A CONTEXT FOR SCIENCE EDUCATION

Science education is influenced by the values, goals, and norms of larger contexts: school, home, and community. While these values and goals influence the learner directly, they also influence the education of science teachers. Chapters in this section illuminate these points.

Influence of School and Home Factors on Learning

What implications for science education can be drawn from research on effective schools and classrooms? What school and home environmental factors influence student achievement and attitudes toward science?

During the past fifteen years a great corpus of educational research has identified a variety of factors that directly influence and enhance student acquisition of knowledge and student achievement. While our understanding of how knowledge and skills are acquired has increased dramatically, this impressive accumulation of findings seems to have gone unnoticed by many educators, as well as by the general public (52, 54). Perhaps much of this information has been ignored because of the negative findings of some earlier research. During the late 1960s and early 1970s, educators were told by researchers that: most educational techniques seem to hinder as often as they aid learning; learning is spontaneous; maturational forces within the student cause learning to proceed at a given rate, notwithstanding wide variations in educational conditions; a lack of relationships exists between educational conditions and student learning; and, improvements in schooling do not make a difference in the achievement of poor and minority students (12, 25, 50).

Statements such as the above severely hurt, and continue to haunt, the education profession. Such statements also initiated a new genre of research: effective schools research. This research is based on the idea that schools can be organized to improve student achievement, especially achievement of poor and minority students (3, 14, 15). Although reports such as that of the National Commission on Excellence in Education and Goodlad's study of schooling accuse schools of mediocrity and paint a grim picture of the current status of education in the United States, recent research findings, combined with the desire to develop exemplary programs within effective schools, should provide encouragement for the future. Further, it is essential for educators and the gen-

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eral public to realize that school personnel, particularly teachers and principals, are a vital factor in improvement efforts. Teachers are significant in the successful implementation of programs (13). In fact, Purkey and Smith note that change will not take place without the support and commitment of teachers (42). In addition, principals must be effective instructional leaders (1). In this chapter, we will focus on characteristics of effective schools, classrooms, and other factors contributing to the success of exemplary science programs. In addition, we will look at home factors that enhance student achievement and attitudes in science.

Are there effective school practices that are not widely used that should be encouraged for more widespread use?

Recent growth in school improvement activity is phenomenal. Most states currently have a school improvement program underway that reflects features of the effective schools literature. Similarly, the National Science Teachers Association, in 1982, conducted the Search for Excellence in Science Education (7, 33, 34, 36, 38, 39, 40, 58). The criteria for this research emerged from the findings of Project Synthesis (22). There are a great many schools around the country where careful, thoughtful, and well-planned efforts to improve have been extremely successful. Benefits have accrued to students, teachers, administrators, the school as a whole, and to the community. However, these successes are not accidental. Effective schools and exemplary programs are designed to be excellent, involve several years of development, and are still evolving (29, 35).

Research on educational improvement has been conducted from two distinctly different perspectives: micro-effectiveness and macro-effectiveness. The micro-effectiveness perspective uses the classroom as the unit of investigation and analysis and contends that individuals concerned about improving schools must address the question: "What are characteristics of an effective classroom?" The macro-effectiveness perspective contends that an abundance of classroom research exists and that, by using the school as the unit of investigation and analysis, we can address the question: "What are characteristics of the school as a whole that influence student cognitive and affective performance?"

In synthesizing research from both perspectives, Squires, Huitt, and Segars have identified five school and classroom indicators that are associated with student achievement: school leadership, school climate, student behaviors, teacher behaviors, and supervision (48, 49). It seems clear that a comprehensive look at the factors affecting student achievement must encompass both research perspectives. Using the Squires, Huitt, and Segars school and classroom indicators as organizers, let's look first at the macro-effectiveness perspective.

The primary finding of effective schools research is that "active leadership creates a school climate in which success is expected, academics are emphasized, and the environment is orderly" (49). In other words, effective schools have effective leaders, both principals and teachers. This point is extremely important for science educators because, although the new science curricula of the 1960s were highly successful in enhancing student performance (27, 28, 45, 46, 47), the influence of the principal was overlooked in our efforts to improve the quality and quantity of science education (31). As a result, many principals did not understand the significance of these new curricula. When pressured to "return to the basics," teachers and principals often abandoned them.

Six conditions related to school leadership have been found in the schools whose students excel (1, 10, 14, 15, 31, 44, 48, 49, 51). In effective schools, achievement is emphasized. High priority is given to activities, instruction, and materials that foster academic success. The principal, as an instructional leader, is involved in school and classroom activities. Teachers are aware of the school's commitment to academic excellence. Further, excellence is stressed in all academic areas—not just reading and mathematics. Although standardized tests are used as a basis for evaluating a school's minimum obligations, an instructional emphasis is also placed on the development and enhancement of higher-level intellectual skills.

In effective schools, instructional strategies are set. Principals and teachers are actively involved in instructional decision-making, especially decisions about the selection of content, materials, methods, and evaluation procedures. Plans are developed for resolving students' learning problems and/or deficiencies. The instructional strategies are selected to ensure that students master the content and develop the requisite skills, thus providing students with the cognitive and affective prerequisites for each new learning task.

In effective schools, an orderly atmosphere exists. The school climate is conducive to learning. Effective schools recognize a universal standard of discipline, which is enforced by administrators, teachers, and students and is fair. Classroom routines also promote an orderly environment: lessons start and end on time, students are prepared, teachers give and correct homework. An orderly environment helps keep students on task and, therefore, actively engaged in learning.

In effective schools, students' progress is evaluated frequently using both formal and informal strategies. The results of these evaluations influence teachers' decisions about re-teaching, supplementing, and enriching students' understanding of the subject. All students are expected to master the content, and the students' need for success is considered in lesson planning. Standards for achievement are high, but attainable.

In effective schools, instructional programs are well articulated and well coordinated. There is an interrelationship among course content, sequences of objectives, and materials within each grade and across the grades. What transpires in the classroom is related to the overall goals and program of the school. Instruction also has practical application beyond the school.

In effective schools, teachers receive the necessary support for improving teaching. Teachers are encouraged to attend professional meetings, workshops, and inservice sessions. The principal monitors classrooms, supervises instruction, and provides time for teachers to plan together. The tone and focus of the school is established.

In studies of schools where exemplary science programs have been developed, we find similar conditions (7, 31, 33, 34, 35, 36, 37, 38, 39, 40). In these programs, teachers are the critical factors in designing and creating an environment conducive to inquiry. These teachers are included in developing curricula for their grade/course; they do not have a textbook-oriented program; they integrate more laboratory investigations and spend less time lecturing than teachers in general; and, they find that other teachers, coordinators, university faculty members, inservice programs, professional organization meetings, and journals are good sources of information. Teachers in exemplary programs have high expectations of themselves; they provide a stimulating environment and an accepting atmosphere, while encouraging student action, decision-making, creativity, and excitement. They challenge students, expect different students to achieve differently, and develop effective communication skills, all while stressing the development of higher level intellectual skills. It should be evident that these teachers put in far more than minimal time and they do make a difference.

Teachers are encouraged by strong administrative support. The administration views itself as an integral part of successful curriculum development and implementation. At the same time, teachers in these programs gain the support of, and work closely with, the administration, parents, community leaders, and business and industry representatives.

The programs are designed, developed, and implemented by teachers who intend the programs to be exemplary. Further, the programs are organized in an orderly, sequential manner in which the quality and quantity of science instruction is known.

Inservice training is viewed as a long-term effort, which is never-ending. Inservice is relevant and designed to meet the needs of individual teachers in their classrooms.

Principals support good science programs. Principals are actively involved with the program, they demonstrate positive attitudes toward the program, they communicate their interest in science to teachers and members of the community, and they observe classes when science lessons are being taught. Principals also provide the necessary materials and provide inservice opportunities in science that address the needs of individual teachers. Finally, principals recognize that science is a basic part of their curriculum.

Thus, effective schools and schools with exemplary science programs are characterized by strong teacher and principal leadership in a school climate that emphasizes academics and success in an orderly environment.

In turning our attention to the micro-effectiveness view, we see that effective classrooms can be examined from three perspectives: student behaviors, teacher behaviors, and supervision. While each of these dimensions influences student achievement, student behaviors are most directly correlated with student achievement scores. Student and teacher behaviors will be the primary focus of the discussion that follows.

Squires, Huitt, and Segars maintain that three specific areas of student behaviors have the most potential for affecting student achievement: involvement, coverage, and success (48, 49). *Involvement* is the amount of time a student actively works on academic content. The key term here is "actively works." This is often referred to as engaged time—when the student is concentrating on an academic task—in contrast to "allocated time," or the amount of time scheduled or planned for instruction. *Success* refers to how well a student performs on classroom tasks. *Coverage* refers to the amount of content covered by a student during the school year. Each of these variables is measureable and each of these variables is alterable (4, 5, 49). It is for these reasons that Squires, Huitt, and Segars believe that measures of involvement (engaged time), coverage, and success should become the focus of school improvement efforts. It should be remembered that these three behaviors are interdependent. In the following discussion, however, each will be treated separately, before the interdependence is considered.

Student acquisition of the content and skills, as well as the ability to apply such knowledge, will be enhanced if teachers attend to both allocated time and engaged time (17). First, it is clear that time must be allocated to teaching and learning a specific skill if that skill is to be mastered. Many elementary schools simply do not allocate time for science in their curriculum plans. If time is allocated, it may amount to so little that meaningful activities cannot be pursued. Goodlad states that "the amount of time spent on a given subject is a powerful factor in learning" and that this influence appears to be greater for subjects such as science that are not usually taught outside of school (21). It is, therefore, imperative for teachers and principals to become more aware of, and efficient in, their allocation of time for school science. This is in addition to assuring that student engaged time leading toward successful experiences in science is maximized. Thus, teachers and principals must be innovative in their time allotment and classroom planning.

Elementary teachers often struggle with the problem of how to integrate inquiry-oriented science activities into traditional 25-35 minute daily science classes. Similarly, junior and senior high school science teachers are frustrated in their attempts to complete extended investigations in 45-55 minute lessons. A few simple schedule modifications would ensure that students have the necessary time to engage in meaningful, productive inquiry-oriented science activities. In elementary classrooms, rather than teaching science approximately 30 minutes per day, science could be scheduled for two or three 60-90 minute periods per week. Realistically, up to five minutes may be spent organizing activities, getting supplies and material organized, and engaging students in a science activity/lesson. Similarly, up to five or seven minutes may be spent cleaning up, returning supplies, and ending the activity. What results in the traditional setting is that less than 66% of the allocated time is available for students to engage actively in learning. With two or three 60-90 minute lessons, however, preparation time and clean-up time remain constant while the amount of potential student engaged time has been increased to about 90%. An additional benefit for elementary teachers is that with extended periods and alternate daily scheduling of disciplines such as science and social studies, there are fewer daily preparations. At the junior high and senior high levels, science courses should be scheduled with at least one double laboratory period per week. Such allotment changes would significantly increase student engaged time, assuming the coverage issue has been resolved. Effective schools are noted for their flexibility in time and scheduling. Similarly, many of the exemplary science programs identified by NSTA use flexible scheduling.

One high school, recognized by the Secretary of Education as part of the U. S. Department of Education's 1982 Search for Excellence program, schedules English classes and chemistry classes together. A sample schedule might call for a two-hour chemistry class on Monday and Wednesday (with no English class on those days), a two-hour English class on Tuesday and Thursday (with no chemistry class), and one

hour classes for chemistry and English on Friday. Following this pattern, chemistry teachers can organize and conduct labs and English teachers can engage in extended activities during their two double periods per week.

While allocated time refers to "official time," "engaged time" refers to the amount of time within the allocation that the student spends actively learning. Different students learn at different rates, so the amount of needed engaged time will vary by individuals. Moreover, different learners prefer different types of learning activities. The point is, however, that unless the student is actively working at learning, learning will not occur. Time allocations will need to be different for different students in the same class. A student will spend a portion of the allocated time engaged in working on the task, e.g., manipulating materials, reading, thinking, interacting with students or the teacher, or processing information.

