DOCUMENT RESUME

ED 388 512 | SE 056 674

TITLE	Building Scientific Literacy: A Blueprint for Science in the Middle Years.
INSTITUTION	National Center for Improving Science Education, Washington, DC.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE	92
CONTRACT	R168B80001
NOTE	74p.
AVAILABLE FROM	NCISE, 2000 L Street, N.W., Suite 603, Washington, DC 20036.
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF01/PC03 Plus Postage.
DESCRIPTORS	*Educational Change; Evaluation; Intermediate Grades; Junior High Schools; *Middle Schools; Science Curriculum; Science Education; *Scientific Literacy
IDENTIFIERS	*Reform Efforts; Teacher Development

ABSTRACT

This report is a blueprint for the creation of an effective, national program of science education for students in America's middle-grade schools. It draws together the best that is now known about curriculum, instruction, assessment, and teacher development for middle-level science and was written in response to a widely expressed need to improve American education in general and science education in particular. This document is designed as a briefing for those who have a concern with, and a responsibility for, education in public schools: middle-level teachers and principals, science specialists, curriculum directors, assessment personnel, staff development leaders, school district superintendents and administrators, state and federal education officials, university professors, and policy boards at all levels of American education. Chapters include: (1) "Science and Technology Education in the Middle Years"; (2) "A Vision of Science and Technology Education at the Middle Level"; (3) "Achieving the Vision"; (4) "Special Concerns"; and (5) "Summary and Recommendations." Contains 24 references. (JRH)

Building Scientific Literacy: A Blueprint for Science in the Middle Years

The National Center for Improving Science Education

The Center is a division of

The NETWORK, Inc.

Andover, Massachusetts
Washington, D.C

in partnership with

The Biological Sciences Curriculum Study
Colorado Springs, Colorado

Building Scientific Literacy: A Blueprint for Science in the Middle Years

The National Center for Improving Science Education

The Center is a division of

The NETWORK Inc.

Andover, Massachusetts
Washington, D.C.

in partnership with

The Biological Sciences Curriculum Study
Colorado Springs, Colorado

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

The National Center for Improving Science Education
2000 L Street, N.W., Suite 603
Washington, DC 20036

The Center is a division of
The NETWORK, Inc.
300 Brickstone Square, Suite 900
Andover, MA 01810

To order Center publications, call 1-800-877-5400

National Center for Improving Science Education

The mission of the National Center for Improving Science Education is to promote changes in state and local policies and practices in the science curriculum, science teaching, and the assessment of student learning in science. To do so, the Center synthesizes and translates the findings, recommendations, and perspectives embodied in recent and forthcoming studies and reports in order to develop practical resources for policymakers and practitioners. Bridging the gap between research, practice, and policy, the Center's work is intended to promote cooperation and collaboration among organizations, institutions, and individuals committed to the improvement of science education.

The Center was originally a partnership between The NETWORK, Inc., of Andover, Massachusetts and Washington, D.C., and the Biological Sciences Curriculum Study (BSCS) of Colorado Springs, Colorado and funded by the U.S. Department of Education's Office of Educational Research and Improvement. Currently funded through a variety of public and private sources, the Center conducts research, technical assistance, and policy-related projects, while continuing its synthesis and dissemination work. For further information on the Center's work, please contact Senta A. Raizen, Director, 2000 L Street, Suite 603, N.W., Washington, D.C., 20036, or Susan Loucks-Horsley, Associate Director, 300 Brickstone Square, Suite 900, Andover, Massachusetts, 01810.

5

The National Center for Improving Science Education Advisory Board Members

William Baker
Chairman (Retired)
AT&T Bell Laboratories
Murray Hill, NJ

Richard M. Berry
National Science Foundation
(Retired)
Fenwick Island, DE

David P. Crandall
President
The NETWORK, Inc.
Andover, MA

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

Richard Duncan
President
Association of Presidential Awardees in Science Teaching
Whitford Intermediate School
Beaverton, OR

David Kennedy
Science Supervisor
Department of Public Instruction
Olympia, WA

Douglas Lapp
Executive Director
National Science Resources Center
National Academy of Sciences
Smithsonian Institution
Washington, DC

Jerome Pine
Professor of Biophysics
California Institute of Technology
Pasadena, CA

Andrew Porter
Director
Wisconsin Center for Education Research
University of Wisconsin
Madison, WI

Mary Budd Rowe
Professor
School of Education
University of Stanford
Stanford, CA

Kenneth Russell Roy
National Director
National Science Supervisors Association
Glastonbury Public Schools
Glastonbury, CT

F. James Rutherford
Chief Education Officer and Director, Project 2061
American Association for the Advancement of Science
Washington, DC

Thomas P. Sachse
Manager
Mathematics, Science and Environmental Education
California Department of Education
Sacramento, CA

Mare Taagepera
Director
Science Education Programs
School of Physical Sciences
University of California
Irvine, CA

Laurence Vickery
General Director for Regional Personnel Administration (Retired)
General Motors Corporation
Warren, MI

National Middle Grades Panels

Assessment Study Panel

Senta A. Raizen, Chair
Director
The National Center for Improving Science Education
Washington, DC

Joan Boykoff Baron
Director
Connecticut Assessment of Educational Progress Program
Connecticut State Department of Education
Hartford, CT

Audrey B. Champagne
Professor
Chemistry and Education
State University of New York at Albany
Albany, NY

Edward Haertel
Associate Professor
School of Education
Stanford University
Stanford, CA

Ina V.S. Mullis
Deputy Executive Director
National Assessment of Educational Progress
Educational Testing Service
Princeton, NJ

Jeannie Oakes
Professor
Graduate School of Education
UCLA
Los Angeles, CA

Curriculum and Instruction Study Panel

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

C. Edward Buchwald
Professor of Geology
Carleton College
Northfield, MN

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

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

Paul J. Kuerbis
Professor
The Colorado College
Colorado Springs, CO

Carolee Matsumoto
Senior Associate
Education Development Center
Newton, MA

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

Teacher Development and Support Study Panel

Susan Loucks-Horsley, Chair
Senior Associate
The National Center for Improving Science Education
Andover, MA

Jackie Grennon Brooks
Adjunct Professor
Hofstra University and Teachers College, Columbia
New York, NY

Paul J. Kuerbis
Professor
The Colorado College
Colorado Springs, CO

Maura O. Carlson
Co-Director
The Vermont Elementary Science Project
The National Center for Improving Science Education
Burlington, VT

David D. Marsh
Associate Professor
School of Education
University of Southern California
Los Angeles, CA

Michael Padilla
Professor
Science Education
The University of Georgia
Athens, GA

Harold Pratt
Executive Director for Science and Technology (Retired)
Jefferson County Public Schools
Golden, CO

Kitty Lou Smith
Middle-grade Teacher
Fairfax County, VA

CONTENTS

6

FOREWORD

This report is a blueprint for the creation of an effective, national program of science education for students in America's middle-grade schools. It draws together the best that is now known about curriculum, instruction, assessment, and teacher development for middle-level science. It was written in response to a widely expressed need to improve American education in general and science education in particular.

It is designed as a "briefing" for those who have a concern with, and a responsibility for, education in public schools: middle-level teachers and principals, science specialists, curriculum directors, assessment personnel, staff development leaders, school district superintendents and administrators, state and federal education officials, university professors, and policy boards at all levels of American education.

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

- *Science and Technology Education for the Middle Years: Frameworks for Curriculum and Instruction*
- *Assessment in Science Education: The Middle Years*
- *Developing and Supporting Teachers for Science Education in the Middle Years*

An implementation guide to assist educators in realizing this approach to middle-level science is also available from the Center.

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

CHAPTER I

Science and Technology Education in the Middle Years

Introduction

Nearly a decade ago, the National Commission for Excellence in Education published *A Nation at Risk* as an open letter to the American people. Since then, over 300 reports on the condition of education have been issued. One result has been a major effort on the part of the President and state governors to define and then promote national goals for the country's education system. Two of the goals are particularly important to those concerned with science and scientific literacy:

> *By the year 2000, American students will leave grades four, eight, and twelve having demonstrated competency in challenging subject matter including English, mathematics, science, history, and geography (Goal 3).*
>
> *By the year 2000, U.S. students will be first in the world in science and mathematics achievement (Goal 4).*

Few would argue with the importance of these goals, and the importance of the middle grades in reaching them. Yet, to date, no specific plans have been proposed for reforming middle-grades education in general, nor for science education in particular. Yet it is a plan, a detailed blueprint, that local, state, and national leaders in science education need as they reform their middle-level science programs to achieve the national educational goals. To meet this need, the Center has published a series of reports that can inform policy makers who must consider national issues in education, as well as school and district leaders who must manage the day-to-day realities of educating America's middle-grades students. The Center's reports are blueprints for a system that will help meet, well into the twenty-first century, the American student's need for an education in science and technology.

The hands-on, inquiry-based, constructivist approach to science that the Center recommends is easy to set out, but difficult to implement. Complex issues must be resolved before this approach to science education is realized in middle-level classrooms. The issues fall into three general categories: curriculum and instruction, assessment, and teacher development and support. The Center acknowledges that there are many ways to address these issues, while also acknowledging that without a guide -- a set of established principles for resolution -- it would be exceedingly difficult for local, state, and national leaders to develop a consistent and coherent middle-level science program, assessment scheme, and teacher development and support system. With this in mind, the Center's panelists focused on making concrete recommendations that were most likely to achieve the desired results -- providing American middle-grades students with a solid foundation in science.

Scope of the Report

This document, *Building Scientific Literacy: A Blueprint for Science Education in the Middle Years*, consolidates the recommendations contained in three technical reports developed by the study panels listed in the front of this report:

- *Science and Technology Education for the Middle Years: Frameworks for Curriculum and Instruction*
- *Assessment in Science Education: The Middle Years*
- *Developing and Supporting Teachers for Science Education in the Middle Years*

In these reports, the Center addresses science education for early adolescents, students in the age group ten-through-fourteen, who are schooled in institutions variously called middle schools, junior high schools, or even elementary or kindergarten through eighth or twelfth grade schools. Because these school designations each carry organizational and instructional connotations, we use the more neutral terms middle level or middle grades. Furthermore, we believe our recommendations are applicable regardless of the schooling configuration.

Building Scientific Literacy is designed for a general audience, whereas the three technical reports listed above contain extensive detail and documentation that will be especially useful for those responsible for the education of middle-level students -- teachers and principals, science specialists, curriculum directors, assessment personnel, staff developers, district superintendents and administrators, state and federal education officials, university professors, and policy boards at all levels. An implementation guide designed to assist local science leaders in realizing this coordinated approach to middle-level school science is also available from the Center.

Building Scientific Literacy is divided into four parts. In Chapter I, we survey science education in the middle years: the challenge of educating young adolescents and the current state of curriculum and instruction, assessment, and the schools and teachers responsible for science education.

In Chapter II we propose goals for science education in the middle years and a vision for curriculum and instruction, assessment processes, and the kinds of teachers who would support those goals. In Chapter III we address what it would take to make that vision a reality: selecting curriculum and instructional strategies, creating an appropriate learning environment, experimenting with innovative assessments, developing strategies for staff development, and providing organizational support.

In Chapter IV, we address special concerns of science education in the middle years. These include the relationship between assessment and policy, and preparing teachers for middle-grade classrooms of tomorrow. In conclusion, we review the Center's recommendations to those who carry key responsibility for science education.

Fundamental Issues

The Center's position on several fundamental issues has influenced its approach to middle-grades science education. The issues are:

- What is scientific literacy?
- Why is it important?
- What is the current state of scientific literacy?
- Why is science education important, particularly in the middle-grades?

Scientific Literacy

We follow the lead of the American Association for the Advancement of Science (1989) in using the term "scientific literacy" to embrace both science and technology. The scientifically literate person is one who has a basic understanding of common scientific principles and concepts; uses scientific ways of thinking to propose explanations for the unity and diversity of, and the events occurring in, the natural world; uses technology to make structural, functional, or formative changes in the environment; and is aware of the limitations, strengths, and interdependence of science and technology.

If the pursuit of both science and technology is vital for scientific literacy, then definitions of each are useful. We have adopted the following working definitions, which are illustrated in Figure 1:

- Science proposes explanations for observations about the natural world.

