DOCUMENT RESUME

ED 347 061 SE 052 044

AUTHOR	Bybee, Rodger W.; And Others
TITLE	Science and Technology Education for the Middle Years: Frameworks for Curriculum and Instruction.
INSTITUTION	Biological Sciences Curriculum Study, Colorado Springs.; National Center for Improving Science Education, Andover, MA.; NETWORK, Inc., Andover, MA.
SPONS AGENCY	Office of Educational Research and Improvement (ED), Washington, DC.
PUB DATE	90
CONTRACT	R168B80001
NOTE	152p.; For related documents, see ED 314 237, SE 051 821, and SE 052 043.
PUB TYPE	Guides - Non-Classroom Use (055) -- Reference Materials - Bibliographies (131) -- Viewpoints (Opinion/Position Papers, Essays, etc.) (120)
EDRS PRICE	MF01/PC07 Plus Postage.
DESCRIPTORS	*Educational Environment; *Educational Improvement; Intermediate Grades; Junior High Schools; *Middle Schools; *Science Curriculum; *Science Education; Science Instruction; Science Teachers; Teacher Education

ABSTRACT

In the rising tide of reports proclaiming the need to reform various aspects of education, middle level education has been frequently overlooked. The Study Panel on Curriculum and Instruction of the National Center for Improving Science Education recognizes the critical development that occurs during early adolescence and the current reform toward middle schools. This report is a set of policy recommendations for science curriculum and instruction in middle level schools. Because this report's focus is on science education in middle-level schools, it is more concrete than other national reports. Chapters include: (1) "Introduction," a discussion of the early adolescent learner; (2) "Middle Level Education," a discussion of the history and structure of middle schools; (3) "Science Education at the Middle Level"; (4) "A Conception of Science and Technology for Middle-Level Education"; (5) "Science and Technology Education: Goals for the Middle Level"; (6) "Science and Technology Education: Knowledge, Attitudes, and Skills for the Middle Level"; (7) "Learner-Based Instruction"; (8) "The Learning Environment"; (9) "A Framework for Middle-Level Science and Technology Curriculum and Instruction"; and (10) "Summary and Conclusions." Each chapter contains specific conclusions and recommendations. An annotated bibliography and a list of 124 references are appended. (CW)

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

---

Rodger W. Bybee, Chair
C. Edward Buchwald
Sally Crissman
David R. Heil
Paul J. Kuerbis
Carolee Matsumoto
Joseph D. McInerney

The National Center for Improving Science Education

A Partnership Between

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

and

BSCS
The Biological Sciences Curriculum Study
Colorado Springs, Colorado

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

Rodger W. Bybee
C. Edward Buchwald
Sally Crissman
David R. Heil
Paul J. Kuerbis
Carolee Matsumoto
Joseph D. McInerney

The National Center for Improving Science Education

A Partnership Between

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

and

BSCS
The Biological Sciences Curriculum Study
Colorado Springs, Colorado

1990

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 science curriculum, science teaching, and 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, and develops practical resources for policymakers and practitioners. Bridging the gap between research, practice, and policy, the Center's work is intended to promote cooperation and collaboration among organizations, institutions, and individuals committed to the improvement of science education.

The Center, a partnership between The NETWORK, Inc., of Andover, Massachusetts and Washington, D.C., and the BSCS (Biological Sciences Curriculum Study) of Colorado Springs, Colorado, is funded by the U.S. Department of Education's Office of Educational Research and Improvement. For further information on the Center's work, please contact The NETWORK, Inc.; 300 Brickstone Square, Suite 900; Andover, Massachusetts 01810.

To order copies of the Center's reports for the elementary and middle years, or the Center's integrative reports, please contact the Publications Department, The NETWORK, Inc.; 300 Brickstone Square, Suite 900; Andover, Massachusetts 01810. Bulk order discounts are available.

This report is based on work sponsored by the Office of Educational Research and Improvement (OERI), U.S. Department of Education, under grant number R168B80001. The content of this report does not necessarily reflect the views of the OERI, the Department, or any other agency of the U.S. Government. © The NETWORK, Inc., 1990.

Foreword

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

The synthesis on curriculum and instruction herein was derived with the help of the study panel, whose members are listed in the back of this report. We gratefully acknowledge the help provided by those who have supplied materials, offered recommendations, and made suggestions for this report. Although the list is too long to acknowledge each contribution individually, we acknowledge Don Joiner, Elliott Asp, and the staff of Challenger Middle School in Colorado Springs, for their introduction to middle schools. We gratefully appreciate Michael Padilla of the University of Georgia and Steve Rakow of the University of Houston, who acted as outside evaluators of the report, for their critical comments. We also thank Dorothy Gabel for her extensive review. Special acknowledgements are also due to the support by the National Center's monitors at the U.S. Department of Education: John Taylor and Wanda Chambers. We are indebted to Barbara Brandt for her early work preparing materials and meetings, and to Judy Martin for her review and synthesis of materials and preparation of the annotated bibliography. We acknowledge the work of Sandy Keller who pulled the numerous pieces of this report together, Yvonne Wise, who improved the report by pointing out errors and inconsistencies, and Robert Warren who edited the report.