Student learning, however, is influenced not only by the amount of allocated *and* engaged time, but also by the *match* between the task and the student. If the task is so difficult that the student experiences few successes, then student motivation and attitude decrease and little learning results. If students encounter many experiences leading toward success, then learning is more likely to occur.

The term coverage *does not* imply that "the more content covered the better"; or, that science teachers should be concerned about "finishing the book." It is the quality of the science and technology education that students are actively engaged with that is important—not the quantity. Thus, coverage refers to the amount of meaningful content that each student is engaged with throughout the year. The integration of relevant content, scientific processes, and applications of the content to societal contexts should become the focus of the coverage issue for science teachers. It is far better to have all students actively engaged 90% of the time with content that is interesting to the student, appropriate for the learner, and able to be applied by students in their daily lives, but which may not be in the book, than to have less than half of the students engaged approximately 60% of the time while "covering the text." The coverage issue is one that personnel in effective schools and exemplary science programs have thought through extremely carefully as they designed, developed, and implemented well articulated and sequential instructional programs intended to be effective for all students.

Teacher behaviors also have an impact on student behaviors and student achievement. Squires, Huitt, and Segars maintain that teachers have the most influence over student behavior and that they support student achievement through planning, instruction, and classroom management (49). Hunter defines teaching as "the process of making and implementing decisions, before, during, and after instruction, to increase the probability of learning'' (24).

Planning for instruction involves identifying specific tasks or activities that will be presented in the classroom. Planning for student involvement, coverage, and success in effective classrooms, however, involves much more. It encompasses identifying instructional/performance objectives, diagnosing learner characteristics, and selecting appropriate instructional and management strategies (49). In planning for instruction, teachers should take into account students' prior learning. Bloom estimates that 60-80% of the difference in student achievement scores is due to differences in students' past learning (4). The successful completion of science activities and acquisition of scientific skills and processes may depend as much upon the cognitive and affective characteristics that students bring to the class as upon the teacher's planning and preparation for instruction. Diagnosis can be accomplished by pre-testing students at the beginning of a new course and using feedback-corrective procedures to enhance students' knowledge of the prerequisites they missed. Then, throughout the course, continued use of a feedback-corrective approach will ensure that each student has the cognitive and affective prerequisites for each new learning task. Again, it should be evident that in order to implement such procedures successfully a well articulated and sequenced curriculum is necessary within each grade and across all grade levels.

All students can learn most of what they are taught. Teachers, however, can enhance this learning in a number of ways, as we have shown. One way in which learning can be promoted is related to whether the teacher establishes an environment that is supportive of cooperative learning, or one that reinforces individualistic or competitive learning.

In science classes, research indicates that cooperative learning experiences promote greater mastery and retention of the material being taught, as well as more positive attitudes toward the experience, when compared to student performance in competitive or individualistic learning experiences (23, 26). The average student in cooperative learning environments performs at the 79th percentile when compared to other learning environments (6, 53). Thus, the way in which science teachers structure instructional goals determines the nature of student-student interactions, which also affect instructional outcomes (26). A brief synthesis of these three modes of student-student interaction seems appropriate:

1. *Competitive.* Students perceive that they can achieve their instructional goal if, and only if, their classmates fail to achieve their goals. Students are instructed and encouraged to work faster and more accurately than their classmates. Grading is based on a norm-referenced system. Most students perceive school competitively. Competition among students is caused by negative goal interdependence.

2. *Individualistic.* Students perceive that their ability to achieve instructional goals is unrelated to the goal achievement of their classmates. Students are instructed to work on their own, at their own pace, without interacting with other students. Grading is based on a criterion-referenced system; the achievement of one student has no affect on the achievement of others. Individualistic instruction has been offered as an alternative to competition. Individualistic instruction contributes to student loneliness and alienation and adversely affects social and cognitive development.

3. *Cooperative.* Students perceive that they can achieve their instructional goal if, and only if, the other students with whom they are working achieve their goals. Students work together to achieve a group goal. Grading is based on evaluating the quality of the *group's product* on a criterion-referenced system. All members of the group must master the material. Thus, cooperation is encouraged by positive goal interdependence with individual accountability (26).

Science classes, by virtue of the nature of science and scientific inquiry, offer an ideal environment for students to learn cooperatively. A current goal of science teaching is derived from the interaction of science, technology, and society. This goal emphasizes preparing future citizens to recognize and resolve societal issues and concerns rooted in science and technology. The goal emphasizes not only cognitive skills but also affective, ethical, and aesthetic understandings of science and technology. We have a better chance of helping students reach these understandings if we structure learning situations cooperatively.

Thus, ''effective teaching involves the considered selection of a teaching approach to attain a desired educational outcome with a particular type of learner'' (41). It should be clear then, that, despite recent outcries from back-to-basics supporters and direct instruction proponents, an emphasis on basics and direct instruction is *not effective* in all disciplines or for all students (18, 20, 43). This point is extremely important for science teachers and administrators to realize. The objectives of effective science classes focus on higher level processes and cognitive skills (e.g., ability to identify and solve problems, inquiry skills, analytic thinking) in addition to acquiring scientific content. Thus, teachers should implement a variety of instructional techniques (e.g., lab work, demonstrations, group work, projects, simulations, independent study, brainstorming, role playing, questioning, classroom discussions) that bear a logical relationship to the instructional objectives. It must be remembered that the appropriateness of an instructional technique is contextual. That is, it must be judged in terms of the instructional objectives it is supposed to help students master—and, whether or not students master those objectives. Under such learning conditions, all students have equality with regard to learning outcomes (4). Another major goal of education must be to provide all students equal access to knowledge and learning outcomes, not merely equal opportunities to learn (4, 21).

Effective classrooms are, therefore, characterized by a diversity of instructional strategies being implemented, depending upon the objectives and student needs. Wise and Okey characterize an effective science classroom as one in which:

> Students are kept aware of instructional objectives and receive feedback on their progress toward these objectives. Students get opportunities to physically interact with instructional materials and engage in varied kinds of activities. Alteration of instructional material or classroom procedure has occurred where it is thought that the change might be related to increased impact. The teacher bases a portion of the verbal interactions that occur on some plan, such as the cognitive level or positioning of questions asked during a lesson. The effective science classroom reflects considerable teacher planning. The plans, however, are not of a "cookbook" nature. Students have some responsibility for defining tasks (57).

Finally, Squires, Huitt, and Segars maintain that supervision that supports classroom teachers' efforts to increase student involvement, success, and coverage can lead to increases in achievement, especially if supervisors help teachers plan, manage, and instruct toward those desired outcomes. Thus, every supervisor should be proficient in observing classrooms, in conducting conferences, and in planning with teachers to improve performance in those areas. Successful, positive supervision can be rewarding and productive (48, 49).

Systematic innovation in science instruction has been found to produce positive improvements with regard to science learning and attitude

(9). Schools can be effective in educating most students and science programs can be designed to be exemplary. When instructional methods, techniques, and activities match the inquiry-oriented nature of science, students not only enhance their performance on higher level skills, but they acquire more scientific knowledge while developing more positive attitudes about science (27, 28, 45, 46, 47).

Finally there is another area that, while not controlled by teachers, does affect teaching and learning. Class size is a factor that affects cognitive, affective, and instructional outcomes. Other things being equal, students learn more, are more actively engaged in learning, and have more positive attitudes regarding school and learning in smaller classes (19). Under the most extreme learning conditions (1:1 tutoring), the average tutored student exceeds the performance of 98% of the students in conventional group methods of instruction. More impressive is the fact that 90% of the tutored students attain a level of achievement reached by only the highest 20% of the students under conventional conditions (6). Although exclusive one-to-one instruction is obviously not possible in classrooms, there are two important messages to be gleaned from such knowledge:

1. Most students do have the potential to attain the highest levels of learning (6).

2. Measured ability does not account for a great amount of variance in science learning. The primary factors that do influence learning and thus compensate for ability differences are the quality and quantity of instruction; student motivation; and, the home, peer, and classroom environment (6, 8, 53).

The issue now becomes how does the teacher operationalize these two points in classes marked by whole-group instruction? What variables that most influence learning can be altered so that students attain the same level of cognitive and affective performance in conventional class groupings that are attainable with one-to-one instruction? Recent evidence appears to suggest that this goal may be attainable. Bloom and his associates believe that when two or three alterable variables involving *different* objects of the change process are used together their effects appear to be additive (6). The four direct objects of change identified by Bloom and his associates are:

1. the learner,

2. the instructional material,
3. the home environment or peer group, and
4. the teacher and the teaching process.

By attempting simultaneously to alter variables associated with the learner and with the teacher, for example, the results may be greater than if we attempted to alter two variables associated with the learner. A number of possible combinations leading toward enhanced performance in science classes can be envisioned. For example, teachers might use the methods, techniques, and strategies of the new science curricula (which is a change in Object 2) in conjunction with:

1. Learning feedback-corrective methods (Object 1). Bloom estimates that with this combination, the average student would exceed the performance of 90% of the students in conventional science classes.
2. Cooperative learning (Object 4). The average student, according to Bloom, would exceed the performance of 85% of the students in conventional science classes.
3. Home environment intervention (Object 3). The average student would exceed the performance of approximately 80% of the students in conventional science classes, according to Bloom.

In addition to the school environment, what home factors can be identified that affect student achievement and attitudes in science?

The home environment is one of the most important influences in the development of a child's cognitive abilities and affective characteristics (5, 6, 30, 53, 55). Parental involvement is a key factor in influencing a child's desire to learn. Many teachers find it useful to involve parents in learning activities with their children at home (2). Direct "parent involvement in learning activities is a strategy for increasing the educational effectiveness of the time that parents and children spend with one another at home" (2). Teachers should stress the importance of the home environment and out-of-school peer groups. Parents should be encouraged to provide opportunities for their children to learn outside of school; to stress the importance of learning; to establish a regular study schedule; to review their children's homework; to limit the time allowed for television viewing; to support out-of-school peer groups with learning interests, goals, and activities.

Many parents indicate a willingness and desire to help their children, but they don't know where to begin. Bloom has synthesized some home environment factors that influence school learning, which teachers and administrators should share with parents. Such factors include:

1. monitoring work habits in children;
2. allocating times to study or read;
3. placing a priority on schoolwork, reading, and other educational activities over television and recreation;
4. providing academic guidance and support;
5. encouraging activities that have educational value e.g., family discussion of news, current events, TV programs, as well as the use of libraries, museums, and cultural activities;
6. providing opportunities for the enlargement of vocabulary and sentence patterns;
7. supporting and encouraging the child at each stage of educational and cultural development; and
8. assisting the child in establishing academic aspirations and expectations (5).

Ware and Garber note several home environment variables that predict student achievement (55). The *availability of materials* in the home seems to be the most important variable for predicting school success. Parents should be encouraged to have books for school and leisure reading, as well as games and supplemental materials to enhance what is being taught in school. The remaining home environment variables influencing achievement are interactive processes that exist between the parent(s) and child, e.g., awareness of child's development; the system of rewards for intellectual attainment; expectations for child's schooling; and, the reading press the parent places on the child. Home-centered activities that enhance these interactive relationships also have the potential for increasing the child's school success.

Becker and Epstein have identified fourteen specific teaching techniques that teachers can use to involve parents in learning activities with their children. The five major categories include techniques that:

1. involve reading and books;
2. encourage discussions between parent and child;
3. specify certain informal activities at home to stimulate learning;
4. involve contracts between teachers and parents that specify a particular role for parents in connection with their children's school lessons or activities; and
5. develop parents' tutoring, helping, teaching, or evaluation skills (2).

Techniques within each of these groupings are effective regardless of the educational level of the parent and/or socioeconomic status. Walberg notes that "the 'alterable curriculum of the home' is twice as predictive of academic learning as is family socioeconomic status" (53).