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

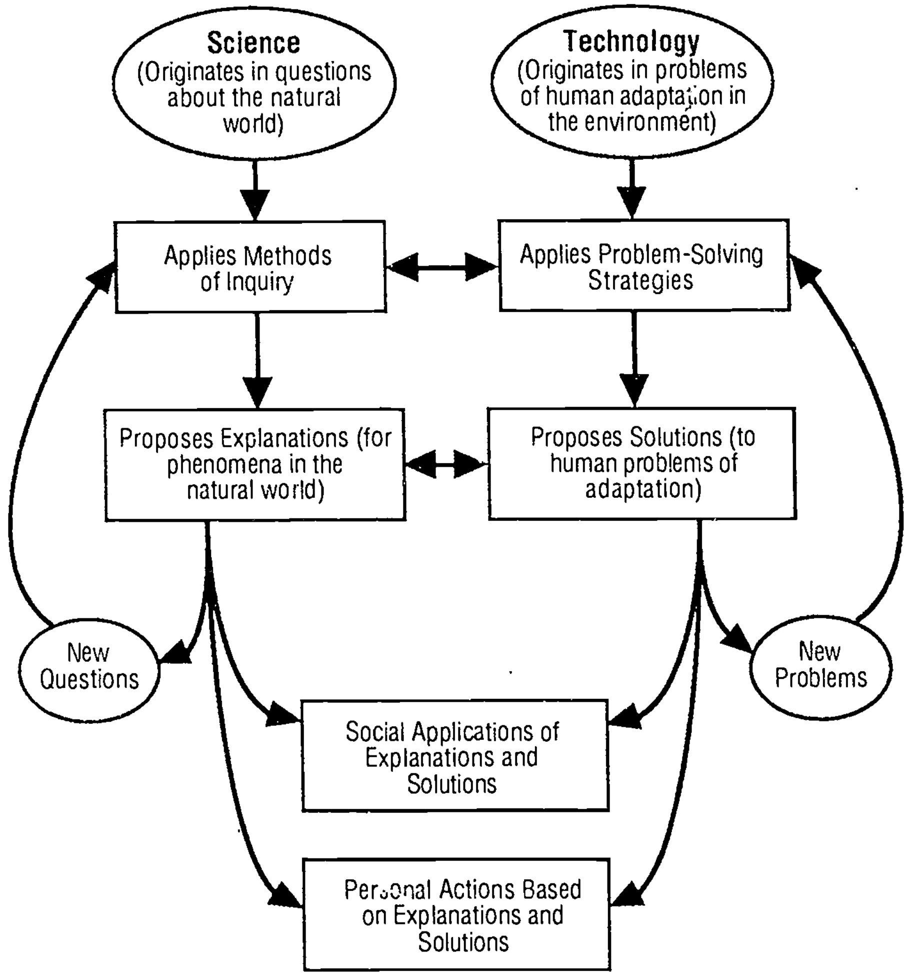
Science begins with questions about the world. How do earthquakes occur? What causes the different seasons in the northern and southern hemispheres? Why do some children look like their parents? As scientists investigate these questions, they employ recognized, though variable, methods of rational inquiry. The scientific community has rules for the game of science. For example, scientists base their explanations on, or derive them from, observations. Historically, these observations were direct, but now they are often collected through a "technologic filter".

The word "propose" signals that scientific explanations are tentative, which is a fundamental idea in science. Scientific explanations are subject to change and do not purport to be the final truth. Generally, however, they are not ephemeral, but have considerable staying power.

Technology originates in problems of human adaptation. Humans need air, water, food, and safety for survival. They need to move objects and information, construct shelters and bridge rivers. Technology helps them meet these needs; the development and use of tools, agriculture, weapons, and compasses are all examples of technologies that originated because of humans' need to adapt to their environment.

Understanding the differences and interrelationships between science and technology is an essential component of scientific literacy.

Figure 1
The Relationship Between Science and Technology and their Connection to Educational Goals



But why is scientific literacy so important? The AAAS (1989) suggests several reasons why *all* Americans need to achieve *some* degree of scientific literacy. These include the necessity for citizens to have the knowledge they need to solve both local and global problems, the respect for nature that informs decisions about using technology, and the scientific habits of mind that help people deal sensibly with problems that involve evidence, logical arguments, and uncertainty. Thus scientific literacy benefits the person as well as society, through informing decisions as personal as those regarding health, nutrition, and reproduction, through decisions with clear societal ramifications such as those regarding the environment, world hunger, and energy resources.

Scientific literacy cannot be reserved for those who are scientifically inclined, nor for those who aspire to science careers; it is vital for all who participate in a democracy.

Scientific literacy cannot be reserved for those who are scientifically inclined, nor for those who aspire to science careers; it is vital for all who participate in a democracy.

The Current State of Scientific Literacy and Implications for Education in the Middle Grades

The past decade has been replete with reports, white papers, and studies that have lamented the sad state of scientific literacy in the United States. Business, political, and government leaders have called for improved scientific literacy on the part of the nation's citizens and workforce (Hurd, 1989), concurring that the rapidly paced high technology and competitive marketplace characterizing today's industrial societies requires a much more scientifically and technologically literate workforce than ever before.

Yet there is clear evidence that most Americans are not scientifically literate. National and international studies alike indicate that not only has the average science achievement of seventeen-year-olds decreased over the past two decades (Mullis & Jenkins, 1988), but comparisons between our young people and those of other countries indicate that U.S. students rank near the bottom on nearly all relevant measures (Lapointe et al., 1989).

This evidence has particular import for middle-grades science education, since there are clear indications that somewhere between ages nine and thirteen youngsters decrease in their relative science proficiency and develop negative attitudes towards science. By the time they reach thirteen years old, students from the United States score significantly lower on cognitive scales than many of their international peers.

Poor achievement and loss of interest result in fewer and fewer students choosing to take science when, in high school, that option is open to them. Further, students who turn off to science in their middle years are largely lost to possible science careers.

In a report for the AAAS, Shirley Malcom and her associates (1984) identified several reasons why the middle years are important to the study of science:

- Students change their attitudes towards science during the middle grades, if not before.
- Critical decisions about high school course-taking begin to be made in the middle years (including decisions about taking algebra, which

in many schools influences what science courses will be open to students).

- Career orientation and exploration begin during the middle years.

- The experience base for high school years.

While the middle years are important to the science learning of *all* students, they are particularly important to female students and those from most minority groups (the notable exception is Asian students). Studies indicate that science performance differences between minority and majority students and between males and females (particularly in the physical sciences) increase significantly during the middle years, and that by the time most female and minority youth reach high school, they are turned off to science (Oakes, 1990). This is not necessarily due to poor achievement or conscious decisions not to pursue science, but often because of limited opportunities and prejudices as to where, for example, "one's place" is in society. Many female and minority students fail to achieve the scores requisite for science and mathematics classes, and consequently end up in remedial or low-ability classes after which they will have little opportunity to take additional science classes or pursue careers in science (Oakes, 1990).

Clearly, the needs of tomorrow's citizens must be addressed today, with all students given opportunities to learn science.

Keeping minority and female students involved in science in the middle grades is important to the long-term viability of the nation, since minorities and women are taking an ever-increasing role in the workplace. By the turn of the century, they will constitute over 62 percent of the net new workers in America (U.S. Department of Commerce, 1987). Clearly, the needs of tomorrow's citizens must be addressed today, with *all* students given opportunities to learn science.

One trend is clear: American students begin to fall behind in their science learning in the middle years. Furthermore, *all* American students are not receiving the science and technology education that will adequately prepare them to be citizens capable of making scientifically informed decisions. It is imperative, then, for policy makers, principals, teachers, and others responsible for educating students in the middle years to acknowledge these problems and reform science education accordingly. Later sections of this report present a blueprint for how this reform can be realized. But first, we turn to a capsule description of early adolescence and a brief appraisal of the status of science education in the middle grades.

Early Adolescence

Most adults view adolescence as a traumatic and unpleasant time, and they tend to assume that adolescents find this period in their lives as painful as those around them. Evidence from research and interviews with adolescents, however, contradicts this assumption (Offer et al., 1981). No firm evidence indicates whether the so-called trauma of adolescence is inevitable and universal or an artifact of particular cultures. The Center's position on this matter is based more on philosophy than science: the extent of adolescent "trauma" can be reduced considerably if society provides more support for youth in this period.

To understand what kind of support might be best for early adolescents first requires an understanding of the significant physical, social, and cognitive development that occurs in this age group. The magnitude of physiological change that takes place in early adolescence is second only to that which occurs in the first eighteen months after birth. The rate of physical growth accelerates, the secondary sexual characteristics develop, and the physiology of the brain changes.

The variations and duration of these changes vary from youngster to youngster. "Growth spurts" occur at any time and differ between girls and boys; thus variation among individuals of the same age and grade level is enormous. Rapid changes in metabolism and hormone activity result in unpredictable appetites, energy levels, and needs for personal hygiene.

These physical changes influence and are in turn influenced by the early adolescent's social development. During this time in their lives, youngsters transfer family allegiance to peer-group allegiance. Because self-confidence is only beginning to emerge and is not yet robust enough for young adolescents to reach far into the unknown, they commonly vacillate between seeking independence and desiring regulation, supervision, and direction. They question and redefine conventions of value, trust, and compromise. and often behave recklessly, as though impervious to the dangers of everyday life.

Even in this time of turmoil, early adolescent students are active and enquiring.

Even in this time of turmoil, early adolescent students are active and enquiring. As they search for meaning in their physical environment and interpersonal relationships, they can find that science offers many answers and can open up exciting new worlds for them to explore. But in order for this to happen, their science instruction must be based on an understanding of their cognitive development.

Reflective thinking allows the adolescent to consider issues and situations from different perspectives, to consider the thoughts of others, and to contrast differing perspectives.

In contrast to elementary students who develop understanding through manipulating concrete objects, early adolescents are developing the ability to be formal operational thinkers. Formal operational thinking is characterized by the ability to develop alternatives to reality and test them systematically; use abstract propositions, hypotheses, and symbols; and develop experimental designs and plans for data analysis. It also includes reflective thinking, which enables young adolescents to describe how they learn best, to improve their own learning, and to assess the strengths and weaknesses of their problem-solving skills, the extent to which they understand, and how well they are meeting the teacher's expectations. Not only do these and other related skills make it possible for students to assess their work, but they also enable students to improve themselves. Reflective thinking allows the adolescent to consider issues and situations from different perspectives, to consider the thoughts of others, and to contrast differing perspectives. This helps them to place themselves in a wider social context, which gives them a sense of personal and social destiny.

The physical, social, and cognitive changes that take place in early adolescence offer many unique opportunities to build on the questions and problems that adolescents have. Because adolescents prefer active involvement, both physically and mentally, rather than passive learning, they can enjoy science activities that are hands-on while posing intellectual challenges that require critical thinking. That adolescents generally find learning interesting when it is related to their immediate concerns, questions, and goals suggests that teachers need to make fundamental scientific and technological concepts and processes meaningful to their students.

The adolescent's physical, social, and cognitive development, then, provides a unique opportunity for science education. How this opportunity can be addressed, however, depends upon the structure of schools at the middle level, the curriculum, and the teachers themselves.

The Current State of Science Education

As we pointed out in the introduction, schools with a wide variety of grade level configurations serve students at the middle level, and the demands on teachers are unique. Many of these special demands are due to the distinctive needs of middle-level students. Other demands lie in the design of the public school system itself.

The physical, social, and cognitive changes that take place in early adolescence offer many unique opportunities to build on the questions and problems that adolescents have.

Schools at the Middle Level

The history of schools that serve middle-level students is long and interesting; arrangements of grade levels have changed over time as the perceived needs of the students changed. Until the 1890s, students through grade eight were largely served in elementary schools (the eight-four plan). Thereafter a three-decade debate ensued about whether secondary schools would better meet the needs of those who were to continue their education (a six-six plan). By the 1920s, a seeming compromise was reached. The idea of a school especially for middle-level students was born, and the junior high school began to take root. Such schools were supposed to address the needs of adolescents, smooth the transition to high school, eliminate dropouts, and provide vocational preparation.

The rhetoric surrounding the early days of junior high schools has continued into the present as represented by the middle-school movement. Hurd (1987) described some of the essential characteristics of schools for early adolescents, with special attention to science learning:

- A program specifically designed for pre- and early adolescents that encourages exploration and personal development;
- A positive and active learning environment with a flexible schedule for time and grouping, and varied instructional approaches;
- A staff that recognizes the students' needs, motivation, fears, and goals;
- An emphasis on the sequential and individual acquisition of essential knowledge, skills, and attitudes, with opportunities to develop decision-making and problem-solving skills; and
- Interdisciplinary learning and team teaching.

Numerous writings have reiterated these basic characteristics as critical for the special educational needs of middle-level students (Carnegie Task Force on Education of Young Adolescents, 1989; National Middle School Association, 1982; Superintendent's Middle-Grade Task Force, 1987).

Noticeably absent from any of these writings on what young adolescents need is the more traditional approach of teaching the disciplines as disciplines, within a school characterized by the organization, curricula, instructional strategies, and psychosocial environments of senior high schools. Yet this is what junior high schools have largely been since their birth in the early 1900s.

[M]iddle-level schools appear to mirror rather rigid high school organizational structures and practices -- far from those recommended for addressing the special needs of early adolescents.

Today, there is some indication that more middle-level schools are adopting the characteristics listed above, although the labels on schools (e.g., "junior high" vs. "middle school") often do not indicate what happens behind their doors. In two-thirds of schools serving seventh through ninth graders, for example, students take separate courses in each subject from specialist teachers, i.e., they are departmentalized (Cawelti, 1988). Over two-thirds of middle-grades science teachers polled in a recent science survey indicated that their classes were homogeneous -- i.e., their classes were characterized as having either high-, medium-, or low-ability students (Weiss, 1987). With departmentalization and grouping by ability, middle-level schools appear to mirror rather rigid high school organizational structures and practices -- far from those recommended for addressing the special needs of early adolescents.

Curriculum and Instruction at the Middle Level

Traditional content and instructional modes dominate curriculum and instruction at the middle level. Rather than being exposed to exploratory, integrated science, most students are taught a series of traditional science topics. The topics emphasize learning specific scientific information, rather than integrating science with everyday life, pressing social issues, or personal concerns of students. Rather than learning science in connection with other content areas, most students at the middle level take a sequence of specialized courses -- life science, physical science, and earth science -- or a series of "general" science courses. Lecture, textbook reading, recitation, and tests most frequently characterize science instruction.

Typically, a single text is used as the source for lessons, activities, lectures, and reading assignments for middle-grade students, and most texts are but watered-down versions of those used in high school science. Although some demonstrations and laboratory work supplement these dominant modes of science instruction, students have few opportunities for direct experiences and hands-on activities that engage them in doing science (Weiss, 1987).