Two other panels have produced companion reports on assessment and on teacher development. A summary report integrating all three documents is available from the National Center. This integrative report will be supplemented by an implementation guide for state and district policymakers and practitioners.

The National Center, a partnership between The NETWORK, Inc., of Andover, Massachusetts, and the Biological Sciences Curriculum Study (BSCS) of Colorado Springs, Colorado, is funded by the U.S. Department of Education's Office of Educational Research and Improvement. Members of the National Center's Advisory Board are listed in the back of this report For copies of this report, or further information on the National Center's work, please contact Audrey Champagne, Co-Director, or Senta Raizen, Co-Director, National Center for Improving Science Education, 1920 L Street, Suite 202, Washington, D.C. 20036, or Susan Loucks-Horsley, Associate Director, National Center for Improving Science Education, The NETWORK, Inc., 300 Brickstone Square, Suite 900, Andover, Massachusetts 01810.

Preface

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

In the rising tide of reports proclaiming the need to reform various aspects of education, there has been little attention to middle-level education. Notable exceptions to this statement include the Carnegie report *Turning Points* and the California report *Caught in the Middle*. While the numerous commissions and reports give little attention to the unique education needs of early adolescents there is a significant movement of middle-level educators and physical facilities called middle schools. The panel recognizes the critical development that occurs during early adolescence and the current reform toward middle schools. Yet, thus far, the middle school reform movement has not thoroughly addressed the particular issues of the disciplines, in our particular case, that of science.

This report is a set of policy recommendations for science curriculum and instruction in middle-level schools. Because this report's focus is on science education in middle-level schools, it is more concrete than other national reports. Just as the study panel that prepared the report went through a process of reviewing the data and translating the data into a policy statement, so too must those who use the report consider the unique characteristics of the school districts, teachers, and students for whom they plan to develop and implement new programs.

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

The study panel has done its best to bring educational reform in science programs for middle-level schools one step closer to reality. But, the final step is perhaps the most difficult — translating ideas for reform into practice.

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

Contents

Chapter I

Introduction

The Early Adolescent Learner

Developing a description of the early adolescent has challenged educators and psychologists for years. The need to match adolescents' characteristics with appropriate curriculum and instruction is an even greater challenge. Consequently, both the individuals (students aged 10-14 years) and the educational programs developed for them have been caught in a space and time referred to as "middle." This designation, by nature of its root meaning, results in definitions and characteristics that are traditionally based on either elementary or secondary terminology, expectations, and trends. Yet, as illustrated in the vignettes in this report, "middle" also means transition, where by youth are experiencing change and maturation that will eventually lead to adult behaviors, opinions, and skills. Early adolescents are neither children nor adults, yet they are individuals destined to experience the human life cycle. As Joan Lipsitz (1977) points out, renewed interest in a more holistic view of development and education gives us a philosophical and a sociological framework for recognizing transition as a stage in and of itself. Since the 1960s, as we increased our understanding about the stages of early childhood and later adolescence and simultaneously developed comprehensive school programs of elementary and secondary education, a concept of a "middle school" emerged and with it a clearer description of the individuals who might attend such a school.

Students between the ages of 10 and 14 years of age are an excitable, curious, and intense group. They are also tremendously diverse and varied. This variation is indicative of the significant physical, psychological, and sociological changes occurring in each individual at this stage. Moreover, the often described "roller coaster" of emotions and self-esteem during these years is a natural consequence of having a group of similarly aged individuals watching themselves and each other go through these tremendous changes. These extraordinary dynamics and the general characteristics of early adolescents, viewed in light of their educational and developmental interests and needs, must be better understood by educators who design curriculum materials and instructional strategies to assist and enrich adolescent learners.

The vignettes included in this report provide a variety of characterizations of the middle-level learner, and the learning environments that may contribute to the success of those learners in both formal and informal settings. The panel chose this format of descriptive example to demonstrate the importance of context when discussing middle-level learners. The individual characteristics of each student will determine which techniques, topics, and format of presentation are most effective. Conversely, selecting of certain topics, allowing for personal expression, and planning a variety of approaches will create a learning environment where individual characteristics become more evident. When we view science and technology education as a dynamic process involving both learner and learning facilitation, we begin to form a clearer understanding of how this education can be improved. In this section we briefly list some of the characteristics that best define a middle-level learner. We also describe the context — home and school factors — within which middle-level youngsters find themselves. This information complements vignettes throughout the report.