Family environmental variables can be altered by educators and parents to promote a child's cognitive and affective development. Many teachers complain about the lack of interest some parents have about education. Reality is that many parents do not know how to express their concern or how to enhance the likelihood of their child's school success. Thus, for parental involvement to be successful teachers and administrators may need to help parents create environments that encourage cognitive and affective learning. Teachers and administrators will need to establish parental involvement programs and to be familiar with the socio-psychological dynamics of families (30). Techniques for parent involvement in home-learning activities have far greater potential for actively involving parents in important educational exchanges with the teacher than have traditional school visitation nights and/or parent-teacher conferences (16). Castenell has noted differences among achievement motivation in adolescents (11). Not all adolescents perceive academic achievement as being necessary for success in life. Adolescents, however, are capable of perceiving achievement in home situations and/or peer relationships. Thus, it is imperative for teachers to recognize diverse life experiences of students and adjust the curriculum accordingly. Similarly, teachers can provide parents with suggestions that could originate at home and could lead toward academic success. Castenell also asserts that traits such as cooperation, collectivity, and interdependence are important in motivating students for academic achievement.

Finally, with regard to the home environment, research on home factors indicates that the influence of television on achievement depends on the amount of viewing time. Thus, television is neither the villain nor the redeemer with regard to academic performance. "Up to 10 hours per week of television viewing may actually enhance achievement slightly. Beyond 10 hours, achievement diminishes with increased viewing up to 35 or 40 hours per week" (56). Parents then, should monitor the quantity and quality of television viewing. Teachers, however, should encourage parents to watch educational programs with their children for the purpose of discussion. Teachers could even prepare a few open-ended discussion questions for such viewing. The benefits derived by students, parents, teachers, and society alike are extremely valuable. As educators, we must not ignore the potential of the home environment.

Summary

Learning does not occur in a vacuum. Students' progress is affected by factors in the school and in the classroom, as well as by conditions in the home.

Science teachers can profit from the research on effective schools and effective teaching. Many programs reflect features of the effective schools literature. This research can be viewed from two perspectives: by looking at the characteristics of an effective classroom, and by asking what characteristics of the school as a whole influence student performance.

Several factors in the classroom influence student achievement. These include students' use of time in the classroom; teachers' planning, instruction, and management of the classroom; and supervisors' support of teacher behaviors in the classroom.

Effective schools and schools with exemplary science programs are characterized by strong teacher and principal leadership in a climate that emphasizes academics and success in an orderly environment.

The home is one of the most important influences in the development of children's cognitive abilities and affective characteristics. Family environmental factors can be altered by educators and parents to promote children's development. Teachers and administrators are encouraged to establish ways for parents to be involved in their children's learning.

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Science Teacher Preparation and Professional Development

Is there a shortage of science and mathematics teachers? Are new science teachers being prepared to enter the profession?

There is a severe shortage of teachers in science and mathematics now, and it will grow steadily worse over the next ten to fifteen years (14). In 1982, on the average, teacher training institutions throughout the country each graduated only three mathematics teachers and only five science teachers, most in biology (23).

This problem of declining numbers of science and mathematics teachers will be further exacerbated by the increasing numbers of high school students beginning in 1985, by increased high school graduation and college entrance requirements, and by the high number of science teachers who will leave the profession for retirement, for higher-paying industrial positions, and because of teacher burnout.

According to the National Center for Educational Statistics, there are currently about 200,000 science and mathematics teachers in elementary and secondary level classrooms (18). In 1980, thirty states reported shortages in mathematics; sixteen states reported these shortages as critical (8, 9). By 1981, the number of states reporting shortages in mathematics and science had grown to forty out of the forty-five responding (25). A look at trends over the years 1972 to 1982 reveals that the number of secondary school science teachers decreased by 65%. The corresponding decrease for mathematics teachers was 75%. Moreover, almost five times more science and mathematics teachers left teaching in 1981 for employment in non-teaching jobs than left because of retirement (15, 19). Overall the supply of individuals with science and mathematics education degrees has been falling since 1972 (20).

Perhaps the most severe problem facing science education presently is the critical shortage of *qualified* science and mathematics teachers, es-

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pecially at the secondary level (40). When one reviews science teacher education programs nationally, it appears that science education at the elementary school level is no better off.

While many reports identify critical needs for teachers in both science and mathematics, some states are reporting no shortage of either science or mathematics teachers. Since we know that universities are graduating fewer science teachers and that enrollments are on the increase in high school science classes, why is the shortage problem not more severe?

A review of data generated by one state department of education reveals that positions are being filled by people with emergency teaching certificates (32). In these cases, teachers who have not fulfilled all of the necessary requirements in science or mathematics are given an emergency teaching certificate for one to three years. During this time, they must complete the coursework to meet the minimum requirements of the position for which they have received an emergency teaching certificate. If this practice is widely followed throughout the states, then teacher shortages will appear to vanish. This practice has resulted in decreased numbers of teaching vacancies, as well as decreased reports of teacher shortages. However, it raises the important question of the qualification of teachers.

The problem of adequate numbers of qualified teachers, at all levels, is complicated by the quality of students drawn to the education field. The average SAT scores for all students in the country have been falling for over twenty years. Hurd reports that the average SAT verbal scores for education majors has dropped from 418 to 330—a drop of 79 points (15). Hurd also reports that education majors placed 17th out of 19 fields of study on the ACT math tests; they placed 15th out of 16 fields on the SAT mathematics test (15).

There have been efforts to improve science teaching preparation programs. Several preservice science teacher programs were established in the 1970s during the development of the innovative science curricula supported by NSF funds. Examples include the Purdue and Iowa UPSTEP programs, funded by NSF (6). These two programs, together with many other UPSTEP programs, resulted in new and improved preservice science education programs. In addition, nine programs were funded by the U.S. Office of Education for the improvement of elementary teacher education. Helgeson and his colleagues report no research findings to indicate that any of these programs had a significant impact (12).

Other new programs started in the late 1970s in order to improve preservice science education include the New Elementary Program, University of Florida; A College School Cooperative Science Teacher Education Program, Richmond College of City University of New York; The University of Iowa Model and Project Assist, The University of Iowa; and the Cooperative Teacher Education Program, University of Illinois (12). Many of these programs were the result of a landmark survey conducted in 1968 by Newton and Fletcher. Called the Research on Science Education Survey (ROSES), it revealed that preservice science teachers saw education courses as irrelevant to their future teaching careers (6, 12). Many felt that professional education courses were useless or a waste of time.

Several states have begun to consider ways to improve methods for selection of new teachers (30). Some states require higher admission standards for preservice teacher applicants. These procedures have taken three forms. Some states test for entry level literacy and computation skills. Others test the applicant's general education background, which covers the liberal arts program of the first two years of college. In this approach, students wishing to enter schools of education must achieve a specified minimum score or be denied admission into the program. Another approach that is being instituted is the raising of grade-point-average requirements for admission into colleges of education.

Some states are beginning to test teachers after the completion of their undergraduate training. In these efforts, before a teaching certificate is granted, candidates must attain a minimum score on a norm-referenced test. High cutoff points are set to ensure improved teaching. The National Teacher Examination is used by some states for this purpose; other states have elected to develop their own examination. The state-developed tests generally are of two types: basic skills tests, or tests of specific competencies that teachers are expected to have mastered to be effective teachers at either the elementary or the secondary level, specifically in specialties such as science. Georgia has spent over $2 million to develop a performance evaluation system for beginning teachers. Florida has also developed an evaluation program to assess new teachers' skills before issuing a final teaching certificate. Similar procedures are planned by other states.

What do we know about the training of science teachers throughout the country? What is the effect of this training on teachers' attitudes and practices?

Many educators, including school principals, supervising teachers, and science educators, agree that beginning teachers lack competence in science subject matter. Often they have experience in one subject area (e.g., life science, physical science, earth science), but are expected to teach several subject areas during the course of the year. Usually state certification is based on course titles, number and distribution of university credits, and grades earned (6). Certification is thus based on the "approved program" approach, involving colleges and universities in the certification procedure.

Undergraduate courses by preservice teachers are the same as those usually taken by students preparing for graduate study or for professional schools (e.g., medicine, law, engineering, etc.). Further complicating the problem is the fact that secondary level science teachers receive training in two major areas: general undergraduate academic courses and professional education courses. Of the education courses, a small number are in their major subject area, and few or none are in other science areas. For instance, biology preservice teachers take, on the average, eight undergraduate biology courses, or an equivalent of twenty-four credit hours (31). However, they are required to take few or no courses in chemistry or physics. The same is true for earth science, chemistry, physical science, and physics majors. Surveys reveal that about 21% of the nation's biology courses are taught by teachers with less than eighteen semester hours in biology (31).

Elementary preservice teachers are rarely required to take more science content than is required for the academic foundations component of their undergraduate program (12). This usually amounts to no more than two science courses, or six semester hours. Another problem in teacher education at the elementary level is the certification process. Certification of elementary teachers is a responsibility of each state and its department of education. There is a wide variance of requirements, as reported by Fiestritzer in her state-by-state analysis of education (10). Most state education department requirements for teacher certification stipulate a science course with a laboratory and a science methods course for all elementary preservice teachers (22). But some states are beginning to eliminate this requirement. In order not to increase the number of hours in a teacher education program, substitutions are allowed or old standards are altered or changed. This has resulted in some states certifying teachers without any credits in science (36).

There have been some improvements in the subject competence of preservice teachers. Yet, the typical undergraduate sequence of required science courses is inadequate. A major problem noted by Hurd is that "the college or university major for science teachers is not typically based on a content analysis of (present) school science, or, in other words, what the teacher is expected to teach" (15).

In 1969 the American Association for the Advancement of Science (AAAS), together with the National Association of State Directors of

Teacher Education and Certification and the National Science Teachers Association (NSTA), formulated and published guidelines for the preservice science education of elementary and secondary teachers (1, 21). NSTA has recently issued another position statement on preservice elementary and secondary science teacher education (23). NSTA and AAAS continue to endorse and support the guidelines. Most universities and colleges, however, have not followed the guidelines. While the guidelines have caused some science education courses to be changed, the changes have had little, if any, impact on college requirements for certification (10). While these national science education organizations continue to refine their positions, there is no mechanism for translating these positions and statements into science education courses that can improve the preparation and quality of preservice science teachers at both the elementary and secondary levels.

How teachers get trained in their profession affects both their teaching practices and their attitudes. To cite but one example, use of inquiry methods has been a major objective of science education at all levels since the early 1960s. Several reports using meta-analysis as the major research method have convincingly demonstrated strong empirical support for the use of inquiry methods for teaching science (29). The reports conclude that this teaching strategy significantly affects students' performance on seventeen out of eighteen performance criteria (29). Students involved in the programs developed during the curriculum reform era of the 1960s had the greatest gains in such areas as science process skills' development, attitudes toward science, and science achievement. The new science programs that stressed inquiry methods appeared to offer many avenues for improving science education (29). If more science teachers were adequately trained in methods used in these programs as part of their preservice science education, the quality of science instruction would increase dramatically throughout the country. However, as shown by Helgeson and his colleagues in their study of various science teacher preparation programs, traditional teaching methodologies—lecture and verification laboratory exercises—are predominant in our teacher-training classrooms (12).

Research indicates that inquiry-methods training can and does result in significant changes in inquiry methods teaching (12). Evidence exists to demonstrate that, in the development of process teaching skills, participation in designing inquiry lessons is more important than knowledge of science (12). But teachers at both the elementary and secondary levels found inquiry methods to be difficult to establish and manage (31). Some teachers felt that state guidelines for laboratory work were impossible to meet (31). Approximately 20% of the teachers interviewed by Stake and Easley stated that equipment and supplies were difficult to acquire; other teachers considered inquiry methods dangerous, especially in classrooms with many discipline problems (31).

Science taught as inquiry at the elementary and secondary level is valued, however, by most teachers and school principals (12). A major barrier to the teaching of science as inquiry is the preparation of science teachers. A large percentage of teachers (about 78%) are ill-prepared, by their own admission and in the eyes of others, to guide students in inquiry methods (31). While one-third feel that they receive adequate support for this style of teaching (36), their college and teacher training did not emphasize or use such methods (12). There have been attempts to improve process skills' development in teacher training programs, but not much has come of these efforts (12). The National Science Foundation attempted to overcome this problem through summer institutes and academic year programs during the 1970s (12). About half of all teachers surveyed by Helgeson and his colleagues had attended at least one NSF inservice workshop. However, only a few of these NSF programs were specifically designed for elementary school teachers.