Perhaps as a result of a mismatch between the needs and interests of young adolescents and the science curriculum, many students appear to find science difficult, boring, and irrelevant (Goodlad, 1984). And, while these programs are turning the students off, they seem to affect girls more negatively than boys. Many surveys have consistently revealed gender differences in thirteen-year-olds' attitudes toward science.

Assessment at the Middle Level

The kinds of assessment practices teachers select and use complete this picture of current middle-grades classroom practice. Science learning is typically assessed with "objective," paper-and-pencil instruments focused on the mastery of basic science facts. Teachers use individual (rather than group) assessments exclusively, place students in individual competition for grades, and measure the quality of their programs by aggregating students' test scores.

Through the assessments they use, teachers often communicate that they do not expect students to master difficult concepts.

These assessment practices send clear messages to students. They lead students to believe that science is a static body of facts, principles, and procedures to be mastered and recalled on demand, not a way of thinking or knowing about the natural world. Through the assessments they use, teachers often communicate that they do not expect students to master difficult concepts; such low standards and expectations can retard learning and consequently make the transition to high school science needlessly difficult, or, worse, keep it from occurring. Or, if students experience the facts and principles they are expected to master as too hard, they can be reinforced in the belief that science is too difficult and not for them. And these messages are being given selectively more often to females and minority students.

Teachers at the Middle Level

Early in the history of junior high schools, most junior high teachers were trained for high school, and they had neither the background nor the motivation to teach at the junior high level. This is one of the reasons why such schools became "mini" high schools.

Today the situation is even more complicated. Typically, teachers do not end up teaching at the middle level by choice (Carnegie Task Force on Education of Young Adolescents, 1989). Many consider it a "way station" on their path back to either elementary or secondary assignments. Many lack confidence in their ability to teach middle- level students, which is reinforced by their lack of success.

According to the Carnegie Task Force on Education of Early Adolescents (1989), many teachers share with other educators and parents of early adolescents the belief that their students are incapable of complex thought because of their rapid physical and emotional development. These teachers believe they should expend only minimal effort to stimulate the early adolescent's higher levels of thought, and that adolescents become "teachable again" only when they reach high school. While no persuasive evidence supports this argument, and there is much to refute it (see earlier description of increasing cognitive abilities), this argument does in fact form the basis on which many middle-grade educators rest their instructional practice.

It is no wonder that many middle-grade teachers question their ability to teach young adolescents. As of 1987, fewer than one-third of teacher education institutions in the country had programs for middle-level teachers (McEwin & Alexander, 1987). It is likely that what teachers who are currently teaching in the middle grades know about teaching students at that level, they have learned for themselves, constructing their own knowledge base from their experiences. Given the relative isolation of teachers, they have had little opportunity to discuss, refine, and validate that knowledge with others.

Science teachers face particular constraints with school facilities and equipm nt that are inappropriate for inquiry-based, exploratory science activities.

The practice of middle-grade teachers is influenced by the norms and structures of their organizations, as well as by their knowledge and beliefs. As noted earlier, a large majority teach in departmentalized schools, with ability grouping. Research on ability grouping has indicated that the kind of group teachers face causes them to differentiate their instruction according to different expectations of performance (McPartland, J.M., 1987). Those from whom they expect less are challenged less and given fewer opportunities to learn material in depth (Oakes et al., 1990).

Many middle-level teachers must work in more difficult physical environments than teachers of older or younger students. Many junior high school buildings are converted high schools -- older buildings that might have few of the physical arrangements, such as clustered classrooms, that are conducive to integrated, cross-disciplinary programs. Science teachers face particular constraints with school facilities and equipment that are inappropriate for inquiry-based, exploratory science activities. In a recent national survey, about one-quarter of the teachers of seventh, eighth, and ninth graders reported that inadequate facilities, insufficient funds for purchasing equipment and supplies, and the lack of materials for individual instruction were serious problems at their schools (Weiss, 1987).

Summary

Up to this point we have focused on the realities of science education at the middle level. These realities include the physical, mental, and social development of adolescents, the organizational environment of their schools, the current curriculum and assessment strategies, and the constraints placed on and limits of teachers. This leads into the question: What should be happening instead? In Chapter II, the Center presents its vision of the ideal in curriculum, instruction, assessment, and teacher development and support.

24

CHAPTER II

A Vision of Science and Technology Education at the Middle Level

Goals

The education of early adolescents has two main purposes: promoting the individual's continued intellectual, emotional, and social development; and helping develop productive, responsible citizens. Articulating these purposes for science education, students in the middle years should learn to:

- think scientifically;
- use the tools and strategies of science; and
- apply science knowledge and skills when addressing individual and societal problems.

To help students meet these ends, the Center has framed the following five goals. These goals represent general directions, not specific objectives that each student must achieve. As with any large group of students, some will develop a deeper understanding of science than others, and some will acquire more proficiency than others, yet all students need to develop minimal understanding and proficiency.

- Goal 1: Science and technology education should develop adolescents' ability to identify and clarify questions and problems about the world.
- Goal 2: Science and technology education should broaden adolescents' operational and critical thinking skills for answering questions, solving problems, and making decisions.
- Goal 3: Science and technology education should develop adolescents' knowledge base.

- Goal 4: Science and technology education should develop adolescents' understanding of the history and nature of science and technology.

- Goal 5: Science and technology education should advance adolescents' understanding of the limits and possibilities of science and technology in explaining the natural world and solving human problems.

If these goals are to be achieved, we must address the following questions:

- What should be taught?

- How should it be taught?

- How should it be assessed?

- What do middle-level teachers need to know and be able to do?

- What support do teachers need?

In the following sections, we take up these questions in turn.

What Should Middle-Level Students Be Taught?

[Science knowledge] must be organized and connected into meaningful structures.

What middle-level students should be taught can be grouped roughly into three categories: knowledge, skills, and attitudes.

Knowledge -- the "what" of science and technology -- includes facts, concepts, principles, laws, and theories that scientists use to formulate their explanations. But it is not enough to know these in isolation. They must be organized and connected into meaningful structures. The Center's curriculum panel identified ten conceptual themes as a focus for the knowledge middle-level students need to learn. The themes were chosen because they:

- apply to science and technology;

- apply to other disciplines;

- accommodate different developmental levels;

- relate to the personal and social lives of adolescents; and

26

• provide powerful explanations.

The conceptual themes are paired: some because, like cause and effect, they simply go together; in other situations, the pairing occurs because the understanding of one concept is enhanced by the juxtaposition of another concept, for instance, energy and matter, and diversity and variation. The ten themes are:

- Cause and Effect. Searching for causes and explanations is the major activity of science; effects cannot happen without causes. Understanding the nature of evidence required to demonstrate cause-and-effect relationships is an appropriate goal for middle-level students.

- Change and Conservation. Change is ongoing and ubiquitous in the natural world, although it often occurs too slowly or on too grand a scale to be observed. Middle-grade students can be introduced to the concept of patterns of change, as well as to conservation as the idea that, while things are observed to change, matter and energy are neither created nor destroyed.

- Diversity and Variation. One of the most obvious characteristics of the natural world, diversity has been found to be important to the maintenance of natural systems. Middle-grade students can begin to differentiate and understand the implications of both continuous and discontinuous variation.

- Energy and Matter. The middle level is the time to introduce the fundamental concepts of energy and matter. Energy can take different forms, and is transformed when changes occur in the natural world. Students learn that the materials they observe as varying greatly, actually consist of a relatively small number of basic elements (atoms) and can change their forms when energy is applied.

- Evolution and Equilibrium. By exploring phenomena that illustrate these two concepts, middle-level students can begin to understand the paradox of a world that is constantly undergoing change while at the same time seeking a steady state of equilibrium.

- Models and Theories. The nature of science and technology is introduced to middle-level students through the use of models and theories. Students learn the relationship between hypotheses, theories, and models, and hone their abilities to imagine and then explain scientific phenomena.

27

- Probability and Prediction. Probability is the relative certainty (or uncertainty) of certain events happening (or not happening) in a specified time or space. It is related directly to scientists' need to predict, i.e., use knowledge to identify and explain observations or events ahead of time. These concepts are easily introduced to middle-level students in the context of the questions and problems that they find meaningful.

- Structure and Function. Middle-level students are at a prime age to actively explore the relationships between how organisms and object look, feel, smell, sound, and taste, and the actions they perform. Of particular interest is the evolution of structures and functions of organisms over time.

- Systems and Interaction. Middle-level students can be introduced to both simple and complex systems and study the interactions of their component parts. The hydraulic cycle and a properly tuned heating system are examples from science and technology of systems for adolescents to explore.

- Time and Scale. Students' understanding of time includes consideration of the succession of events, the interval separating events, and the duration of events. The different time periods represented in science -- from fractions of a second to geologic periods -- serve to illustrate the concept of scale. At the middle level, students begin to understand the importance of scale to the viability of organisms (such as water striders and newborn babies) and to the efficiency of operations of technology (such as the fuel efficiency of multi-passenger vehicles).

[Students] should be able to use microcomputers independently to enter, store, and retrieve data, and to simulate experiential conditions.

These themes are described in more detail in the Center's curriculum report (Bybee et al., 1990). How they contribute to selecting science content is discussed in Chapter III.

Skills for middle-grade science include practical laboratory skills, scientific intellectual skills, generic thinking skills, and a wide variety of social skills.

Practical laboratory skills for middle-level students include the ability to measure length, volume, mass, time, and temperature, using instruments capably and quantitative data comfortably. They should be able to use microcomputers independently to enter, store, and retrieve data, and to simulate experiential conditions.

26

Scientific intellectual skills include the ability to generate a hypothesis; to design an experiment that is a valid test of a hypothesis; and to collect, reduce, present, interpret, and analyze data. Skills related to technology include the design and building of artifacts intended to perform a specified function. The combination of intellectual skills relevant to science and technology also includes procedural knowledge-knowing "how" to apply the "what," or the factual and conceptual knowledge and laboratory skills one has acquired. Procedural knowledge is the key to addressing unfamiliar scientific questions or operational problems that may arise in the course of one's work, for students as well as for working scientists, engineers, or technicians.

Generic thinking skills are associated with other disciplines in addition to science. They include skills and quantitative, logical, and analogical reasoning.

When young adolescents employ their developing skills in science learning and do so in working groups, the classroom becomes a replication of a community of science scholars pursuing scientific knowledge as a social activity.

Finally, **social skills** are an important focus. They include listening carefully and respectfully, exchanging ideas and information, welcoming a diverse array of approaches to solving problems, and acknowledging that a variety of "right" answers (or reasonable interpretations) are possible. Such skills enable the students to grapple actively and productively with complex knowledge and ambiguous problems. Given a problem or task that is within their capability to solve, students who are working together can be expected to take on challenges that require perseverance and commitment. Moreover, when young adolescents employ their developing skills in science learning and do so in working groups, the classroom becomes a replication of a community of science scholars pursuing scientific knowledge as a social activity. Thus, the students begin to learn about the culture of science and to learn skills valued in the workplace, where the application of science usually proceeds through teams working together.

Attitudes also need to be the focus of science instruction. Attitudes to be reinforced by science programs include dispositions towards using scientific knowledge and skills, and scientific "habits of mind" such as desiring knowledge, being skeptical, relying on data and reason, and accepting ambiguity.

How Should Students Be Taught?

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

[S]tudents are active learners who constantly reconstruct their understanding, as they try to reconcile past experiences and their current concepts with new experiences and information.

Another view of learning that has gained popularity in the past decade proposes that students are active learners who constantly reconstruct their understanding, as they try to reconcile past experiences and their current concepts with new experiences and information. This emerging school of thought is called "constructivism" by many researchers and educators.

This view of learning extends the developmental perspective of Piaget, which focused primarily on the learners' logical structures, by recognizing that "learners build conceptual frameworks that are complex, highly organized, and strongly tied to specific subject matter (Linn, 1986:9)." This view also recognizes that dialogue among students is an important strategy for encouraging them to deal with newly introduced knowledge and experience. Increasingly, research supports the view that learners construct understanding by making connections between new information and their existing understanding. If the new information is consistent with a learner's existing ideas, the learner can easily assimilate the new knowledge. However, if the new experience and information is sufficiently discrepant from the learner's current views, then the learner must accommodate that new information by actively reconstructing his or her understandings.

Teachers cannot transmit correct views of scientific concepts to their students through the spoken and written word. Even conducting a science demonstration designed to help the students overcome an existing concept is probably not sufficient. Researchers have noted that students who observed such demonstrations reported observations that were more closely aligned with their existing viewpoints than with what actually happened (Champagne et al., 1985). Learning that leads to a changed conception takes time, because a student needs to compare and contrast new information (sometimes presented by the teacher, sometimes discovered by the students themselves through inquiry) with an existing concept. With time and ample experiences, the student gradually modifies or replaces the pre-existing idea with a new, more sophisticated concept. Teachers have a responsibility to select appropriate, meaningful materials, but it is the student who must bring meaning to those materials. Thus, teachers must consider the processes of learning, as well as the content of science, as they structure the classroom learning environment (Driver, 1981).