During the 1970s, three major status studies concerned with various aspects of science education were commissioned because of national concern about science education. The first was a literature search and summary conducted by Helgeson and others (12). The second was a collection of in-depth case studies carried out in several school systems (31). The third was a comprehensive survey of teachers, school administrators, and curriculum supervisors (36).

The studies found that some teachers were using more inquiry-oriented and "hands-on" activities in their classrooms. Much of this change away from didactic methods was due to NSF summer workshops and academic year institutes. Student-centered classrooms were prevalent among teachers who had attended at least one NSF-sponsored program. Yet a large percentage of classrooms relied heavily on textbooks, recitations, and teacher-directed activities. Demonstration at the secondary level was used a great deal.

Not surprisingly, the three studies identified the teacher as being central to science education. Concern was raised over the way teachers are both trained and taught. Preservice teachers are poorly prepared in several areas of science. The case studies by Stake and Easely revealed that teachers were poorly prepared to teach many of the NSF-supported science curricula and usually required inservice courses as soon as they graduated (30).

There have been a number of studies assessing the attitudes of preservice teachers toward science and science teaching; many have investigated the relationship between attitudes and inquiry-teaching methods. Barufaldi and his colleagues investigated the changes in attitudes

of preservice teachers as a result of experiences with inquiry methods (2). After completing an inventory of attitudes toward science, students took a methods-of-teaching course that stressed "hands-on" experiences as well as inquiry activities. Results showed that significant positive changes in attitudes toward science and inquiry teaching methods had occurred (2).

A similar study was undertaken with elementary teachers in order to assess the effects of an inquiry-oriented, hands-on, all-day workshop on attitudes toward science and inquiry teaching (2). The procedure gave preservice teachers opportunities to handle materials, to do experiments, and to interact in small groups. These activities significantly improved attitudes toward science and science teaching that emphasized inquiry methods (2).

Preservice elementary teachers are usually required to enroll in an undergraduate science methods class. The methods course in science is expected to do many things in one semester: teach science concepts, develop a philosophical view of science, provide a refresher course in educational psychology and learning theories, and provide the structure for development of science inquiry teacher strategies. However, Renner suggests that research in science education has demonstrated two important findings:

1. Science inquiry activities from the elementary science "alphabet" programs are effective in changing attitudes toward science and science inquiry teaching.

2. Training models used to instruct preservice teachers are effective in developing specific teaching behaviors such as observing students, evaluating students' classroom performance in science, developing effective questioning strategies, and other behaviors related to teaching science in inquiry (26).

Other studies have demonstrated a relationship between teaching methods and attitudes. Yeany developed three procedures designed to encourage and instruct preservice teachers to use inductive/indirect teaching methods for science instruction (41). The first method consisted of instructing preservice teachers in the use of the Teaching Strategies Observation Differential (TSOD), a science teaching strategy analysis method. The second procedure required preservice teachers to view videotapes of model science lessons that demonstrated inductive/indirect teaching methods. The third procedure was a combination of the previous two. Yeany found that the group receiving the combination treatment adopted a more inductive/indirect teaching style than the control group, which only viewed the films. The data supported the hypothesis that activities can be planned and used with preservice teachers and that these activities significantly affect teaching style as well as attitudes (41).

Science educators at the University of Georgia have reported a number of investigations related to teacher performance in the classroom (5, 13, 33, 34, 35). Many of their studies have reported on the Teacher Performance Assessment Instrument, which is used to assess teacher behavior and performance in the classroom.

Herron and his colleagues summarized several elementary science teacher education studies conducted prior to and during 1974 (13). A number of the studies focused on the development of science process skills and their use in classroom teaching. It was reported that most experimental groups, when compared to control groups, improved significantly in their development and use of these skills and exhibited improved attitudes toward science (13). Apparently, however, attitudes were unaffected in one case after science process skills instruction (24). It would, therefore, appear that programs that stress the development and use of science process skills not only improve these skills, but also tend to improve attitudes toward science and science teaching.

It can be concluded that neither elementary nor secondary school science teachers have been exposed to science courses where the teaching methodology emphasized inquiry and the development of concepts (31). Good, sound model interdisciplinary courses have been nonexistent (31).

Another factor that affects, in particular, elementary teacher attitudes toward science is the relatively small amount of required science content coursework. Because elementary science teachers are required to take so few courses in science, many feel they are not adequately prepared to teach science. This lack of training in the science disciplines is believed to be one of the biggest obstacles to improving elementary science programs (31). Weiss reports that only 22% of elementary school teachers feel qualified to teach science, while 39% feel qualified in social studies, and 49% feel qualified in mathematics (36). In another survey of elementary school teachers' perceptions of their ability to teach science, she found that 16% felt "not well prepared," 60% felt "adequately qualified," and 22% felt "well qualified" (36). Stake and his colleagues wrote:

> Although a few elementary teachers with strong interest and understanding of science were found, the number was insufficient to suggest even half of the nation's youngsters would have a single elementary year in which their teachers would give science a substantive share of the curriculum and do a good job doing it (31).

Hurd reports that almost 51% of elementary teachers say that their preservice training did not prepare them to teach the science they are required to teach on a daily basis (14). Another 71% reported that they had never had inservice science training, while 64% revealed that they no longer had science consultants to help (14).

Do teachers really need science inservice? If they do, how effective is it? What is the current status of science inservice?

There is no question that today's science teachers are better educated than were their colleagues of the 1950s and 1960s. But research reveals that teachers perceive inservice education to be of little or no value (3, 4, 28). Teachers complain that inservice is irrelevant to the classroom; that inservice is too didactic; that inservice provides few opportunities to participate actively; that they have few or no opportunities for input during inservice planning; and that there is a lack of a continuous, long-term inservice plan. These complaints have a large measure of truth.

Gardner and Yager identified the late 1950s and early 1960s as a critical period in science education (11). This was the time of Sputnik and the growing realization that our elementary and secondary school science programs were out of date. We also realized that science teachers were poorly educated in science. These conditions resulted in the NSF funding a series of summer institutes. The institutes were designed to assist science teachers in subject matter competence and to upgrade their science content knowledge (27).

The NSF program grew rapidly in popularity and size. Science courses were designed for science teachers. The courses emphasized the latest developments in various science fields. NSF also funded new science curriculum programs (e.g., CBA, CHEM study, PSSC, BSCS, etc.) in order to update the content of science classes. The new programs reflected more closely the nature of the scientific enterprise and reflected what scientists do. It was hoped that these new science courses would cause more students to pursue careers in science. However, little or no attention was devoted to the development of instructional strategies or teacher behaviors necessary to successfully implement many of the new science materials and programs.

The summer institutes were popular and successful. To get more young science teachers involved in science inservice during the school year, Academic Year Institutes were initiated during the early 1960s, also with NSF funding (27). These gave science teaching professionals an opportunity to concentrate on science studies during the academic year. Many science teachers took advantage of this opportunity (27).

Many more science teachers (at both elementary and secondary levels) attended one or more NSF-sponsored workshop, conference, or institute than did social studies and mathematics teachers. More than 46% of the elementary teachers responding to the Weiss survey and 56% of the secondary teachers responding reported having taken at least one inservice science course prior to 1976 (36). At least 50% of the elementary teachers and 42.5% of the secondary teachers had enrolled in at least one inservice science course during 1967 to 1977 (36). A large percentage of teachers earned one or more degrees beyond the bachelor's degree. Obviously, many teachers were striving to keep abreast of new developments and to stay current in their science knowledge (36). Significantly more secondary teachers earned one or more graduate degrees than did elementary teachers (52% and 29% respectively) (36). In addition, secondary teachers were exposed to more science courses than were elementary teachers because of their assignments.

Weiss' survey showed that more and better science inservice opportunities for elementary teachers are required. Her analysis showed that elementary teachers' perceptions about their qualifications for teaching science were consistent with the amount of time spent teaching it. On the average they reported teaching science nineteen minutes a day in kindergarten through 3rd grade and thirty-five minutes a day in 4th through 6th grade (36).

Who profits most from local science inservice efforts? Weiss reported that elementary teachers felt local science inservice was more useful than did secondary level teachers (40% and 22% respectively). She found that elementary principals rated local inservice higher than did principals at progressively higher grade levels (from 47% to a low of 25%) (36).

The NSF-funded surveys also reveal some disturbing facts concerning federally-supported science inservice. The majority (over 50%) of teachers surveyed in 1977 reported that they had never participated in NSF- or U.S. Department of Education-sponsored science institutes (36). Science inservice for teachers in kindergarten through 9th grade appears to be critically needed. When we realize that the majority of science teaching occurs in these grades, since over 50% of the students enrolled in schools today are not required to take science beyond 10th grade biology (12), this need becomes particularly acute.

Funding of science inservice programs by the NSF was curtailed during the early 1970s, thus precipitating another crisis in science education (40). All federal funds for both curriculum development and science inservice were denied. This retreat on the part of the federal government was, in fact, a retreat away from the views of the leadership in science education. Paradoxically, however, NSF did agree to fund science education research through a program entitled Research in Science Education (40).

Currently, as a result of the findings and the wide dissemination of the three large science education status studies, the National Assessment of Educational Progress science assessments, the NAEP results, and the NSTA Project Synthesis study, together with prominent positions taken by the National Academy of Sciences, the American Association for the Advancement of Science, NSTA, and a host of individual science educators, the federal government has resumed some of its leadership role. A major program, the Presidential Awards for Excellence in Science and Mathematics Teaching, has been launched to identify outstanding science teachers from every state.

It is important that the federal government assume some role of leadership in science education, particularly through the funding of science education programs, including inservice. It is virtually impossible for any state to assume the major leadership of science education through the funding of innovative science programs and inservice. Most states are doing well to maintain their current funding levels in education. The resumption of funding from NSF offers promise for the future.

A major overhaul of the inservice program must be made if it is to assume its rightful position in improving the quality of education. Education personnel must define the mission of inservice education. It must be viewed in different terms. For instance, if large numbers of our science teachers at all levels are not adequately prepared to teach science when they graduate, then inservice science education must be viewed and treated as continuous with preservice science education. Teachers must have meaningful input into inservice planning. If necessary, incentives should be offered to sustain interest and attendance. Inservice must be relevant to teachers' needs, concerns, and interests; it must also meet the needs of teachers and students. Finally, there must be adequate financial support from both federal and state sources, and adequate community support from both administrators and interested parents.

There are some excellent plans and models for improving the quality of inservice and staff development. Many of these are applications of the effective schools and teaching research (3, 4, 16, 17, 37, 38, 39). Most of them can be adapted for the local delivery of quality science education inservice.

Summary

As more opportunities for science educators open up in business and industry, we can expect to see more people leaving classroom teaching. This situation is exacerbated by relatively low numbers of students electing science education majors in college. At the same time, many states are increasing the science credits needed by high school students to graduate. Taken together, these factors add up to a significant and growing problem in education. Assigning teachers without science certification to science courses is, at best, a short-term answer to this problem.

The real issue, of course, is the quality of teacher education in science. At the preservice level, students must be given adequate preparation in the "content" areas of science and in the process skills that form the basis of teaching methods classes. Students who experience inquiry-teaching methods courses are more likely to adopt such methods in their own classrooms than are students who follow lecture-and-discussion courses in the university. The lack of success of the alphabet programs that feature inquiry methods is probably due more to the reluctance of teachers to use them than to any other single factor.

Inservice education also needs to be strengthened to continue honing the skills of practicing teachers. However, the focus of inservice sessions needs to shift from theory-building lectures to hands-on experiences so that teachers can become accustomed to more active science teaching methods.

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PERSPECTIVES ON SCIENCE EDUCATION

The final two chapters are unlike previous ones: These are "perspectives" papers, which give the authors' views about some aspect of science learning. In the first paper, we read about learning science as science is practiced. If the methods for learning science were the same as the methods for doing science, how would the classroom look? The final chapter presents recent research by cognitive psychologists. This research offers teachers a new way to understand how people process information and how what people already know influences what they will learn.