A Teaching/Learning Model

Consistent with this emerging constructivist view of learning, the National Center for Improving Science Education suggests a teaching-learning model that parallels the methods scientists and engineers use to uncover new knowledge and solve problems. A template that teachers can use to design daily lesson plans and weekly (or longer) unit plans, the model encourages multiple approaches to learning (tantamount to the experiences of active scientists and engineers). Learners are asking questions, experimenting, and communicating their new knowledge to colleagues; they have the opportunity and responsibility to act on newly reformulated knowledge and to ask new questions. The model suggests to teachers and students that science and technology, as fields of study and human endeavor, are dynamic: questions and problems lead to tentative explanations and solutions and in turn generate new questions and problems.

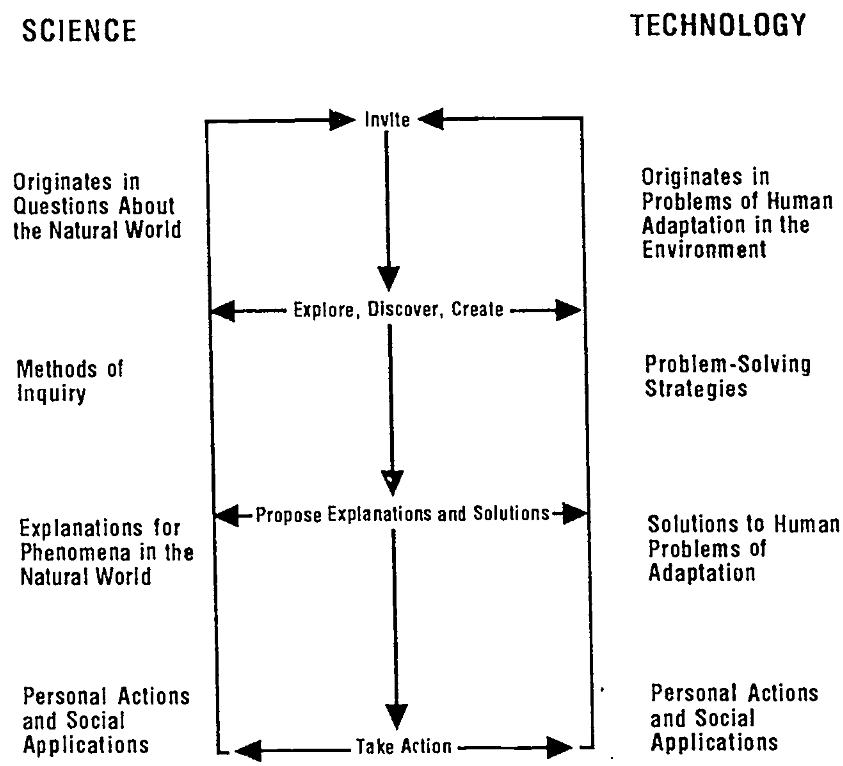
The model has four stages: (1) invitation; (2) exploration, discovery, and creation; (3) proposing explanations and solutions; and (4) taking action. Figure 2 lists key activities that might characterize each of the stages, activities that practicing scientists and engineers might engage in as they learn. We consider the model to be universal in describing any learning in science and technology, including learning by professional scientists, teachers, and students, as well as learning that takes place in less formal settings, such as the home, a park, museums, and nature centers.

For classroom purposes, however, Figure 3 lists specific teaching behaviors for each stage.

Invitation

The learning process beings with an invitation, which originates with a question about the natural world (science) or a problem in human adaptation (technology). An invitation may be spontaneous, such as a student discovering an eggshell in the park, or it may be planned, such as a demonstration of a discrepant event. In both cases, questions emerge immediately, students and teachers observe together, and the

Figure 2
Instructional Model



stage is set for further investigation. Invitations must engage the learner, who must understand the event, questions, or problem well enough to begin actively thinking about it. If the question or problem is not one students are curious about, one they initiated, or one they want to address or solve, then further engagement will be difficult and may result in rote learning. Often it is the teacher's challenge to invite students in a way that engages them.

Exploration, Discovery, and Creation

This stage of the teaching model builds upon and expands the science learning initiated by an invitation. At this point, it is critical that young adolescents have access to materials and that they have ample opportunities to observe, collect data, begin organizing information, and

Figure 3
The Teaching-Learning Model

Teaching-Learning Examples for Science	Stages in the Model	Teaching-Learning Examples for Technology
	Invitation	
Observe the natural world		Observe the human-made world
Ask questions about the natural world		Recognize a human problem
State possible hypothesis		Identify possible solutions
	Explorations, Discoveries, Creations	
Engage in focused play		Brainstorm possible alternatives
Look for information		Experiment with materials
Observe specific phenomena		Design a model
Collect and organize data		Employ problem-solving strategies
Select appropriate resources		Discuss solutions with others
Design and conduct experiments		Evaluate choices
Engage in debate		Identify risks and consequences
	Proposing Explanations and Solutions	
Communicate information and ideas		Construct and explain a model
Construct a new explanation		Constructively review a solution
Evaluation by peers		Integrate a solution with existing knowledge and experiences
	Taking Action	
Apply knowledge and skills		Make decisions
Share information and ideas		Transfer knowledge and skills
Ask new questions		Develop products and promote ideas

think of additional experiments that they might try. This stage is characterized by a strong element of constructive play and informal investigation. Students begin to explore how new information gained from their investigations relates to previous experiences and their current level of understanding. The teacher is a co-learner and a facilitator who chooses materials and activities that are likely to lead the students to new discoveries and information, observing and asking questions with the students. Teachers can model many of the responses, such as awe, enthusiasm, curiosity, and the temporary suspension of judgment, that are characteristic of scientists.

Proposing Explanations and Solutions

In this stage, the learners continue to refine their developing understanding of a concept. They construct a new view of the concept by integrating their current conception with new information, which they have gained through their investigations and through the appropriate use of the textbook, other materials, and information provided by the teacher. Students then analyze data that they began to organize in the preceding stage and consider alternative interpretations prepared by classmates and the teacher. Cooperative learning is often used. Guided by the teacher, students may decide to perform additional investigations, usually more focused than their earlier ones. The results will help resolve conflicts between students' previous understanding of a concept and a newly emerging view. The cooperation between students and teacher is an opportunity for the teacher to model qualities that characterize scientists: proposing and accepting alternative points of view, listening and questioning, persisting in seeking solutions, and working together cooperatively.

The teacher's role is to encourage the students to take action and to assist them in transferring their new knowledge to other fields of study.

Taking Action

Once the students have constructed a new view of a concept, they are usually ready to act on that new level of understanding. They might defend a point of view before the class or write a letter to a local authority, thereby learning what it means to conceptualize a point of view. Their new level of understanding may, and frequently does, lead to new questions that provide the foundation for new explorations and subsequent refinement of conceptual understanding. The teacher's role is to encourage the students to take action and to assist them in transferring their new knowledge to other fields of study. The teacher also can assess, informally and formally, each student's new level of understanding and gauge the effectiveness of the experience. This will help the teacher plan future activities appropriate to the students.

Reflection on the outcomes of such a teaching and learning process requires a new way of thinking about and conducting assessment.

How Should Learning Be Assessed?

Early in this section, we described the kinds of science outcomes we envision for middle-level young people, which include science knowledge, skills, and attitudes. Here we address strategies for strengthening the assessment of each.

Assessing Science Knowledge

The first task in assessing the science knowledge acquired by students is deciding which categories of that knowledge are to be probed, and what knowledge within each category should be represented on a test. Once these decisions have been made, testing of factual and theoretical knowledge and knowledge about the scientific and technologic enterprises can be carried out with relative ease, using paper and pencil. Often, short-answer or multiple-choice items are used. This type of assessment format allows a single person to administer the test in group settings; hence, the exercises making up the assessment can be given to a large number of individuals.

Because of the relative ease and efficiency of paper-and-pencil tests, particularly those, like multiple-choice, that can be scored by machines, most tests intended for monitoring purposes, that is, providing national, state, or district-wide information on student achievement, take this format (for example, state-mandated tests, commercially available standardized tests, and tests used by the National Assessment of Educational Progress and in international comparisons). Unfortunately, all too often, multiple-choice items test recall of unconnected bits of information, thereby conveying a distorted message about the nature of science. Knowledge assessments, however, need not be limited to this form of test. Teachers, in particular, have other strategies available to them. They can design essay questions and review written and oral reports. They can use non-written assessments that parallel the hands-on activities used in instruction to develop students' understanding of scientific concepts. They also can use more informal methods for gauging their students' science knowledge and embed assessment of what knowledge has been learned in more holistic assessment strategies (such as those described in the next section).

Assessing Laboratory Skills

To assess these skills requires laboratory equipment and materials. This sort of assessment distinguishes between knowledge about how to do something, which can be probed with paper-and-pencil tests, and having

In science classrooms that include science activities as a regular part of instruction, teachers have many opportunities to observe these skills in action.

the competence to do something, which cannot. To assess the latter, assessment techniques need to match closely the ability to carry out a given scientific procedure or design task. Obviously, this type of assessment is more difficult to administer and score and requires more material resources than do paper-and-pencil assessments. Nevertheless, the National Assessment of Educational Progress (1987) conducted a successful pilot study of such assessment and Connecticut, New York, and California also are now experimenting with incorporating performance tasks in their science assessments. In science classrooms that include science activities as a regular part of instruction, teachers have many opportunities to observe these skills in action, with the added benefit of being able to do corrective teaching as deficiencies are observed.

At the middle level, observing, classifying, measuring, and other laboratory skills useful for gathering information will recede from prominence, being no longer ends in themselves. This aids the assessment situation to some extent, as students will be able to record in a journal or notebook observations and data that can be easily monitored by a teacher. The importance of keeping records in accessible forms can be made clear to students by presenting challenging and meaningful problems whose solutions depend, at least in part, on the accuracy of measurements made over time and the careful recording of changes in experimental conditions.

Assessing Intellectual Skills

Hypothesis generation, experimental design, data collection, data analysis, and data interpretation -- all these are important scientific intellectual skills. Such skills integrate a complex variety of generic thinking skills with the ability to select and perform appropriate practical laboratory skills. In most tests and assessment exercises, scientific intellectual skills are assumed to be generic skills that the students should be able to use in any scientific context.

Teachers can discover ways to assess the application of scientific processes in the context of the learning units they create. Students can be asked to conceive of and conduct experiments, design and build models, and conduct sophisticated oral and written presentations on the development and results of their investigations. In each case, the assignment will yield a product or record of student achievement that can be evaluated.

Assessing Generic Thinking Skills

Included in this category are problem-solving skills and quantitative, logical, and analogical reasoning. Again, these skills can best be assessed within the context of scientific inquiry. Students can be asked to justify their answers, explain how their experimental procedures and findings support their inferences, demonstrate how their designs serve the intended functions, or otherwise make their reasoning explicit.

Assessing Social Skills

Teachers can discover ways to assess the application of scientific processes in the context of the learning units they create.

Most communication skills involve direct interaction with other persons, and so these skills are best observed during group work. Teachers can regularly look for specific social skills, e.g., listening carefully and respectfully, exchanging ideas and information, problem solving, and challenging others' ideas appropriately. Using a set of index cards, focusing on a few skills at a time, and observing all students equitably, are considerations for assessing social skills.

Assessing Dispositions and Scientific Habits of Mind

Making judgments about the extent to which students have acquired the habits of mind that dispose them to apply scientific knowledge and skills outside the formal classroom setting is another assessment challenge. One might attempt to assess disposition by the use of a self-report -- that is, describing situations and asking individuals to indicate whether or not they would take a "scientific" approach to analyze them; or observe the students and determine whether they use a scientific approach to personal and civic problems. Neither of these methods have been found to be particularly trustworthy in single instances, but they can be sources of assessment data when collected over time.

A teacher can also measure observable behaviors, for example, the students' interest in voluntarily undertaking science activities beyond prescribed classroom work, the students' self-monitoring of their work, and their monitoring of peers. Teachers might add observations on these behaviors to the records they keep on their students. Some structured performance tasks might also provide opportunity for observing these behaviors, particularly if the tasks call for sustained work.

The range of assessment strategies just described is not used regularly in middle-level science classrooms; most are not used at all. Nor is the kind of teaching-learning model described in the previous section. The fault is not that of teachers, for few have been prepared to use any of these approaches. The following section discusses what teachers need to know and be able to do to facilitate the kind of learning we envision as ideal for young adolescents, and we foreshadow a discussion in Chapter III of strategies to promote teacher development in these areas.

What Do Middle-Level Science Teachers Need To Know?

Teachers need to know the nature of normal adolescent social and emotional development and to be aware of implications of students' rapid physical growth.

At the most fundamental level, middle-level science teachers need to know about *the intellectual, psychological, social, and physical development of young adolescents*. They must understand concrete and formal reasoning patterns, and be able to use strategies that are effective with students at different levels of cognitive development.

Teachers need to know the nature of normal adolescent social and emotional development and to be aware of implications of students' rapid physical growth. With so much happening to young adolescents, their teachers need to understand the tensions between intellectual and academic priorities and the emotional and social needs of adolescence. Because of changing American demographics, teachers also need to be able to recognize cultural differences and their relationship to the development of the young person.

General knowledge of adolescent intellectual development is helpful, but knowing how students think about and learn science and specific science topics is vital for the science teacher. Without this knowledge they cannot help their students as they go through the complex process of conceptual change, restructuring and integrating their personal knowledge with scientific knowledge.

Middle-grade science teachers need a solid foundation in *the concepts, principles, and skills of science*, across the science disciplines, because without this fundamental knowledge, they cannot teach science effectively nor adapt their instruction to incorporate other content areas, such as reading.