A PERSPECTIVE PAPER

A Science-Based Approach to Science Learning

This chapter is based upon a simple assumption. The assumption is that the techniques needed for effective science teaching are the same as those used for effective scientific investigation. Put another way, it says that the methods for learning science should be the same as the methods for doing science.

The assertion that science education should imitate science is not new. In fact, it was the basis for much of the curriculum development activity in the 1960s. However, this relationship was more implicit than explicit, and it influenced curriculum materials more than the behavior of students and teachers in the classroom. In the discussion that follows, the assertion becomes the basis for prescribing an approach to science learning.

Although there is some research evidence and considerable logic to support this argument, it is not my purpose here to justify it (2). Rather, I ask you to accept the assumption and examine the resulting implications for science education. What is the nature of a science program that patterns itself after the nature of the scientific enterprise? What are the obligations of science teachers and learners? How does a classroom look that derives its essence from the key elements of scientific inquiry? In the discussion that follows, I will address these questions and compare several of the characteristics of the implied program with the science program usually found in American schools.

Before we proceed, however, we need to identify the key elements of the nature of science. Analysis of these elements will provide guidance in determining the ingredients of the corresponding science classroom. Unfortunately, there is no universally accepted description of the nature

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of the scientific enterprise. However, examination of several statements on the nature of science processes reveals considerable overlap. There is enough agreement to identify the key elements accepted by most authors and study groups (3).

The practice of science is carried out by people and, thus, the human factor is very important. Understanding science requires knowing what scientists do, what they believe, and what personal traits they possess. For example, scientists observe natural phenomena; they believe that knowledge is tentative; they are, by nature, very curious. One can quickly see how a science lesson would be structured to be consistent with these characteristics.

Time and space do not permit a thorough description of all the aspects of science inquiry. However, I will list several widely agreed-upon traits together with a brief description of each. Much of this discussion is based on previous writings in this area (3, 4).

Activities

The activities of scientists are procedures of investigation by which knowledge of natural phenomena is gained. They are the tactics and strategies of science: the ways scientists behave in their pursuit of understanding.

There are four major physical activities and a set of mental activities or processes commonly found in the literature.

Observation. Science begins with observations of matter of phenomena; these observations lead to the asking of questions. Crucial to the method of science is the ability to ask the right question and to make selected observations relevant to that question. Observations are influenced by past experience, often involve instruments (telescopes, oscilloscopes, etc.), and require careful recording and description. Surprising or unexpected observations occasionally contribute new and important knowledge. Observation is the *sine qua non* of scientific research.

Measurement. Measurement is the assignment of numbers to objects or events that may be arranged in a continuum according to a set of values. Expression of observations in quantitative terms is desirable because such expression adds precision and permits more accurate descriptions. In addition, the formulation as well as the establishment of laws is facilitated through the development of quantitative distinctions. Not all scientists are able to make quantitative descriptions of their observations, but measurement appears to be a broadly desired goal.

Experimentation. An experiment is a series of observations carried out under special conditions. The distinction between observation and experimentation is slight. An experiment always consists of observations, but it is more than that because the observers usually interfere to some extent with nature. They create events to observe that are favorable to their purposes, e.g., placing a rat in a maze.

Experimentation is the hallmark of good science whether it comes at the beginning—as a gathering of facts—or at the end, in the final test of a theory or hypothesis. It is an essential ingredient of scientific activity.

Communication. A scientist is obligated to make the information from observation and experimentation available to the scientific community for independent confirmation and testing. Discussion and critical analysis of findings are key means by which science advances. Scientists disseminate their results in journals, professional meetings, seminars, and through informal networks. This dissemination contributes to the common core of knowledge of the past and provides the vehicle for continuous review of this body of knowledge.

Communication is the means by which purpose and usefulness are given to scientific investigation.

Mental processes. Although the boundaries are hazy, it appears that certain thought processes are part of the common pattern of scientific investigation. These include inductive reasoning, formulation of hypotheses and theories, deductive reasoning, and a variety of mental skills such as analogy, extrapolation, synthesis, and evaluation.

In addition to these traditional processes, scientific inquiry abounds with approaches described variously as speculation, guess, intuition, hunches or insight. The exact mechanisms by which these processes function are unknown but they are commonly cited in the autobiographies of the great scientists. Perhaps Percy Bridgeman, who wrote that "science is doing one's damnedest with one's mind, no holds barred," describes this set of mental processes most accurately.

Beliefs and Assumptions

Scientists appear to operate in accordance with a set of beliefs about the natural world, their methods of inquiry, and the knowledge these methods produce. For example, they believe that a real world exists that can be understood. They assume that events in nature have causes and that nature is not capricious.

Scientific inquiry is guided by a code of ethics imposed by the community. These professional standards of conduct have developed as part of the success pattern of science and provide boundaries for the actions of scientists. The ethics one finds often in the literature are objectivity, skepticism, replication, and parsimony.

Objectivity is the desire to make unbiased and impartial observations. Realizing that perfect objectivity can never completely exist, the scientist recognizes the existence of preconceptions and attempts to account for their influence on the conclusions.

Skepticism towards the conclusions of science is necessary because of the tentative nature of these conclusions. Authority beyond the facts of nature is rejected.

A scientist believes that the results of experiments can be replicated, indeed, that they must be replicated and verified through independent confirmation. There is an obligation to provide a description of procedures used so others may check the results. Replication is the means by which the skepticism of science is confronted.

Parsimony is the desire to explain phenomena in simple and far-reaching terms. Activities are guided by the belief that simple explanations are preferred to more complex ones.

The application of the methods of inquiry yield knowledge about the natural world. This knowledge is characterized, in part, by the beliefs scientists have about it. The knowledge is contained in a variety of facts, concepts, hypotheses, theories, and laws. These structures make it possible to communicate the knowledge, give it logical coherence, offer explanation, and make predictions. However, a key aspect of the knowledge of science is its tentativeness. Findings are not viewed as final statements, but rather as probabilistic statements that represent a series of successive approximations toward some distant, but seldom reached, truth.

The extent to which scientists actually adhere to these assumptions is problematic. However, those who write about the philosophy of science report these tenets appear to guide their behavior.

Characteristics of Scientists

Science is a game played by people called scientists. Some of these players are far more productive than others. Certain personality traits seem to characterize the more successful scientists and may provide us with additional guidance on the appropriate way to structure a science program. Several of these characteristics have been identified and are described below (1).

Curiosity. An intense wonder about the world around them is a universal characteristic of effective scientists. Their thirst for knowledge is great and much of their life is focused on the seeking of that knowledge. They are active physically and mentally, work in many different environments, and tend to exchange views with scientists in diverse fields.

Usually, this trait appears in their youth and is retained throughout life. The drive to learn is a dominant focus in their lives.

Creativeness. Creativity depends on an ability to generate ideas and the ability to distinguish good ones from trivial ones. Klemm suggests that creativity is coupled with curiosity because curiosity leads to learning and one is most likely to be creative when one is learning (1). Fresh, unbridled views seem to foster creativity and many scientists are most creative when they enter a new field.

To be creative requires that one be sensitive. When pursuing the unknown, heightened sensitivity is necessary to recognize the important clues that emerge from careful observations or experimental results.

Commitment. There are three other traits that seem to characterize successful scientists, which are largely personality traits. These are self-centeredness, compulsiveness, and initiative; factors taken together that represent commitment. The critical nature of science requires those who succeed to be extremely strong-willed and confident. The constant threat to their work demands a strong ego with a compulsive and persistent desire to succeed.

The compulsion seems to arise, in part, from the joy of discovery. Successful scientists find great excitement in research, and they seek reward for their discoveries by communicating their results to other scientists. The competition for discovery and the recognition that comes from peers is a powerful factor in explaining the behavior of a scientist.

Finally, good scientists are aggressive, and possess a great deal of initiative. They do not sit back and wait for things to happen, but rather they take action based on their hunches and beliefs. The good scientist is hungry for knowledge and recognition and works hard to achieve both.

These elements describe what scientists do, reveal some beliefs and assumptions that guide their behavior, and identify several personality characteristics of successful scientists. This description of the domain of science inquiry, outlined in Table 1, provides a brief overview of several key elements of the scientific process.

The Learning of Science

We turn now from the process of science to the learning of science. The scientist who seeks to understand nature will be replaced in our discussion by the student seeking knowledge. The domain of science inquiry, outlined in Table 1, suggests ways that the student should behave in this quest.

Note that the point here is not to instruct the student about the nature of scientific inquiry, but rather to create an environment that permits and encourages the use of the means of science to gain knowledge about science. The process of science becomes a model for learning.

Table 1

Domain of Science Inquiry

ACTIVITIES	BELIEFS	PERSONAL TRAITS
Observation	*About Nature:*	Curiosity
Measurement	Intelligible	Creativity
	Causal	
Experimentation	Noncapricious	Commitment
Communication	*About Method:*	
Mental Processes	Objectivity	
Induction	Skepticism	
Deduction	Replication	
Form Hypotheses	Parsimony	
Create Theories	*About Knowledge:*	
Analysis	Structure	
Synthesis	Explanation	
Extrapolation	Prediction	
Evaluation	Tentative	
Estimation		
Speculation		

The model suggests that successful students must participate in certain activities; be guided by a number of beliefs about the knowledge sought, about the methods used, and about their perceptions of that knowledge; and that they should exhibit certain personality traits. The science-based learner must make observations, take measurements, conduct experiments, communicate, and be given opportunities to carry out the full range of mental skills used by the scientist. The effective learner will deduce, analyze, speculate, and evaluate, and actively use the rest of the mental skills listed in Table 1.

The conduct of these activities will be guided by various beliefs and assumptions. For example, students will assume that learning is possible (intelligible), will seek verification of knowledge gained (replication), and will realize that this knowledge is likely to change as new activities are carried out (tentative). They will believe that events have causes (causality), they will critically examine new information (skepticism), and they will use the knowledge to forecast future events (prediction).

The pursuit of knowledge requires the student to imitate certain personality characteristics. Effective students will be curious and creative and they will possess a strong sense of self-responsibility. This responsibility will be manifested in their personal commitment and compulsion, as well as in their willingness to take the steps necessary to learn (initiative).

Not only will the effective science learner conduct various activities, but he or she will conduct these activities in a responsible and purposeful manner, guided by a code of ethics that provides a system of checks and safeguards on the pursuit. The science-based learner will be active, respectful of the ethics of the discipline, and responsible for his or her own learning.

The Science Program

An analysis of the scientific pursuit of learning calls for an active, reverent, and responsible learner. An effective science program is one that facilitates and accommodates this kind of learner. Opportunities and resources must be provided for students to observe natural phenomena both within and outside the classroom. Students must be taught how to make relevant observations and must be sensitized to the importance of these observations to science. These observations need not be limited to the four walls of the classroom but can be part of the life experiences of children carried out in places children live: museums, zoos, the backyard. Science takes place in a variety of settings and so does science learning. The pursuit of science cannot occur while the learner sits passively in a classroom.

A science program that fosters and supports the scientific pursuit of learning will engage students in the activities of measuring, experimenting, and communicating. Quantitative skills and techniques must be taught and opportunities must be provided to practice these skills. Science classrooms can be patterned after research laboratories. Perhaps the outdoors will become a natural adjunct of the classroom. Students will spend much of their time conducting experiments in the laboratory or in their natural surroundings. These experiments will be designed to yield the knowledge of science to the student. Through observation and experimentation, students will learn such things as the laws of motion, the behavior of butterflies, and the cause of a solar eclipse.

A science-based classroom will facilitate communication of ideas, findings, and predictions among students and between students and teachers. The class will be set up as a science research team is, with the teacher serving as the principal investigator. Scientific journals will be subscribed to and read, reference books will be available, and results of class or student investigations will be written, referred, and published for distribution.

Students will attend meetings that are a facsimile of professional meetings. New knowledge will be shared, findings will be criticized, and ideas exchanged. Results of student investigations will be presented and the abstracts of the papers made available to those unable to attend.

At the same time students are participating in these activities, they must also be carrying out the range of mental processes described earlier. The science program must demand this of the students. They need to formulate hypotheses to explain observations, learn to reason by analogy, synthesize data, evaluate, speculate and perform all the other mental skills used by the scientist to seek understanding. They must be challenged to "do one's damnedest with one's mind, no holds barred." They must become thinking and reasoning seekers of knowledge.