Teachers at the middle level need laboratory skills, and they must also know how to generate hypotheses and design experiments, reason scientifically, and solve problems. They need to have scientific habits of mind, such as skepticism, honesty, and a thirst for knowledge. Further, they must be able to bridge social, scientific, and technological issues. They need to understand the ways in which science has changed society's view of the world, how technology has changed how people live, and the three-way relationship between science, technology, and society.

To enable learning to occur, the teacher has to present the scientific enterprise and select scientific knowledge so that it is accessible to early adolescents (Anderson, 1987). The teacher is a mediator between the culture of science and the student's educational culture. It follows, then, that the teacher must determine what is essential to the scientific enterprise, what is peripheral, which scientific concepts are *accessible*, which are not, and how much of the technical language of science can be sacrificed for students' understanding without undermining the students' grasp of important scientific principles. Being able to perform these complex thinking and reasoning tasks requires that teachers have a firm grasp of science, both content and process.

Teaching science requires that the teacher arrange and manipulate the learning environment in such a way that students can develop their own knowledge of scientific principles.

Teachers also need *skills in pedagogy and classroom management.* Without the ability to help the students use their scientific knowledge as a tool to make sense of the world around them, the teacher can neither teach, nor expect the learner to learn. Teaching science requires that the teacher arrange and manipulate the learning environment in such a way that students can develop their own knowledge of scientific principles -- the key word here is construction, not instruction. This includes the ability to help young adolescents articulate their conceptions of scientific and technological phenomena, being aware of certain common misconceptions the students are apt to hold, and skill at crafting learning experiences that will demonstrate scientific principles in such a way that the students can enlarge their conceptions or change their misconceptions.

Teachers of early adolescents also must have *the skills and knowledge to enable them to work within an exemplary middle-school setting.* They must be able to work as members of interdisciplinary teams who collectively allocate budget and space for their assigned students, choose instructional methods and materials, identify and develop interdisciplinary curricular themes, schedule classes, and evaluate student performance. They need problem-solving and decision-making skills, and they need to know how to resolve conflicts and run efficient, productive meetings. Middle-level teachers also need the skills to work closely with administrators, health-care providers, and others who perform services necessary to meet the needs of early adolescents. They need to be able to work with the community to set up youth service opportunities, which are becoming more and more a part of the early adolescents' educational experience.

Teachers of young adolescents need to have *professional attitudes and commitment.* These qualities include, but are certainly not limited to, flexibility and enthusiasm, a sense of humor, and, most important, patience. Exemplary teachers have a strong commitment to their work and students. They not only demand achievement, but provide opportunities for it. They are committed to their students' welfare and learning outside of class, viewing them as whole individuals, worthy of their respect, who operate in a broad context that extends beyond the classroom. Exemplary teachers have their own personal goals and have determined a course of action for attaining them. They stay enthusiastic, and their greatest reward is seeing their students exhibit understanding and achieve their goals. Such teachers actively seek innovation.

These five areas of knowledge, belief, and skill -- knowledge of middle-grade students; knowledge of science and technology content and skills in "doing" science; knowledge and skills in science pedagogy, general pedagogy, and classroom management; knowledge of the middle-school concept; and professional attitudes and commitment -- portray an ideal teacher of middle-level science.

CHAPTER III

Achieving the Vision

To achieve the vision described in the previous chapter requires:

- strategies for selecting curriculum and instructional approaches;
- learning environments that foster inquiry learning and teaching;
- assessment strategies that capture important outcomes and help teachers improve their science instruction;
- opportunities for teachers to develop the kinds of knowledge and skills they need; and
- school and district support for this new way of teaching and learning.

A Framework for Curriculum and Instruction

Earlier we addressed several components of a framework for curriculum and instruction: a conception of science and technology, goals for the curriculum and their rationale, major conceptual themes, and a learning model. Here we describe a framework for the design and development of curriculum materials, including strategies for learning, criteria for the selection of content, and guidelines for selecting materials and assessment approaches that should be part of the framework. We then identify and describe several issues that can impact the framework and its implementation.

A framework is like the broad sketches of an architect's plan. A framework for curriculum and instruction is halfway between the idea and the specifics. It specifies and explains the basic components used to design the science program, including the information needed to make decisions about content, sequence of activities, selection of instructional strategies, and appropriate assessment practices.

The Center's framework for curriculum and instruction calls for

The Center's framework for curriculum and instruction calls for instructional strategies that are appropriate for early adolescents and congruent with the constructivist learning model.

instructional strategies that are appropriate for early adolescents and congruent with the constructivist learning model described in Chapter II. At each of the four stages (invitation; exploration, discovery, creation; proposing explanations and solutions; and taking action), teachers and students do different things. This can be used as a guide by curriculum developers as they sequence learning activities.

Teachers play multiple roles as they teach science to middle-grade students. They are *facilitators* of student learning, *managers* of the learning environment, *curriculum coordinators*, and *assessors* of student learning. A curriculum and instructional framework needs to incorporate these roles as it designs classroom learning strategies.

Guidelines for the Design and Development of Curriculum Materials

1. Design the program so it builds upon the middle-school concept, e.g., integrate science with other disciplines.
2. Base the program on both science and technology by using the unifying concepts recommended in Chapter II to link units and topics of study.
3. Design the curriculum to span the entire middle level, usually two or three years.
4. Select the number of units based on how the district divides the school year (e.g., quarters, semesters).
5. Include an instructional model in the program.
6. Decide on the curriculum emphasis or goal of each unit (e.g., understanding scientific and technological concepts, knowing the history of science and technology).
7. Include a variety of activities.
8. Determine how other content areas will be integrated with science.
9. Design units with these principles in mind: the units should progress from personal to social and local to global; begin with a question (science) or problem (technology); result in a tentative explanation (science) or proposed solution (technology); include scientific and technological processes and skills.
10. Include both informal and formal assessment approaches that produce information to inform instructional decisions.

If schools and curriculum developers are to respond to recommendations that less is more -- that is less be taught in greater depth -- how are they to select from among the myriad topics in science and technology?

Here are some **criteria for selection of content:**

Selection Criteria for Content

1. Content should relate to the life and world of the early adolescent.
2. New knowledge, skills, and attitudes should be presented in a context that makes them understandable.
3. Conceptual themes should be the focus for content; specific subject matter is learned as examples of these themes.
4. Science programs should progress from concrete to abstract.
5. Topics that allow in-depth, extended learning should be selected.

Several important issues need to be addressed by curriculum developers. The first issue requires recognition of the changing demographics of our nation's student population. The children entering our schools are poorer, more ethnically and linguistically diverse, and have more disabilities that affect learning than has been true in the past (Hodgkinson, 1985); these are characteristics of the students who have traditionally been underserved and underrepresented in the sciences. Curriculum developers must be aware of these changing demographics and shape their programs to better meet the needs of students. Among the strategies are making science content more personal to students; ensuring that science teachers understand and value different cultures, learning styles, world views, and ways of approaching problems; recognizing the advantage of using cooperative rather than competitive learning strategies, when appropriate to the cultures of the students; and acting out a belief that *all* students can learn science.

Curriculum developers must be aware of the drawbacks of current texts and guide teachers to use them differently.

A second issue is that of the predominance of textbooks and lectures as the vehicles for learning in middle-grades classrooms. Current science texts are not compatible with the constructivist approach to learning; they focus on coverage of material rather than student understanding. Yet a majority of teachers indicate that they are satisfied with the textbooks they use. Similarly, current teaching is dominated by the lecture format, which restricts the active involvement of learners in constructing their own interpretations of knowledge (Weiss, 1987).

Curriculum developers must be aware of the drawbacks of current texts and guide teachers to use them differently. Students need time and frequent opportunities to read, to discuss new words and ideas with peers, and to relate that information to what they currently know. They profit from readings *after* they have initially explored a topic, and can be helped by teachers to link the new information to their existing knowledge. Likewise, lectures can be the basis for learning, provided that students have time to reflect on the new information and link it to their existing knowledge and to problems they are solving. Teachers need to use wait-time after asking questions and pause occasionally (e.g., every ten minutes) for students to reflect on new information through writing, discussing with peers, or raising questions and issues. Providing students with ample time to think about and interpret new information improves the effectiveness of lectures.

Another issue for curriculum developers to consider is the accumulating research about learning styles. Students learn differently, and they do so along a number of dimensions (Dunn & Dunn, 1978). As more cultures are represented in a classroom, student learning styles become even more diverse. Instructional strategies and curriculum design need to take this into account.

[C]urriculum developers have a myriad of choices about how and where to integrate different software applications into the science curriculum.

Two final issues involve integrating the science curriculum with technology and other content. With the increase in availability and quality of instructional technology, curriculum developers have a myriad of choices about how and where to integrate different software applications into the science curriculum. Similarly, with increasing calls for integrating curriculum areas, especially in the middle grades, curriculum developers have a number of choices to make about how the learning of science and other subjects can be mutually reinforcing. The potential for interdisciplinary teaching is limited only by the time and creativity of curriculum developers (including teachers), but the challenges to maintain the integrity of each discipline and respect for the strategies by which it is best taught are great. Carefully constructed integrated units, however, can be an important avenue to meeting the learning and development needs of *all* middle-level students.

Using a framework for curriculum and instruction such as the one presented here can guide curriculum developers as they create new science programs for middle-grade youngsters -- and can make great strides towards achieving the vision for science education.

Optimal Learning Environments

An effective middle-level science and technology program requires a special educational environment. The environment must be designed to achieve the two goals of middle-level schools: student development and student learning. Some characteristics of such an environment are described below.

Flexible Schedules for the Unit, Day, and Year

The most typical time unit for students in the middle grades is the 40-50 minute block, yet there is widespread agreement that this arbitrary unit of time does not foster learning of material in depth. Rather, the length of time spent on a unit of instruction should be dictated by the nature of the material to be learned, the needs and interests of students, and the existence of special learning opportunities, such as current events and field trips. Decisions about scheduling the school day are best left to the professional judgment of teacher teams who can organize for extended blocks of time for science activities, alternating emphasis on core subjects, elective studies, shared team planning time, and different assignments for students with special needs.

Research has indicated that, while most teachers believe it to be effective, tracking has deleterious effects on teacher expectations and instructional practices.

Cooperative Groups and Peer Teaching

Between-class tracking has proven to be a divisive and damaging school practice (Johnston & Markle 1986). Research has indicated that, while most teachers believe it to be effective, tracking has deleterious effects on teacher expectations and instructional practices (especially for students in lower-ability groups), students' perceptions of themselves and of others, and the academic performance of lower-ability students. It interferes with opportunities for students to learn from peers from different socioeconomic and cultural backgrounds, and may perpetuate notions of superiority and inferiority.

Classrooms where cooperative learning and cross-age tutoring are used appear to be far more effective in teaching diverse groups of students.

Facilities and Equipment

Flexible facilities are required for the kinds of hands-on activities, peer discussion, cooperative learning, and large-group presentations that support inquiry learning and teaching. Such facilities include plenty of space, tables or desks with ample surface area, running water, and electrical outlets. Adequate equipment, media, and supplies need to be available and maintained in such a way that they are replenished and accessible to teachers without too much extra work.

Creative teachers can compensate for restricted classroom facilities and/or enrich even the best classroom environment by taking advantage of the learning opportunities available in outdoor environments, and with resource people, museums, nature centers, zoos, industries, and businesses.

Instructional Materials

Instructional materials should include a variety of resources that support a hands-on approach to instruction.

Instructional materials should include a variety of resources that support a hands-on approach to instruction. Textbooks typically focus on learning *about* science rather than encouraging active involvement *in* science, emphasizing description, explanation, and identification, rather than higher-order thinking processes.

Instead of or in addition to the judicious use of textbooks, middle-grades programs need to take advantage of a variety of resources, including manipulative materials that students interact with and activities that engage students and provide greater realism and concreteness.

Technology

Instructional technology is becoming increasingly more available for use in science teaching and learning -- and the quality is improving dramatically. While science teachers to date have made limited use of technology, opportunities will increase in the next few years. Several types of microcomputer-based courseware are available that can be used selectively to enhance science learning. Courseware types include: information processing, hypermedia, microcomputer-based laboratory, telecommunications, systems modelers, simulations, and tutorials. In addition, video courseware, including interactive video, is beginning to emerge as a powerful tool for learning science.

Time

Science learning occurs in many different ways -- during laboratories, museum visits, reading, math, and writing lessons. As science slips into different disciplines, the topics in the program are instructionally integrated, and students may study science and technology for a larger percentage of time than in previous programs. Yet it is important to ensure that the development of science concepts and skills is the focus of learning experiences for an average of one hour a day, with 50 percent of this time for experiential learning in the form of laboratories and activities. While increased time spent teaching science does not, in itself, guarantee higher achievement, greater amounts of time spent by students in active learning does (Stallings, 1975).

Inquiry learning and teaching calls for a variety of student grouping arrangements, with different teaching strategies for each.

Grouping

Inquiry learning and teaching calls for a variety of student grouping arrangements, with different teaching strategies for each. Grouping arrangements include full-class involvement, small-group or paired cooperative learning, and individual projects or independent study. Effective groups are designed to address the content to be learned, student interest, management of equipment and laboratory space, student abilities, and the need for some random divisions. Effective learning groups can greatly increase quality learning time.

Learning environments that incorporate most if not all of these features are ones that enhance the potential for quality science learning and teaching experiences for middle-grade students. They are ones that will support the kinds of curriculum, instruction, and assessment processes described in Chapter II.

Innovative Assessment

In Chapter II we described approaches to assessment that are compatible with our vision of science education for the middle grades, attending to the multiple goals for middle-level students. Some educators argue, however, that assessments should go beyond monitoring student learning and be learning experiences for students in their own right -- that tests should model instruction. This section briefly describes some experiments currently underway that are working towards these expanded goals for assessment, experiments that can guide and inspire similar experimentation in middle-grades classrooms.

Innovative Curriculum and Assessment from the Netherlands

One example of innovative assessment is that developed by de Lange and his colleagues (1987) for a secondary mathematics curriculum in the Netherlands. This effort has implications for middle-level science in the U.S. because the curriculum's focus is on making mathematics useful, particularly for those not proceeding to careers in mathematics. This is a real concern for middle-grades science teachers who know a large number of their students will not pursue science beyond what is required.

De Lange developed the following principles for effective assessments, which serve as criteria for judging assessment approaches:

DeLange's Principles for Effective Assessments

1. Tests should improve learning through motivating students by providing them with short term goals toward which to work, and with feedback concerning their learning process.
2. Tests should allow students to demonstrate what they know (positive testing) rather than what they don't know.
3. Tests should operationalize the goals of the curriculum. When, as in their mathematics curriculum, the goals include being able to produce and synthesize ideas, tests should provide the freedom of response required for measuring these outcomes.
4. Test quality is not primarily measured by the accessibility to objective scoring. While objective scoring is important, it should have certain limits.
5. Tests should fit into the usual school practice.

De Lange's assessments involve four different strategies that can be combined as appropriate. The **two-stage task** uses a first stage, short-answer test that measures lower-level outcomes in a traditional time-restricted manner. The teacher scores the test, indicates only the biggest mistakes, and hands it back to the students, who use the feedback to repeat the work at home over a designated time (perhaps three weeks). The students hand in the work and the teacher scores it again. The second stage follows the five principles listed above and is done by students at home. Findings indicate that, while there is a relatively wide spread in first-stage scores, that spread is greatly reduced in the second stage, with more students doing well. Further, students have enhanced self-confidence when they are able to improve in the second stage.

The second strategy is the **take-home task**. Following a fifty-minute written task, students are allowed to choose one out of five subjects to work on at home, either alone or in pairs.

The **essay task**, a third strategy, gives students an activity to do and reflect upon. In de Lange's work, he gave students a newspaper article with much numerical information and asked them to rewrite it using graphs, which called on students to use a wide range of mathematics skills and knowledge.

The **oral task**, the fourth strategy, uses an interview that begins with different questions for each student, depending on the expected performance level. A noted advantage is that this strategy reveals how much relevant information a student really needs to start solving an assigned problem. Some disadvantages of this strategy are time constraints and student nervousness.

De Lange recommends some combination of these assessment strategies, given that they measure different outcomes and that boys and girls show differential success with them. The strategies do, indeed, parallel the goals of the mathematics curriculum (which are similar to those we espouse for middle-grades science).

Profiling and Moderating Panels in Great Britain

Great Britain is developing national assessments that can be used by teachers for their instructional and evaluative purposes and also aggregated at the school level (Department of Education and Science and the Welsh Office, 1987). An interesting twist is that the final responsibility for decisions about the progress of individual pupils will rest with their teacher.

The emphasis of the new assessments is on developing profiles of each student on between four and six components. For each component, there are twelve attainment targets that have been identified, which are identical for all grade level tests (ages seven, eleven, fourteen, and sixteen) but take into account the expected growth in knowledge and skills. The assessments are intended to be like teachers' day-to-day assessments; they are directly concerned with what is being taught and are designed to reveal the quality of each pupil's performance irrespective of the performance of others.

To ensure comparability of the results, teachers use "moderation" meetings with teachers from other schools to discuss the progress of their groups of children, considering the spread of results from the tasks compared to the spread of results from their own assessments. In this way, teachers maintain final responsibility for decisions about their pupils' progress.

Performance Assessment in Connecticut

As part of a National Science Foundation grant to the Connecticut Department of Education, teachers from seven states are designing a set of performance tasks to assess high school students' attainment of science knowledge, attitudes, and skills, and their ability to work effectively in groups and to communicate their findings effectively. Criteria for developing effective tasks include:

Connecticut Criteria for Effective Tasks

1. The tasks should be based on essential rather than tangential aspects of the curriculum, i.e., on "big ideas".
2. The tasks should be authentic rather than contrived, using processes that scientists use, with outcomes of value to students.
3. The tasks should be rich rather than superficial, causing students to raise related questions, consider other problems, and make new connections.
4. The tasks should be engaging.
5. The tasks should require students to be active rather than passive.
6. The tasks should be integrative rather than fragmented, expecting students to bring together many separate pieces of knowledge.

One of the key areas of interest is the use of group tasks that take anywhere from a part of a class period to several weeks to complete. The project is developing experimental group tasks, establishing criteria for determining whether a task is appropriate for group work, and exploring different scoring strategies to address the issues of assigning grades from group tasks to individual students.

Portfolios in Vermont

The State Department of Education in Vermont is currently experimenting with the use of student portfolios for statewide assessment of writing and mathematics in grades four and eleven, and considering the use of portfolios in other areas, including science. Such portfolios will be used to provide data in areas not reasonably addressed through standardized tests. The content of the portfolios is meant to reflect evidence of a wide range of student knowledge and skills in both individual and group situations. They include evidence of student growth over time, reflections on students' thought processes, as well as a self-assessment of strengths and areas needing improvement.

Portfolios will include a few examples of a student's best work collected over a period of more than one year. Portfolios for science might also include write-ups of experiments, both assigned and student-designed; reports including science information; reports of a group activity or project; pictures of science inquiries; art work; a videotape of a student giving a presentation; and entries from the student's journal.

The Potential of Computers for Assessment

In an earlier section we noted several ways computers (and other technologies) can be used to enhance instruction. Here we suggest four computer applications that have particular potential for use in student assessment: item banks, simulations, telecommunications, and microcomputer-based science laboratories (MBLs).

Many teachers are currently using computers to develop **item banks** from which they can assemble a variety of tests; the format of these items is typically multiple choice. The promise of this use lies in the potential for exchange and quality control of items among teachers, provided the items are openly available.

Two kinds of **simulations** can be used for assessment. *Passive simulations* are like teacher demonstrations, where the students observe scientific phenomena. Computer simulations have many advantages, including the ability to reduce or elongate the time it takes for phenomena to occur; allowing students to observe phenomena that would require expensive, unwieldy, unavailable, or dangerous equipment; and enlarging or reducing the scale of phenomena to make them observable in the classroom. Such simulations may deepen the understanding of students about how things actually occur, making possible more complex analysis and evaluation activities. The simulations can become the stimuli for assessments that ask students to explain the phenomena and make and justify predictions about related phenomena.

Students' thinking can be tracked by programming the computer to keep records of the strategies they use to try out their solutions.

In assessment contexts, *active simulations* can create a hands-on environment in which students can be asked to solve complex problems by manipulating many of the variables involved in scientific phenomena. Different levels of abstraction, transfer, and application to real-world contexts can be incorporated in the assessment problems. Students' thinking can be tracked by programming the computer to keep records of the strategies they use to try out their solutions.

Telecommunications permits students from different locations to work together on a common problem. Sometimes this entails studying the effects of environmental variables on natural phenomena. As students manage data and consult their textbooks, teachers, and other experts, teachers are provided unlimited opportunities to monitor virtually any combination of students' scientific understandings and research and communication skills.

The use of sensors or probes in **microcomputer-based laboratories** allows students to conduct hands-on investigations, with the computer assisting in gathering and presenting data. MBLs provide many opportunities for students to develop scientific understandings and dispositions. Assessment opportunities arising from the application of MBLs are limited only by the teacher's time and inclination to make use of them. Records kept by students can provide a rich base for assessing their operational and conceptual knowledge as well as their thinking skills. Problems ranging in complexity and sophistication can be developed, and social skills can be assessed. Almost every strategy for assessing science that goes beyond paper-and-pencil, short-answer formats can benefit from the use of MBLs.

Innovation in assessment is a key to achieving our vision for middle-grades science education.

Many of the innovative assessment processes described in this section are still under development. In this there is good news and bad news. The bad news is they are not readily available for adoption and are not debugged and validated for use. But the good news is that a great deal of thinking has been done about what makes appropriate assessment for the important outcomes of middle-grades science education -- thinking that science teachers can take advantage of and use to start experiments of their own. Small experiments and adjustments in assessment perspectives and practice, made over time by those most influential in science learning -- classroom teachers -- have a great potential to make a difference. Innovation in assessment is a key to achieving our vision for middle-grades science education.

Professional Development for Teachers

Teachers are the key to real change in middle-grades science education, since they have the most influence on the immediate learning environment of students. It, therefore, stands to reason that the development of teachers needs to take a high priority, and the designs for teacher development opportunities need to incorporate state-of-the-art knowledge.

The purpose of staff development for middle-grades science teachers is to help them acquire the knowledge, skills, and beliefs described in Chapter II as part of our vision for science teaching and learning. This then defines the "content" of staff development.

The "process" of staff development needs to mirror what is known about effective learning for students, taking a constructivist perspective in which teacher learning is viewed as a dynamic process, one that is continuous and constantly changing. Teachers are provided with sufficient and appropriate experiences to incorporate new ideas and materials in their own knowledge base and their teaching strategies. They are helped to articulate their own conceptions of teaching and learning, giving them experiences to enhance or change those conceptions, and opportunities to apply their new learnings in a variety of situations.

These kinds of experiences do not take place in the typical staff development offering: a one-shot inservice workshop. Rather, they are part of staff development programs that feature a variety of approaches (Sparks & Loucks-Horsley, 1990), including:

- **Training.** The training approach is most frequently equated with staff development, which rarely includes all the components needed to be effective. These components are: (1) development of the theory and rationale behind the new behaviors to be learned; (2) demonstration or modeling; (3) practice in the training setting; and (4) guided practice in the classroom with feedback on performance. Because of the need for guided practice "back home," good training necessarily takes place over time and fosters meaningful collaboration on the part of its participants (Joyce & Showers, 1988).

- **Observation and assessment.** This approach involves the careful observation of teaching, with particular attention to certain behaviors, and open discussion of the results. A sequence of activities often includes: (1) agreeing on a focus for the observation, which may come from the teacher, the observer, or a framework established elsewhere; (2) the observation, with the observer recording behaviors as they occur or according to a predetermined schema; and (3) a conference during which the observation is discussed, strengths and weaknesses are assessed, and goals for the future and ways of achieving them are set. As a form of supervision, this approach has received much attention for its potential for formative rather than summative evaluation. As coaching, usually among peers, it encourages collaboration and experimentation.

- **Inquiry.** The inquiry approach incorporates such practices as action research and reflective inquiry, and as such it is highly attuned to the constructivist perspective. Teachers are supported to reflect on their own practice, gather data to better understand the phenomena of interest, and consider and enact changes based on careful analysis.

- **Curriculum and program development.** Another approach to staff development is the involvement of teachers in the development of new programs. Teachers begin with a problem or challenge -- for example, the curriculum is outdated, needs review, and is not being used; or student achievement or enthusiasm for science is low. Teachers, usually as a coordinated group, gather information, materials and other resources, consider existing knowledge about effective science teaching and learning, and develop and implement a new curriculum or program.

- **Individually guided staff development.** This approach is based on the assumption that individual teachers need different interventions to help them improve their practice. Here teachers, either as individuals or with others who share their interests or concerns, establish a goal and seek to achieve it through coursework, workshops, library research, visits, and other forms of self study. Self-determination and focused support by their principal, peers, or others in the use of their new knowledge or skills make this approach different from more traditional staff development.

Regardless of the approach(es) they use, effective staff development programs have these characteristics:

- They are collegial and collaborative, providing opportunities for teachers to work together in meaningful ways.

- They encourage experimentation and risk taking, incorporating and modelling a constructivist approach to learning.

- They draw on research for their content in such areas as effective classroom practices, the learning process, effective schools and organizations.

- They involve teachers in decisions about their own professional growth, through collaborative goal setting, implementation, and evaluation.

- They provide strong leadership, drawing on teachers as leaders as well as those in authority positions, and administrative support.

- They build in sufficient time for teachers to participate in staff development opportunities and to assimilate new learnings.

- They provide appropriate and adequate incentives and rewards.

- They incorporate principles of adult learning and the process of change into their designs.

- They integrate the goals of individuals, departments or curriculum areas, schools, and districts (Loucks-Horsley et al., 1987).

Staff development programs with these characteristics are needed for middle-level science teachers to develop the knowledge and skills necessary to improve science teaching and learning.

Organizational Context and Support

Rich classroom learning environments, innovative assessment techniques, and good staff development programs alone are insufficient to achieve what we envision for middle-grades science education, particularly if the school setting does not welcome and support new ways of working with students. We need to recall one of the lessons of the 1960s and 70s, a major time for innovation in science education. Then, many teachers who attended summer institutes returned enthusiastic and provisioned with new curriculum materials and approaches to transform their science teaching -- but trying to make meaningful changes in schools where nothing else had changed was often difficult, if not impossible. Principals balked, parents complained, facilities were not available. The skills, attitudes, and materials were there -- the setting was not.

This time must be different. We must address the question: what organizational features and structures need to be in place to achieve our vision of middle-grades science education?

One perspective is that the school itself must be the unit of change, for it is only at the school level that science learning can be related to other disciplines in ways that are meaningful for a particular group of middle-grade students. An alternative is to adopt an interdisciplinary team structure within the school, and empower the team with decision-making prerogatives for such things as scheduling, student assignments, and teaching and learning formats. Either way, the school (as opposed to the individual teacher or the district) plays an important role in fostering and coordinating changes.