Teacher Responsibilities

The environment of a science classroom that emulates the nature of science will be shaped in part by the assumptions and beliefs of the discipline. A code of ethics will guide the quest for knowledge. Effective teachers will be reverent to this code and use it to guide their actions. They will convey these beliefs to their students.

Among other things, these teachers will operate on the assumption that nature can be understood, that events have causes, and that there is a consistency to nature across space and time. Defeatism, pessimism, magic, astrology, and dogma will not be found in this teacher's class. Rather, objectivity, verification, critical thinking, and simplicity are the hallmarks of the methods the teacher instills in the class seeking science knowledge.

Once knowledge is acquired, teacher and students realize that it needs to be tested by its ability to explain and predict, and that knowledge is always subject to change in the light of new knowledge. The teacher does not make dogmatic announcements of truth. Instead, the class and teacher together present their best estimation of knowledge gained and continuously subject it to critical analysis and refinement.

The domain of science inquiry gives us some guidance on the personal traits needed by a teacher in a scientifically-based science program. These traits should be modeled by the teacher and also used in the recruiting and selection of teachers. At the top of the list of such traits is curiosity. Effective teachers wonder about their world and actively seek to understand it. Their thirst for knowledge is great; their desire to learn is strong. They are good role models and they seek to stimulate this curiosity in their students. Sentences begin with, "I wonder. . .?" or "Why do you suppose. . .?" Those sentences that begin, "There are six steps in. . .!" or "The cause of ______ is. . .!" are not used by effective science teachers. Their language is sprinkled with question marks, not exclamation points.

Creativity characterizes these teachers as well. They are full of ideas and give their students many opportunities to generate ideas. They are sensitive to their world and to their students. These teachers are unafraid to take risks and they work hard to create an open, unobtrusive environment for the science students. Brainstorming occurs more than recitation. Students are taught that the only bad idea is the one not expressed.

Coupled with the traits of creativity and curiosity is the more demanding personal factor of commitment. Commitment is a blend of compulsion, self-confidence, and initiative. An effective science program not only demands committed students, it requires the same of its teachers. Seeking knowledge is a difficult task. It requires hard-working students and teachers who are persistent in their quest. They must be confident they will succeed and not be deterred by the many difficulties that will be encountered. The reward for their persistence is the joy of discovery. The successful teachers and students will be those for whom the joy of discovery is a great reward. They possess the initiative to make things happen and take the necessary actions to achieve their learning and teaching goals.

Effective science programs are those with curious, creative, and committed teachers. Such programs reward students who exhibit these traits and seek to instill them in students who do not.

An effective way, then, to pursue science knowledge is to imitate the processes of effective science. This proposition is based upon the many parallels between the scientist's pursuit of understanding the scientific world and the student's pursuit of knowledge. Several key elements of science process and scientists have been described and applied to the elements of science education: students, teachers, and science programs.

What emerges from our description is a portrait of students as scientists. The model suggests that the most effective learners are those who are active, responsible for their own learning, and reverent to a code of learning conduct. Effective teachers are those who model these behaviors in classrooms and who encourage students to develop and practice these qualities.

Discrepancies between this kind of science education and that practiced in many schools are apparent. Instead of actively participating in observation and experimentation, students are passive listeners. Rather than assuming responsibility for their own learning, many students wait to be taught—often seeming to resist learning. Instead of guiding their behavior by a set of beliefs about the learning process, their behaviors are guided by the latest fad, a TV ad, or a drive for instant gratification.

To be sure, there are some students who are effective learners in fine science programs. The challenge that faces science education is to make all students effective pursuers of knowledge. A scientifically-based pursuit should help us meet that challenge.

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A PERSPECTIVE PAPER

Research in Science Education: The Cognitive Psychology Perspective

A body of psychological theory is accumulating that will have major impact on the practice of science education in the 1980s and beyond. The theory developed by cognitive scientists—cognitive psychologists and researchers in artificial intelligence and information theory—is changing our conceptions of science learning and teaching (7, 22). This cognitive perspective on learning stands in contrast to the behavioral and developmental perspectives that have been influential over the past quarter century in the practice of science education.

In this chapter, we discuss certain basic assumptions of the new cognitive perspective on human learning and illustrate the relevance of the perspective to science teaching and learning. The behavioral perspective, which is familiar to most science teachers, builds its theories on data drawn directly from overt human behavior and regards the human mind essentially as a black box. In contrast, cognitive science builds its theories on models of cognitive processes and the contents and structural organization of human memory.

Cognitive scientists theorize about human cognition using computational metaphors. To explain cognitive processes, they use the computer as a metaphor for the mind, computing as a metaphor for thinking, and data structures as a metaphor for the knowledge in memory. The notion of thinking as computation is not new. In 1651, Thomas Hobbes observed that "reasoning is but reckoning" (18). This view is quite consistent with the perspective that associates human thought and machine computation. Both are, in essence, symbol manipulation.

Researchers and practitioners in the behaviorist tradition character-

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Audrey B. Champagne and Leopold E. Klopfer, Learning Research and Development Center, University of Pittsburgh

ize learning in terms of permanent changes in observable behavior. In contrast, researchers in the developmental and cognitive traditions describe development and learning in terms of changes in the contents and structural organization of the mind.

One implication of this difference in perspectives relates to ways in which objectives for science teaching are stated. Currently accepted practice dictates that objectives should describe the desired instructional outcomes in terms of overt behaviors. Recently, cognitive psychologists have proposed that it is both reasonable and productive to specify instructional outcomes in terms of the cognitive processes and knowledge structures that students ought to acquire. Cognitive objectives of instruction specify cognitive structures, processes, and skills that *underlie* successful performance of academic tasks. Overt behavior provides important data to cognitive researchers; however, their theorizing is not limited to data from this source.

Objectives emphasizing overt behaviors and cognitive objectives are contrasted in Figures 1 and 2. The first figure shows some typical behaviorally specified instructional objectives for a unit on the physics of sound. The example of a cognitive objective shown in Figure 2 is for the same topic. Here, the declarative knowledge structure for the physics of sound that students should acquire from instruction is represented. One way cognitive scientists specify declarative knowledge in human memory is in terms of propositions. In this diagram, the concepts are shown as the links and the relations are shown as the nodes of a propositional network. The diagram does not represent all that the students are expected to learn. The students also need knowledge of the procedures that enable them to apply the knowledge appropriately in the solution of problems. Nonetheless, this representation specifies the information that should be present in some form in the student's memory as the result of instruction.

The proposal to state instructional objectives in cognitive terms undoubtedly comes as a surprise to teachers who have been taught that the description of learning in terms of unobservables is neither scientific nor productive. However, the contributions of cognitive theorists to our understanding of human cognition, and the development of formal methods to assess and model human thought have made thinking about science learning in cognitive terms both scientific and highly productive.

The cognitive perspective differs from the behavioral in its view of the nature of the learner, emphasizing both the active and constructive nature of learning. Developing cognitive theory provides a new perspective on the role of prior knowledge in the learning process and helps explain the results of research by science educators and psychologists

that documents the persistence and pervasiveness of naive theories of the physical world. (We will discuss naive theories in some detail later in this chapter.)

The emphasis by cognitive scientists on the role of prior knowledge is quite consistent with the theory of David Ausubel (2), but differs in some significant ways from the developmental theory of Jean Piaget (12). This theory, as it has been interpreted and applied by North American science educators, argues for a causal relationship between what a student is capable of learning and the level of the student's cognitive development, expressed in terms of the mental operations or reasoning processes available to the student. In this framework, the student's gen-

After completing the unit, the student should be able to:

describe how waves are created and how they transfer energy;

discuss the meaning and relationships of the following quantities: wavelength, frequency, period, amplitude, displacement, phase, reflection, refraction, diffraction, interference;

distinguish between longitudinal and transverse waves;

use Huygens' principle to predict wave behavior;

cite experimental evidence that sound energy is transferred by waves;

describe the waveforms of sounds as shown on the screen of a cathode ray oscilliscope;

measure the approximate speed of sound in air;

set up standing waves in a long spring and observe similar waves in a guitar string;

describe how sounds are created, how they travel, and how sound differences are related to the wave form; and

discuss the physical and psychological characteristics of sound waves.

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Figure 1

A Portion of the Instructional Objectives for a Unit on the Physics of Sound (27)

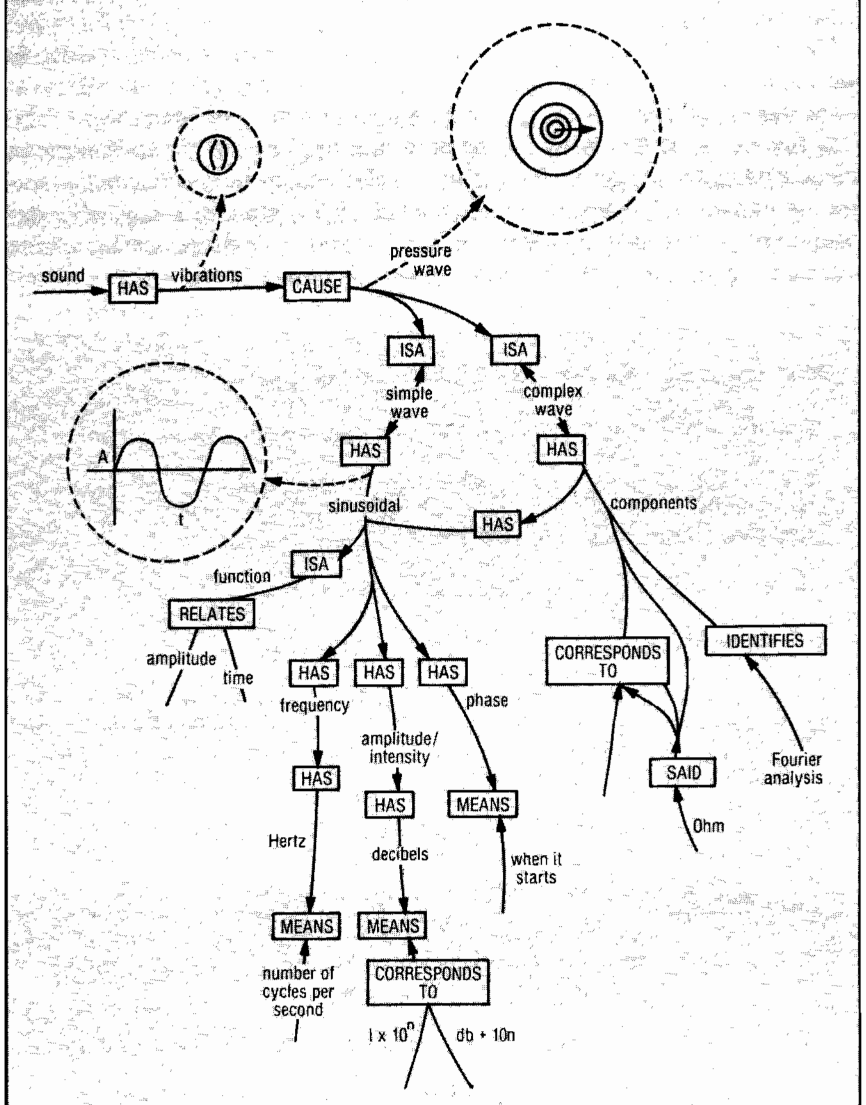

Figure 2

Knowledge Structure (in the Form of a Network of Propositions) for the Physics of Sound (15)

eral level of cognitive functioning determines the complexity of the science content that the student is capable of learning. Although Piaget's theory recognizes that the student's utilization of particular mental operations depends on the context, when the Piagetian paradigm is applied to research on science learning, the emphasis is on the level of mental operations available to the student. The Piagetian perspective has become so familiar in science education that talk about levels of cognitive development—Piaget's preoperational, concrete operational, and formal stages—has become commonplace, not only in reports of researchers, but in discussions among practicing teachers as well. The new cognitive perspective directs greater attention to the structure of the student's knowledge and to the influence of science-specific knowledge on the student's acquisition of science information and concepts. This view of science learning is the principal new insight of value to science educators that we want to discuss here.

Schemata: Form and Function

There is general agreement in both Piagetian and cognitive theories that knowledge is stored or represented in memory in an organized fashion. Both theories use the term *schema* to refer to a knowledge structure in memory. It is useful to think of knowledge in memory as being of two types: *procedural knowledge* (knowing how) and *declarative knowledge* (knowing that). In Piagetian theory, a schema is a "cognitive structure which has reference to a class of similar actions" (12). If actions are assumed to be synonymous with procedures, a schema in the Piagetian perspective is a procedural knowledge structure. In contrast, the information processing perspective generally defines a schema as a declarative knowledge structure that has reference to classes of similar objects, situations, events, and relations.

David Rumelhart, the cognitive psychologist who has made major contributions to schema theory, likens schemata to plays (24). A play has characters. In different productions of the play, the characters are played by different actors. By analogy, a schema has variables (characters) and, in different instantiations of the schema (productions), the variables have different values (actors). For example, an expert physicist has an inclined plane schema. The inclined plane schema is analogous to a play. The inclined plane schema defines certain necessary and inter-related elements (e.g., the inclined surface, the support that holds the surface at an angle). These elements are analogous to the characters in the play. A playground slide, a stairway, a ramp, a hill, and a wedge are specific instances of inclined planes, although different objects are the elements that combine to form them (analogous to the actors in a specific performance of the play). In addition to the schemata for objects, such as the inclined plane, expert physicists also have representations in memory of schemata for situations (e.g., objects in free fall), events (e.g., decay of a subatomic particle), problems (e.g., conservation of momentum problems), and systematic relations (e.g., $F = ma$).

Schemata also differ in their degree of abstractness and their range of applicability. This aspect of schemata is illustrated by the following analogy. Literary compositions are characterized by genre. Novels or short stories are types of literary compositions; on a more concrete level of abstraction are mystery novels and gothic romances, which are specific categories of novels. While all novels have characters and situations, the types of characters and situations you would find in a mystery novel differ from those you would find in a gothic romance. The schema for a mystery novel would include what cognitive scientists call slots for a detective, a criminal, a crime, and a solution, with typical relations among them. The criminal commits a crime; the detective finds the solution. On the other hand, the gothic romance would include slots for hero, heroine, romance, and mystery. The hero and the heroine are driven apart by a mystery and drawn together by romance. Similarly, a schema for Agatha Christie mysteries is less abstract than the schema for a generic mystery, and is different from the schema for mysteries by Sir Arthur Conan Doyle.

As we can see, schemata have different degrees of abstractness and ranges of applicabilities. We will use the terms *microschema* and *macroschema* to distinguish schemata along these dimensions. Microschemata are less abstract and have a narrow range of applicability. A macroschema, in contrast, is a mental structure encompassing several microschemata. The major conceptual schemes of science are examples of macroschemata.

Schemata play a key role in cognitive scientists' theories of text comprehension, learning, and problem solving. Schemata are seen to function in our interpretations of sensory data, both linguistic and non-linguistic, and in the storage and retrieval of information from memory. The following examples illustrate how schemata function. They are drawn primarily from research studies on text comprehension. After these examples, we will describe how schemata function in the interpretation of non-linguistic data, specifically observations reported by students of the motion of objects in free fall.

Our first example, called "Balloons," illustrates what happens when a reader does not have the appropriate schema. Read the text, then ask yourself: "Do I understand it? How do I interpret the paragraph?"

Balloons

> If the balloons popped the sound wouldn't be able to carry since everything would be too far away from the correct floor. A closed window also prevents the sound from carrying, since most buildings tend to be well insulated. Since the whole operation depends upon a steady flow of electricity, a break in the middle of the wire would also cause problems. Of course, the fellow could shout, but the human voice is not loud enough to carry that far. An additional problem is that the best situation would involve less distance. Then there would be fewer potential problems. With face-to-face contact, the least number of things could go wrong (3).

For most people, it is difficult or impossible to interpret the "Balloons" text, even though they recognize the meanings of all the words and can comprehend the individual sentences. The difficulty is that the reader does not possess the appropriate schema. In this instance, the necessary schema can be obtained from the drawing in Figure 3.

Once you have looked at the drawing of the electronic serenader and returned to the example, the interpretation of the "Balloons" text is no longer obscure. Having the appropriate schema makes understanding possible.

Our next example describes a certain procedure, using easily recognizable words and sentences. This is an example of a situation in which, although you have the schema, you do not have enough cues to call it up, as they say in computerese. Read the text. Do you know what procedure is described in this paragraph? How much of the information in the paragraph can you remember?

The Procedure

> The procedure is actually quite simple. First you arrange things into different groups. Of course one pile may be sufficient depending on how much there is to do. If you have to go somewhere else due to lack of facilities that is the next step, otherwise you are pretty well set. It is important not to overdo things. That is, it is better to do too few things at once than too many. In the short run this may not seem important but complications can easily arise. A mistake can be expensive as well. At first the whole procedure will seem complicated. Soon, however, it will

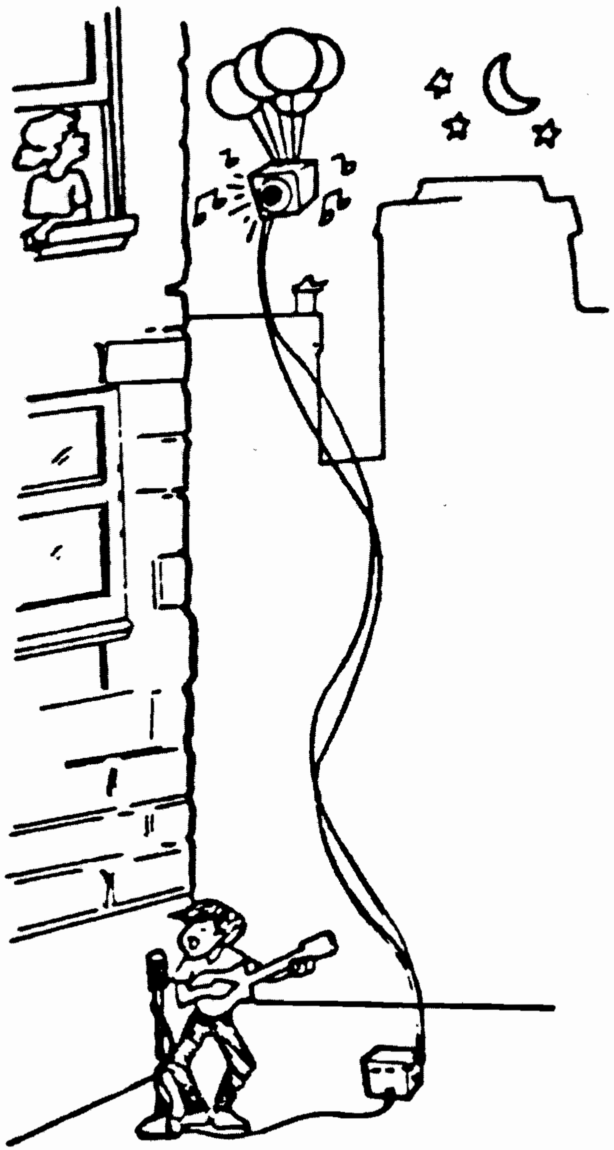

Figure 3

Illustration for "Balloons" Text

> become just another facet of life. It is difficult to foresee any end to the necessity for this task in the immediate future, but then one never can tell. After the procedure is completed, one arranges the materials into groups again. Then they can be put into their appropriate places. Eventually they will be used once more and the whole cycle will then have to be repeated. However that is part of life (3).

In this illustration, the difficulty in interpreting and remembering the text does not arise because the reader does not possess the appropriate schema, because virtually everyone is familiar with the procedure in question. When you are given a clue that lets you retrieve the needed schema, you will both understand and even remember the information in the paragraph without reading it again. (The clue is to change the first sentence to read: "The procedure for washing clothes is actually quite simple.")

Our next comprehension example illustrates the case in which the information in a text is vague and can be associated with two or more schemata. Read the example, "An Evening at Play." What do you think the four people did?

An Evening at Play

> Every Saturday night, four good friends get together. When Jerry, Mike, and Pat arrived, Karen was sitting in her living room writing some notes. She quickly gathered the cards and stood up to greet her friends at the door. They followed her into the living room but as usual they couldn't agree on exactly what to play. Jerry eventually took a stand and set things up. Finally, they began to play. Karen's recorder filled the room with soft and pleasant music. Early in the evening, Mike noticed Pat's hand and the many diamonds. As the night progressed the tempo of play increased. Finally, a lull in the activities occurred. Taking advantage of this, Jerry pondered the arrangement in front of him. Mike interrupted Jerry's reverie and said, "Let's hear the score." They listened carefully and commented on their performance. When the comments were all heard, exhausted but happy, Karen's friends went home (© 1977 American Educational Research Association, Washington, D. C.).

If you are a musician, you probably said they played music. If you are a card player, you probably said they played bridge. When this text was given to college music majors, they said it was about a string quartet. They had trouble even recognizing the existing alternative interpretation even after it was pointed out to them.

Our last example, the cartoon in Figure 4, illustrates that our students do not always associate information we give them with the schema we intended. Undoubtedly, Sally's teacher intended that she attach her newly learned units of metric measure to a measurement schema. However, Sally associates the terms with her familiar and well-understood relatives schema. In this way she constructs her own meaning for the meaningless terms she has been asked to memorize. The example may seem far-fetched, but evidence is accumulating that science students often associate information with schemata other than the one the teacher intends (10, 23). This fact helps to explain both the existence of naive theories of the physical world and their resistance to change under normal conditions of instruction.

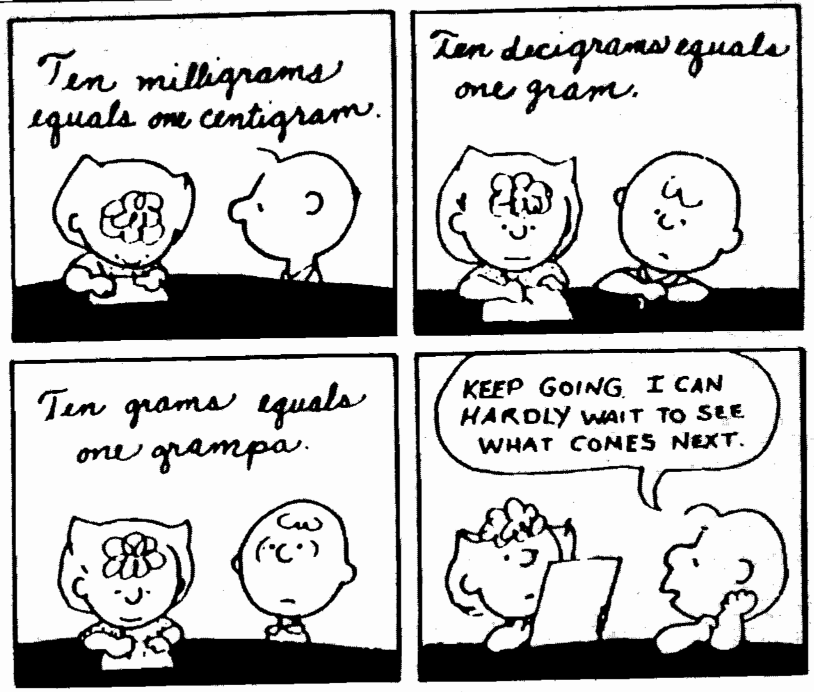

Figure 4

The Gram Schema in "Peanuts"
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Naive Theories

Research conducted by science educators and psychologists in the United States and other countries has yielded persuasive evidence that students, young and old, have descriptive and explanatory systems for scientific phenomena *before* they experience any formal science instruction (11, 13, 17, 19, 25). These naive theories differ significantly from what students are expected to learn in their study of science, and these theories persist in the minds of students even after they have successfully completed science courses taught by the customary instructional methods.