For successful change to occur several conditions must exist at the school level:

- Clear, agreed upon goals and outcomes for all students.
- Adequate, appropriate resources for teaching science well, including time, staff, and materials.
- A conception of and support for staff development that extends beyond the occasional inservice workshop.
- Norms of experimentation, risk taking, collegiality, and collaboration.
- Teacher involvement in decision making.
- Strong leadership and support.

Schools for students in the middle grades need also to consider how they can support the special needs of young adolescents. For example, the middle-school concept includes special attention to integration, exploration, guidance, differentiation, socialization, and articulation.

What goes on in science classrooms is influenced greatly by the values, structures, supports, and expectations of the school, district, and state.

Strong leadership -- at the district and state as well as the building level -- is essential for fundamental change to take place. Effective leaders have a clear and compelling vision, a proactive leadership style, strong communication networks, and flexible strategies for achieving consistent long-range values and goals. They reflect on practice and possible alternatives while maintaining action amid uncertainty. To improve science learning in the middle-grades, leaders need to understand how schools can be designed to address the needs of young adolescents. They need to understand the importance of a curriculum that promotes depth in student thinking and problem solving. They need to be clear about the nature and ingredients of good science teaching, and they need to be collaborative.

What goes on in science classrooms is influenced greatly by the values, structures, supports, and expectations of the school, district, and state. Therefore, leaders at these levels can do much to further the realization of our vision for science education in the middle grades.

CHAPTER IV

Special Concerns

In this part, we take up two issues that are less central to achieving the vision for middle-grades science education described in Chapter II, but nonetheless influence its ultimate success. These issues are the need for and use of a new perspective on assessment for policy decisions, and the preparation of teachers for middle-grades science teaching.

Assessment and Policy

Our earlier discussions of assessment issues focused on those carried out by the classroom teacher in support of good science instruction and to evaluate the students' learning and performance. Yet, many tests, often referred to as "externally mandated tests", are used for broader policy purposes. Indeed, educational administrators, school board members, legislators, and other educational policy makers are increasingly turning to tests for information to assist them in monitoring outcomes, setting goals, allocating resources, and, most important, holding districts, schools, and even individual teachers accountable for the learning of their students. Currently, most tests given for policy purposes are entirely separate from the ones that teachers select or create to use in their own classrooms. However, these tests can have major direct and indirect effects on curriculum, instruction, and learning, and they merit close attention by anyone concerned with science assessment.

Improved tests that focus on the full range of intended learning outcomes could guide resource allocation, formulation of specific improvement goals, and expectations for science learning.

Many examples exist at the district, state, and national level of policy makers using test scores to make comparisons and judgments. When this happens the scores become important in their own right, and the testing becomes "high stakes." The scores become a factor in decisions about budgets, texts, curriculum frameworks and guidelines, and even the way students spend their time in classrooms. This can work against good science teaching if the tests do not value the "less is more" approach and the time spent in classrooms developing skills in science inquiry. But such tests can also work for good science instruction by focusing public attention on the need for reform and increased financial support. Improved tests that focus on the full range of intended learning outcomes could guide resource allocation, formulation of specific improvement goals, and expectations for science learning.

Improving Externally Mandated Tests

Since externally mandated tests appear to be here to stay, the focus should be on ensuring that they assess the full range of learning outcomes. This includes testing of performance and the use of open-ended formats, as well as substantially broadening the range of outcomes measured in written, forced-choice tests.

There are two reasons why alternative testing materials and response formats are needed. First, the education system changes in response to accountability mechanisms, and the format and outcomes emphasized by tests send clear messages about how curriculum and instruction need to change. Second, some of the most important outcomes of middle-level science education cannot be measured adequately using paper-and-pencil, multiple-choice items, for example, the ability to pose plausible hypotheses to explain patterns of experimental findings.

[I]mprovements are unlikely unless concerned parents, citizens, educators, and curriculum specialists insist on better tests, measuring a broader range of important learning outcomes.

Better multiple-choice questions can be constructed to measure a much broader range of outcomes than factual recall, but they take more time both to construct and for students to take. They often need to set up an actual problem associated with relevant factual knowledge. They almost always require the presentation of more elaborate stimuli than most questions measuring factual recall, including more text, figures, charts, graphs, and diagrams to describe the problem situation the students are asked to reason about. The success of such test items thus is complicated by the fact that they require a higher level of reading ability, and greater effort, attention, and motivation on the part of the student. Because they take longer to answer, fewer items can be administered in a given period of time, complicating reliability and validity.

Because of the effort needed and these obvious drawbacks to developing new, improved externally mandated tests, significant improvements are unlikely unless concerned parents, citizens, educators, and curriculum specialists insist on better tests, measuring a broader range of important learning outcomes.

Information Needs of Decision Makers

Valid interpretation of scores on externally mandated tests requires contextual information if policy makers are to use the results to improve students' achievement. In order to interpret why some districts, schools, or teachers did more or less well than others, Oakes (1989) suggests that it is important to examine student access to scientific knowledge; press for science achievement and participation; and professional conditions for science teaching. Thus data on the following variables may be useful: curricular goals, textbooks and other instructional resources, and teaching practices in the classrooms tested; student performance in prior years and in other content areas; characteristics of the communities in which the tests were given; students' opportunity to learn what is covered in the test (i.e., alignment of curriculum and test content); and teachers' formal training, both preservice and inservice.

If large-scale assessments are to help inform policy and ensure accountability, *both* the tests themselves and the background information providing a context for interpreting test performance must be sound, reliable, and comprehensive.

Preparing Teachers for Middle-Grades Science

In Chapter III we discussed the importance of strong staff development programs to help teachers currently in schools develop the knowledge and skills they need to implement our vision of science in the middle grades. Further, we argued that those development opportunities needed to be continuous, to contribute to teachers' learning throughout their careers. What about prospective teachers who are not yet in schools, but who are currently preparing to be teachers of future middle-grades youngsters? What should their programs be like so that they will be able to teach effectively in new ways and in new contexts tailored for the s :cial learning needs of young adolescents?

Prospective teachers, like all learners, need programs that take a constructivist approach to teaching and learning, providing continuous opportunity to reflect upon their emerging practice as teachers. The programs need to include both science content and teaching strategies, but also to integrate the two, so that the special pedagogy required to teach science (i.e., pedagogical content knowledge) is developed (Shulman, 1986). Prospective science teachers need a broad background in the humanities, social sciences, mathematics, and the fine arts in order to help design interdisciplinary and connected units of study. At least two years of undergraduate study should focus on this broad background. Teachers also need content depth in at least one field of science, although two subject-area specialization often is recommended for middle-level teaching (National Science Teachers Association, 1987).

More important than how many science courses are taken, however, is the nature of the courses themselves, for "we teach as we are taught".

More important than how many science courses are taken, however, is the nature of the courses themselves, for "we teach as we are taught". University science courses need to model good pedagogy. They should:

- teach science the way it is practiced by scientists;
- be interdisciplinary and connect their field to related fields;
- ground the discipline in its philosophical assumptions and context; and
- help students relate the content to societal issues (American Association for the Advancement of Science, 1990).

These courses should focus relatively more time on fewer concepts than traditional courses, requiring close collaboration with professors of disciplines other than science. They should prepare teachers with basic facts and principles of science, as well as thinking skills and the ability to access additional information when needed.

Prospective teachers also need to understand the nature of young adolescents. They need grounding in:

- the intellectual, physical, social, and emotional nature of young adolescents;
- basic theories of learning underlying methods of teaching young adolescents;
- the nature of schooling in general and the middle-school concept in particular; and
- how to work successfully with students of differing backgrounds and abilities.

Teachers need to develop interpersonal and leadership skills for their multiple roles as managers, leaders, role models, advisors, language teachers, and as collaborators with a wide variety of people.

Prospective science teachers also need a thorough knowledge of pedagogical principles that promote science learning at the middle-level, including strategies that complement the social nature and cognitive abilities of students; keep students interested in and excited about science; involve students actively in making sense of scientific and technology concepts; and address the learning needs of widely diverse students.

Teachers need to develop interpersonal and leadership skills for their multiple roles as managers, leaders, role models, advisors, language teachers, and as collaborators with a wide variety of people.

Prospective teachers need increasingly more involved, involving, and responsible field experiences in middle-level schools during their entire academic training, not just through a final student-teaching semester. Such clinical guidance should extend through the first year of teaching, with a supported induction year that includes the opportunity to work with a mentor and a less-challenging teaching load than more experienced teachers.

CHAPTER V

Summary and Recommendations

It is difficulty to summarize in a simple, brief manner the key points made by the Center's reports on middle-level science education -- simply because they are so numerous and so connected one to another. To us, this emphasizes one more time the systemic nature of the changes that need to occur if science for young adolescents is indeed to be improved in meaningful ways. Change needs to occur across the system, in curriculum, instruction, assessment, teacher development, and organizational structure; it needs to occur in every organizational entity that is involved in science education, including classrooms, schools, districts, institutions of higher education, intermediate support agencies, state and federal agencies, and professional associations; and it all needs to be coordinated, which implies seeking a common vision of what good science education is and working closely together towards that vision.

Each of the Center's technical reports contains sections that describe in detail their conclusions and recommendations. Here we have chosen to summarize these in two parts. In the first part we list the key principles or messages from the three middle grades reports. In the second part we list some recommendations for several audiences, using examples of specific recommendations from the reports. For a full set of recommendations, we refer the reader to the individual reports listed in the Foreword of this report.

Curriculum and Instruction

Principle 1. Science programs for young adolescents should be rigorous and challenging. They should be sensitive to the emotional and personal development of students, not by coddling them, but by relating science and technology learning to students' questions and providing for active involvement.

Principle 2. A framework for science curriculum and instruction is needed that balances the two goals of middle-level education: (1) personal development of students, and (2) learning and being able to apply the concepts, skills, and attitudes of science and technology.

Principle 3. Goals for middle-level science education should include development of students' (1) ability to identify and clarify questions and problems about the world; (2) thinking skills; (3) knowledge base; (4) understanding of the history and nature of science and technology; and (5) understanding of the limits and possibilities of science and technology in explaining the natural world and solving human problems.

Principle 4. Middle-level science curricula should incorporate major concepts such as cause and effect, change and conservation, and diversity and variation. Scientific "habits of mind" such as being skeptical and relying on evidence need to be included as well as skills in gathering information, answering questions and solving problems, making decisions, and taking action. These concepts, attitudes, and skills can be integrated through themes or topics that build upon adolescents' experiences, capture their interest, are interdisciplinary, and include both science and technology-related activities.

Principle 5. To support students in constructing their knowledge of science and technology, a four-stage teaching/learning model should be used, which includes (1) invitation, (2) exploration, discovery, creation, (3) proposing explanations and solutions, and (4) taking action.

Principle 6. Middle-level science education requires a learning environment that includes flexible schedules, cooperative learning groups, flexible physical space, a variety of instructional materials, technology, and adequate time for science.

Assessment

Principle 1. Assessment must be challenging and interesting. Classroom, school, and large-scale assessments must reflect the educational purposes for science at the middle level and the growth and development of young adolescents.

Principle 2. Assessment must reflect science instruction, which itself should reflect the goals for science learning, which in turn should reflect good science. Assessment must include both science knowledge and the laboratory, intellectual, and social skills crucial to the learning and doing of science.

Principle 3. Reporting systems should reflect science assessments with fidelity.

Principle 4. Educators involved at every level need to understand the new conception of assessment and carry out relevant strategies, and their clients' and audiences' need to understand the purposes and results.

Principle 5. Improving the quality of the science program in a school or district requires information on context as well as on outcomes.

Principle 6. Further knowledge and new techniques must be created so that assessments of science learning and performance are faithful to the goals of science education and to the nature of science.

Teacher Development and Support

Principle 1. Science teachers for young adolescents need special knowledge, skills, and attitudes. These are: knowledge of students in the middle grades; knowledge of science and technology content and skills in "doing" science; knowledge and skills in science pedagogy, general pedagogy, and classroom management; knowledge of the middle-school concept; and professional attitudes and commitment.

Principle 2. Staff development opportunities for middle-level science teachers should reflect the constructivist perspective, i.e., they should provide opportunities for teachers to make sense of their experiences, construct meaning from new information, and form theories to explain the worlds of teaching and learning, as well as science and technology.

Principle 3. Staff development for middle-level science teachers should be continuous and on-going; encourage choices that match teachers' interests, stages of development, and competence; encourage collaboration and experimentation; and use formats in addition to traditional workshops (e.g., peer coaching, institutes, action research).

Principle 4. Schools must become settings that encourage continuous learning on the part of their staffs, collaboration, and experimentation. They must provide teachers with adequate and accessible resources, time for planning and reflection, and opportunities to take part in decision making that affects their students.

Principle 5. District and school leadership must take responsibility for establishing school settings where good science instruction can thrive. This includes providing clear direction and vision, instructional leadership, strong communication networks, and moral and material support for teachers.

Principle 6. Preparation programs for prospective middle-level science teachers need to address directly the required knowledge and skills (see Principle 1), provide coursework taught in a way that models the constructivist approach to learning, and provide a wide variety and increasingly demanding set of clinical experiences for prospective teachers, including support during the teacher's first year.

Recommendations

What Should the Federal Government Do?