One example of a naive theory many students bring with them to science class concerns heat and temperature (29). The naive theory explains temperature change by the flow of heat into or out of objects. In this naive theory, the process of heat flow is analogous to the process of water flow into or out of porous objects, increasing or decreasing their weight. This naive theory is very different from the present scientific theory, which envisions a kinetic-molecular model of matter and heat as a form of energy. Another naive theory held by many students concerns inheritance (4). Before they have formally studied biology, many students believe that acquired physical characteristics can be transmitted to an organism's offspring. An example of this is the belief that, if a fair-skinned couple moves into a tropical climate where their skin becomes darkened by long exposure to the sun, their child will be born with dark skin. By contrast, current biological theory holds that only genetically-determined traits are inheritable. This is the theory taught in biology classes. Nevertheless, the students' naive theory of inheritance persists even after they have completed their biology courses with high grades.

Perhaps the most striking instance of the tenacity of students' naive conceptions concerns their naive theory of the motion of objects (14, 20, 28). Research we have carried out demonstrates that the belief that heavier objects fall faster than lighter objects is not readily changed by instruction (6, 8, 16). In a study of beginning college physics students, about four students in five believed that (all other things being equal) heavier objects fall significantly faster than lighter ones. These results are particularly surprising, since about 70% of the students in the sample had studied high school physics—some for two years. Furthermore, students in the sample who had studied high school physics did not score significantly different from those who had not. Similar findings about the persistence of the heavier-faster belief, and other naive conceptions about the motion of objects, have been reported in studies of physics students in countries on three continents.

The students' naive theory of motion derives from years of experience with moving objects and serves the students satisfactorily in describing the world. Nevertheless, this naive theory is quite different from the formal system of Newtonian mechanics, which physics courses seek to teach. The central principle of the students' naive theory is that velocity is proportional to force. By contrast, in the physicists' macroschema, the formal Newtonian system of mechanics, the central principle is that acceleration is proportional to force.

Another characteristic of the students' naive theory is the lack of coordination and consistency among its components. We previously noted that a macroschema is typically conceived as encompassing several microschemata. For example, three possible microschemata for a motion-of-objects macroschema are those for free fall, the inclined plane, and motion along the horizontal. In the Newtonian macroschema, these microschemata and others are coordinated and internally consistent. All are described by the laws of Newtonian mechanics. In contrast, in the naive motion-of-objects theory, the case is quite different. The lack of consistency among the several components is remarkable. The principles that apply in one situation (say, free fall) tend to remain localized within that situation and are not applied to other situations (inclined plane, horizontal motion). The expectation that an abstract rule or principle could apply to a range of different situations is lacking or poorly developed. Consequently, the various physical situations concerning motion can be quite isolated from one another in the students' naive theory. A major result of this isolation is that the naive theory is able to accommodate new information locally without producing conflict with other parts of the system. In this way, the system can add principles that may contradict other principles already present and yet not require a major reconceptualization.

As we noted before, students do not readily change their naive theories. Schema theory helps us to understand why naive theories do not change with customary instructional methods.

Earlier we illustrated certain functions that cognitive scientists hypothesize for schemata. One function is related to the interpretation of sensory data. Some interesting observations we have made of students' interpretations of science demonstrations can be explained using schema theory. Our observations were made in the context of a study whose goal was to investigate students' interpretations of physics demonstrations (8). The experimental strategy involved showing students some simple physical apparatus and describing a manipulation of the apparatus. The students were asked to predict the outcome of the demonstration and to report the information they used to generate the prediction. Then the demonstration was done and the students were asked to describe their observations and to discuss any conflicts between their predictions and their observations.

In one task the students were asked to compare the times for two identically-shaped objects (plastic and aluminum blocks) to fall equal distances of about one meter. The situation for this task is shown in Figure 5. About 80% of the 500 college, middle school, and high school students we interviewed predicted that the aluminum block would fall about five times faster than the plastic block. A significant proportion of the students who *predicted* the heavier object would fall faster, also reported that they *observed* that the heavier object fell faster. Their free-fall schema, which contained a proposition that heavier objects develop greater downward speed in free fall, distorted their observation.

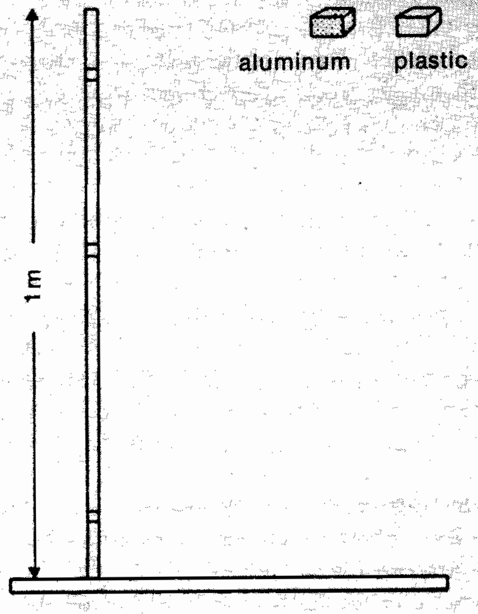

Figure 5

Apparatus for the Aluminum and Plastic Blocks Demonstration

The aluminum and plastic blocks will be dropped simultaneously from 1 meter above the floor. Make a prediction comparing the times when the blocks will hit the floor. Some people predict that the aluminum block will hit the floor first, while some predict that the two blocks will hit at the same time. What is your prediction? What concepts of motion entered into your prediction?

Even when students observed that the objects fell at approximately the same rate, their naive free-fall schemata directed their thoughts to alternative explanations for the observation. Frequently, when students' observations do not fit their predictions, the students will criticize the experiment. In the free-fall case, they argued that, if the blocks had fallen a longer distance, the aluminum one would be observed to fall faster. Students cannot easily give up propositions in their naive schema, as the following scenario illustrates.

In this demonstration, the proposition that the greater the speed of an object, the greater the force on it, leads the students to conclude that an object's weight increases measurably as the object moves about 50 centimeters closer to the earth. The students were observing the motion of a block being pulled along the horizontal by a bucket suspended over a fixed pulley (illustrated in Figure 6). The students observe that the block's speed is about five times faster at point *B* than at point *A*. They explain that the greater speed at *B* is due to the greater pull of the bucket. This is an application of a proposition from their motion schema that velocity is proportional to force. They reason that, because the block moves five times faster when it is at *B*, the bucket pulls five times harder when it is at *b*, and it weighs five times more at *b* than at *a*. Asked how this was possible, the students noted that the bucket was closer to the ground and called upon a proposition in their weight schema that the closer an object is to the ground, the heavier it is. The students were encouraged to weigh the bucket when it was at *a* and *b*. They were genuinely surprised that the spring scale registered *no* difference. Then they argued that there was no weight difference because the distance from *a* to *b* was so small. Only after comparing the weight of the bucket, first when it was held near the floor and when it was held near the ceiling, and then on the ground floor and ninth floor of a building, did they decide that the bucket's weight was not significantly changed by differences in its distance from the earth. Only at this point were the students willing to examine the validity of their lower-is-heavier proposition.

Another interesting example from our study illustrates how an existing schema influences the interpretation and remembrance of science text. Several students who predicted that the aluminum block would fall faster than the plastic block attributed their prediction to some information they had read in a science book. They reported that Galileo had proven that heavy objects fall faster than lighter ones. The students recall, quite accurately, that Galileo asserted that a gold coin will fall faster than a feather. They forget, however, the crucial part of the argument where Galileo asserts that, in a vacuum, both would fall at the same rate. They recall the part of Galileo's argument that is consistent with the heavier-is-faster proposition in their free-fall schema. They forget the part of the story that does not fit into their schema.

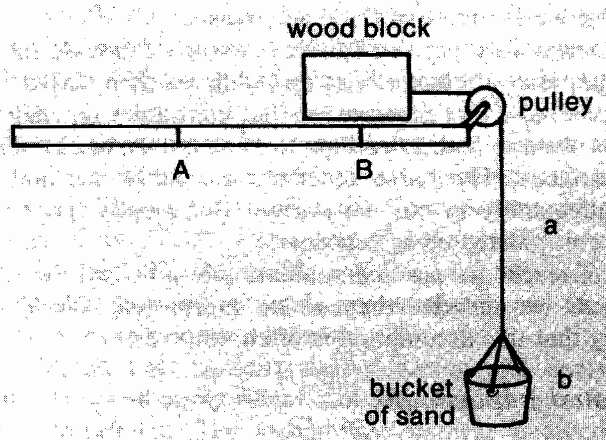

Figure 6

Apparatus for the Block and Bucket Demonstration

One striking characteristic of naive science schemata is their accommodation to inconsistent information. Many students' free-fall schema contains the proposition that heavier objects fall faster because gravity pulls harder on heavier objects. Once the students come to believe that the plastic and aluminum blocks fall at about the same rate, a new proposition appears—gravity pulls equally on all objects. These same students agree that weight is a measure of the pull of gravity on an object. They are, however, quite surprised with a logical implication that can be drawn from these propositions—namely, that all objects have the same weight. However, such contradictions are easily patched. In this instance the students argue that mass is the magical quantity that explains the troublesome contradiction. Not only is information within naive schemata poorly coordinated, it is also poorly coordinated between schemata. Once students are truly convinced that the aluminum block and the plastic block take the same time to fall the same distance, we ask them to make a prediction comparing the times for two toy trucks of different mass to slide down the same incline. They predict and argue vigorously that the heavier truck will get to the bottom of the incline first.

These scenarios provide evidence about how schemata function in our thought processes and suggest some reasons why naive theories of the physical world are so difficult to change.

Naive theories are derived from experience and have inherent validity. It is true, after all, that stones do fall faster than leaves. It is also the case that we have few experiences that contradict our naive schemata. We do not observe feathers falling in vacuums or bricks sliding on frictionless surfaces. The naive schemata are functional and allow us to function adequately in our daily lives. But most important, the naive schemata are undetected by teachers.

When we teach, we assume students interpret text, lectures, and experiments as we intended them to be interpreted. The evidence is accumulating that this assumption is often not valid.

Instructional Implications

The research results and ideas reviewed here have important implications for improving instruction in science classes (7). We will mention but a few of these. Findings from research under the cognitive perspective demonstrate that students' comprehension of science instruction is greatly influenced by the students' existing knowledge. Hence, the teacher should have detailed specifications of the students' relevant knowledge as they begin to study a science unit. Using pretests to diagnose students' knowledge before beginning a unit of instruction is not a new technique, of course. What the cognitive research newly suggests, however, is that the preinstructional diagnosis should be so designed that it reveals to the teacher an accurate picture of the existing knowledge structures and accessible cognitive processes in the students' memories. The teacher needs this picture to plan science instruction from which students will learn effectively. In teaching dynamics in introductory physics, for example, when the students' prior conceptions associate forces only with animate beings, or when they believe that a force is acting on an object moving at constant velocity, appropriate instructional strategies must be planned to take account of such existing knowledge. Again, in teaching evolution in biology, when students come to instruction believing that the characteristics accidentally acquired by an individual organism in its lifetime are transmissable to the organism's offspring, the teacher must plan an instructional sequence that takes account of this existing knowledge.

Information about students' knowledge structures also provides the teacher with a powerful tool for assessing the extent and quality of the students' understanding. All too often, achievement tests in science manage only to assess students' ability to recall specific facts or ideas. We say that we are trying to teach for understanding in science, but we

do not assess students' understanding very well, if at all. The findings of cognitive research offer a remedy, since an indicator of understanding is the number and kinds of connections between concepts in a person's knowledge structure. When students produce a representation of the relationships between science concepts in a given set, they are, in effect, displaying their understanding of these concepts. Various techniques for obtaining representation of science concepts from students are available. One which we developed is called the Concept Structuring Analysis Technique or ConSAT (5). Other techniques include concept mapping (21), word association tasks (9), and free-sort tasks (26). Any of these techniques can be used to obtain representations of the students' knowledge structures of science concepts.

Cognitive research uses various data-gathering and analysis techniques, and teachers can apply them to obtain detailed specifications of their students' knowledge. The availability of these detailed descriptions makes it possible for the teacher to specify with greater precision the instructional tasks and strategies that will best aid the students' science learning and the extent to which students have achieved understanding.

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