In part because of the National Education Goals, the role of the federal government in supporting change in science education is more critical than ever before. Key roles for the federal government include:

- Continue to keep science learning as a high priority for the nation's schools through visibility and funding.

- Promote a shared vision of the attributes of good science education, a vision that is beginning to emerge from efforts of such organizations as our Center, the American Association for the Advancement of Science, and National Science Teachers Association.

- Support experiments in a wide range of areas of science education, including the development of curriculum, materials, programs, and assessment strategies, and programs for preparation and ongoing development of teachers, administrators, and other staff who contribute to science learning. Focus special effort on changing the experiences of underserved student populations. These experiments must have strong evaluation and dissemination components, and participate actively in a national network supported by the federal government to enhance development, evaluation, and dissemination of the results of its experiments.

- Support a strong dissemination system that includes clearinghouse(s), a variety of structures for communication and outreach, and strong implementation assistance for schools.

- Support research in middle-level science learning and teaching, with particular emphasis on how instruction, and what kinds of science activities and content teaching specifically, can help develop formal operational thinking in young adolescents with different backgrounds, competencies, and educational experiences. Through fine-grained longitudinal studies, work to establish linkages between science programs and teaching variables and science learning outcomes for different student groups. Focus special attention on studies to illuminate issues related to the underrepresented in science.

- Develop approaches to and encourage the use of large-scale assessments that support the efforts of classroom and school assessments to reflect the range of educational purposes at the middle level and the growth and development of young adolescents.

What Should State Agencies Do?

- Through a consensus process, develop a state curriculum framework that incorporates a vision for middle-level science education and goals that include the kinds of science knowledge, skill, and attitude development described in this report. This framework then becomes a focus for other parts of the system.

- Promote, through dissemination efforts and funding criteria, curricula, materials, and programs for middle-level science that adhere to the curriculum framework.

- Through a consensus process, agree on assessment strategies and reporting strategies throughout the state, with a focus on attainment of the framework's goals. Provide technical assistance to ensure that comparable procedures are used for administration of assessment exercises and interpretation and reporting of results.

- Base certification of teachers by institutions of higher education on teachers' ability to implement the framework in their classrooms.

- Support professional and organizational development opportunities for school and district teams involved in planning and implementing the framework.

What Should Institutions of Higher Education Do?

- Ensure that the content of teacher certification programs (including preservice and inservice) focuses on the development of the knowledge, skills, and attitudes that are described in this report as required by middle-level teachers.

- Change the process of course taking to incorporate a constructivist perspective on learning, making courses, particularly science courses, more investigatory and less didactic. Model communities of inquiry in which teachers are encouraged to generate new questions, ask clarification questions, and discuss their tentative hunches and hypotheses with others. Include field experiences for teachers that range from working with scientists through working in a variety of middle-grades settings.

- Give teachers opportunities to practice a variety of strategies for monitoring their own level of understanding through individual journals, discussions, and opportunities to compare their own thinking, through discussion and reading, with that of practicing scientists. Similarly, provide teachers opportunities to practice and develop a variety of strategies for assessment of science learning by their students.

- Make special efforts to recruit and support the development of prospective teachers who represent and have a special commitment to underserved student populations.

- Prepare school administrators to initiate and manage change through development of shared visions, collaborative planning and decision making, and focused support for instruction that represents good science teaching and learning.

What Should Building and District Administrators Do?

(Note: This includes science curriculum leaders in the building or district, such as science supervisors and curriculum coordinators.)

- Develop a working understanding of the key principles of middle-level science education in order to promote an organizational vision of learning and teaching, communicate with the public, and monitor and support classroom practice.

- Through a consensus process, begin with the state curriculum framework (or, if none exists, frameworks such as the one described in the Center's reports or by the American Association for the Advancement of Science or the National Science Teachers Association) and specify a set of district goals and objectives for middle-level science education.

- Support teachers with the necessary resources for facilitating district goals in science, including materials, equipment, and staff development. Support their participation in professional associations and networks that focus on improved science teaching and learning.

- Pay particular attention to the integration of instruction and assessment, both by supporting appropriate staff development and ongoing support for teachers, and by educating the community and local school board about the strengths of the approach.

- Create within buildings and district norms of collaboration and experimentation, and of shared accountability and decision making. At the middle level, this can be done by increasing the autonomy of teaching teams responsible for a given number of students, especially in terms of scheduling, assignment of students, and instructional strategies used.

- Promote the idea that all students can learn both basic and sophisticated science concepts and intellectual skills.

What Should Teachers Do?

Teachers are not listed here last because they are least important. Rather, we recognize that they are the key to improvement in their students' learning. But in order to actually make improvements, teachers need the kinds of direction and support described above: often they experience such significant barriers to change that they are unable to pursue changes they value. With other parts of the system acting on the above recommendations, teachers will more readily be able to carry out their parts.

- Use an approach to science teaching that incorporates the state and/or district frameworks, attending to the range of knowledge, skill, and attitude outcomes appropriate for young adolescents, selecting topics and themes that are of high interest, and implementing a teaching model that supports active construction of new understandings and skills. Model the integration of scientific knowledge, skills, and attitudes for students.

- Design science learning activities that integrate disciplines, within and outside of science, incorporate both individual and group tasks, and provide students with tools and opportunities to assess the quality of their own work.

- Integrate assessment and instruction, gathering assessment data as students are engaged in science activities. Assess the wide range of science learning outcomes, using a variety of sources, such as observations, oral presentations, written reports, production of computer or constructed models, drawings, and research efforts in and out of school. Use assessment data to modify and plan for instruction.

- Gather self-assessment data to better understand the impact of science teaching on students, with special attention to the classroom experiences of female and minority students traditionally disaffected by their science learning experiences.

- Get involved in developing strategies to gather, analyze, and portray assessment information that will be meaningful to parents, communities, and policy makers.

- Model continuous learning by taking part in staff development opportunities; model a commitment to investigation through conducting an action research project that involves students directly. Contribute to growth of other teachers by participating in curriculum and program development, conducting training and support for changes in science teaching, and serving as a mentor for a beginning teacher (or one new to science or middle-level students).

Summary

This set of recommendations is just a partial list of the kinds of actions that need to be taken to make real improvement in middle-level science education a reality. But it is certainly a good start. Listing the recommendations separately for different role groups should not imply that these actions can or should take place independently. On the contrary, if change is not seen as systemic -- involving all parts of the system simultaneously and paying special attention to the connections among them -- no change will ultimately occur.

Given the current state of science education for young adolescents, the degree of change called for is indeed high. Yet the time is ripe, for the education community knows more now about what good science education is and how to get there. Thoughtful and skillful science leaders at all levels can take advantage of the current public pressure to muster the resources and the support needed to make and maintain the necessary changes. We hope this report provides some ideas for where to start.

REFERENCES

American Association for the Advancement of Science. (1989). *Project 2061: Science for all Americans*. Washington, DC: Author.

American Association for the Advancement of Science. (1990). *The liberal art of science: Agenda for action*. Washington, DC: Author.

Anderson, C.W. (1987). Strategic thinking in science. In *Strategic thinking and learning: Cognitive instruction in the content areas*. Alexandria, VA: Association for Supervision and Curriculum Development, and Association of Teacher Educators, and New York, NY: Macmillan.

Bybee, R.W., Buchwald, C.E., Crissman, S., Heil, D.R., Kuerbis, P.J., Matsumoto, C., & McInerney, J.D. (1990). *Science and technology education for the middle years: Frameworks for curriculum and instruction*. Andover, MA: The National Center for Improving Science Education.

Carnegie Task Force on Education of Young Adolescents. (1989). *Turning points: Preparing American youth for the 21st century*. Washington, DC: Carnegie Council on Adolescent Development.

Carnegie Forum on Education and the Economy. (1986). *A nation prepared: Teachers for the 21st century*. New York: Carnegie Corporation.

Cawelti, G. (1988). Middle schools a better match with early adolescent needs, ASCD survey finds. *Curriculum Update*. Alexandria, VA: Association for Supervision and Curriculum Development.

Champagne, A.B., Klopfer, L.E., & Gunstone, R.F. (1985). Effecting changes in cognitive structures among physics students. In A.L. Pines, and West, F.H.T. (eds.), *Cognitive structure and conceptual change*. New York, NY: Academic Press.

deLange, J. (1987). *Mathematics insight and meaning.* Utrecht, the Netherlands: OW & OC.

Department of Education and Science and the Welsh Office. (1987). *National curriculum: Task group on assessment and testing: A report.* Great Britain: Author.

Driver, R. (1981). Pupils' alternative frameworks in science. *European Journal of Science Education*, 3(1):93-101.

Dunn, R., & Dunn, K. (1978). *Teaching students through their individual learning styles: A practical approach.* Reston, VA: Reston Publishing.

Goodlad, J.I. (1984). *A place called school: Prospectus for the future.* New York, NY: McGraw-Hill.

Hodgkinson, H.L. (1985). *All one system. Demographics of education, kindergarten through graduate school.* Washington, DC: Institute for Educational Leadership.

Hurd, P.D. (1987). *The middle school as an institution: Implications for an education in the sciences.* New York, NY: Carnegie Corporation.

Johnston, J.H., & Markle, C.G. (1986). *What research says to the middle level practitioner.* Columbus, OH: National Middle School Association.

Joyce, B., & Showers, B. (1988). *Student achievement through staff development.* New York: NY: Longman.

Lapointe, A.E., Meade, N.A., & Phillips, G.W. (1989). *A world of differences: An international assessment of mathematics and science.* Princeton, NJ: Educational Testing Service.

Linn, M.C. (1986). *Establishing a research base for science education: Challenges, trends, and recommendations.* Report of a national conference. Berkeley: Lawrence Hall of Science and University of California at Berkeley.

Loucks-Horsley, S., Grennon-Brooks, J., Carlson, M.O., Kuerbis, P.J., Marsh, D.D., Padilla, M., Pratt, H., & Smith, K.L. (1990). *Developing and supporting teachers for science education in the middle years.* Andover, MA: National Center for Improving Science Education.

Loucks-Horsley, S., Arbuckle, M.A., Dubea, C., Harding, C.K., Murray, L.B., & Williams, M.K. (1987). *Continuing to learn: A guidebook for teacher development.* Andover, MA: The Regional Laboratory for Educational Improvement of the Northeast & Islands.

Malcom, S.M., Aldrich, M., Hall, P.Q., Boulware, P., & Stern, V. (1984). *Education in the sciences -- equity and excellence: Compatible goals.* Washington, DC: American Association for the Advancement of Science.

McEwin, C.K., & Alexander, W. (1987). *Preparing to teach at the middle level.* Columbus, OH: National Middle School Association.

McPartland, J.M. (1987). *Balancing high quality subject-matter instruction with positive teacher-student relations in the middle grades: Effects of departmentalization, tracking, and block scheduling on learning environments.* Report No. 15. Baltimore: Johns Hopkins University.

Mullis, I.V.S., & Jenkins, L.B. (1988). *The science report card: Elements of risk and recovery.* Trends and achievement based on the 1986 National Assessment of Educational Progress. Princeton, NJ: Educational Testing Service.

National Assessment of Educational Programs. (1987). *Learning by doing.* Princeton, NJ: Educational Testing Service.

National Commission on Excellence in Education. (1983). *A nation at risk.* Washington, DC: Government Printing Office.

National Middle School Association. (1982). *This we believe.* Columbus, OH: Author.

National Science Teachers Association. (1987). *Science education for middle and junior high students.* Washington, DC: Author.

Oakes, J. (1989). School context and organization. In R.J. Shavelson, L.M. McDonnell, and Oakes (eds.), *Indicators for monitoring mathematics and science education: A Sourcebook.* Santa Monica, CA: RAND Corporation.

Oakes, J. (1990). *Lost talent: The underparticipation of women, minorities, and disabled persons in science.* Santa Monica, CA: RAND Corporation.

Oakes, J., Ormseth, T., Bell, R., & Camp, P. (1990). *Multiplying inequalities: The effect of race, social class, and tracking on students' opportunities to learn mathematics and science.* Santa Monica, CA: RAND Corporation.

O'Brien, T.C. (1989). Some thoughts on treasure-keeping. *Phi Delta Kappan*, 70(5):360-364.

Offer, D., Ostrov, E., & Howard, K. (1981). *The adolescent: A psychological self-portrait.* New York, NY: Basic Books.

Raizen, S.A., Baron, J.B., Champagne, A.B., Haertel, E., Mullis, I.V.S., & Oakes, J. (1990). *Assessment in science education: The middle years.* Andover, MA: National Center for Improving Science Education.

Shulman, L.S. (1986). Those who understand: Knowledge growth in teaching. *Educational Researcher*, 15(2):4-14.

Sparks, D., & Loucks-Horsley, S. (1990). Five models of staff development. In R. Houston (ed.), *Handbook of research on teacher education.* Reston, VA: The Association for Teacher Educators.

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

Superintendent's Middle-Grade Task Force. (1987). *Caught in the middle: Educational reform for young adolescents in California public schools.* Sacramento, CA: California State Department of Education.

U.S. Department of Commerce, Bureau of the Census. (1987). *Statistical abstract of the United States, 1988.* Washington, DC: U.S. Government Printing Office.

U.S. Department of Education. (1986). *What works: Research about teaching and learning.* Washington, DC: Author.

Weiss, I.R. (1987). Report of the 1985 and 1986 national survey of science and mathematics education. Washington, DC: National Science Foundation.

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

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

BSCS
The Biological Sciences Curriculum Study
Colorado Springs, Colorado