During early adolescence, individuals are undergoing rapid and variable changes. There are changes in physical characteristics, social relationships, emotional needs, and intellectual capacities. These changes are made more complex by home and school settings that threaten young adolescents' success at school. To help unravel this complex and interrelated set of characteristics, it is useful to review the separate components.

Physical Development

Growth is both rapid and disproportionate.

One of the most dramatic aspects of adolescence is the change in physical growth. During adolescence, individuals experience significant changes in growth. These growth spurts occur in all youth; the variation and duration varies from one individual to the next. In girls, this spurt can begin anywhere from 10 to 13 years of age, while in boys, the onset is usually between 12 to 15 years of age.

Average height gain is roughly two to four inches per year, with corresponding weight gains of 8-10 pounds per year. Often feet or hands will grow faster than other body parts, resulting in difficulties in coordination and dexterity, and bone growth may exceed muscle growth, resulting in injury or intermittent periods of strength and fragility.

In addition, variation among individuals of the same age and grade level may be as much as six inches in height and 60 to 70 pounds, with girls usually maturing about two years earlier than most boys.

Metabolic swings cover the full range from hyperactivity to fatigue from one day to the next and on a smaller scale several times a day.

As one might expect, this is a consequence of both physical and psychological phenomena. While bone growth may lead to pain and restlessness (especially sitting at a cramped school desk), hormonal changes may lead to sporadic "adrenalin spurts" (necessary for healthy growth but difficult if you're in the middle of a science activity). Nutrition and digestion are also intensified and "hunger pains" are often over-compensated for by eating excessive amounts of junk food. This overtaxes the digestive system, and when coupled with hormonal change, increased perspiration and a naive conception of personal hygiene can result in offensive odors, acne, and a level of self consciousness that may result in embarrassment and fear.

Sexual development and activity (or lack thereof) results in intense anxiety and concern.

This area of physical change impacts the psychological and sociological aspects of an adolescent's development as well. Any deviation from the norm is considered unacceptable. Since variation within the population prevents a clear "norm" from emerging, the individuals themselves define the baseline through experience, which leads to naive beliefs and experimentation. Research shows a substantial increase in teenage pregnancy in recent years, the most marked increases occurring in girls under age 15 (Hodgkinson, 1985).

Psychological Development

During the ages of 10-14 most individuals will experience changes in patterns of reasoning.

During adolescence, the consequences of intellectual and cognitive activity are most profound. Early adolescents are often characterized as passing from concrete operational thinking to formal operational thought, using Piaget's designations. This change opens the doors to abstract reasoning, problem-solving, and reflexive thinking and contemplation. The educational difficulty occurs when both the learner and the teacher begin to rely on a certain acceleration of capacity for abstract thinking. In any one middle-level classroom, it is possible to find students who have difficulty classifying objects, who demonstrate patterns of logical reasoning only about concrete situations, and those who think quite abstractly. The National Center's companion report on assessment (see Raizen et al., 1990) contains an extended discussion of intellectual development.

Displays of erratic and inconsistent behavior, short attention spans, and indecision are characteristic of this period.

The ability to compare options and alternatives is a reflection on both the mental maturation of the early adolescent, as well as the individual's desire to act independently. Attempts to match independence with responsible action, appropriate behavior, and patience are not always on target. In addition, this reflexive thinking gives rise to a clearer definition of particular learning styles and preferred modalities. When learning styles are not met with appropriate instructional strategies and scheduling, confusion and disinterest may result.

Curiosity and the desire to learn often exceed the opportunity of the moment.

Individuals at the middle level are insatiable when it comes to questions, concerns, willingness to experiment, and their desire to know. Egocentrism is balanced by peer and adult interaction and is fueled by the increased ability to transpose self and situations through creative imagination. Uninhibited and urgent in their approach, young adolescents will often confuse reprimands with a personal rejection. This can lead to self rejection and withdrawal — the antithesis of this period — yet a common consequence of not "fitting in" with the situation at hand.

The early adolescent can be characterized as wanting to know everything and having no time to learn, or, interested in virtually everything but not in anything for very long.

Sociologic Development

Adolescence is a period when individuals redefine their relationships with adults and peers. Individuals focus on their emerging beliefs concerning sexuality, religion, drugs, and schools. Important to this discussion is the point that individual behavior should not be perceived by educators as intentionally rebellious, but rather as an essential and normal process of development during which the student is restructuring his or her knowledge (Kagan, 1971).

Peer influence, competition, acceptance, and the consequences of choice are all strong pressures for change.

As a part of their transition, early adolescents begin to transfer family allegiance to peer group allegiance which is accompanied by a difference in operational parameters. Individuals, through their intellectual ability to compare, will position themselves for interaction and experiences rather than relying solely on adult direction. Yet, self-confidence is only beginning to emerge and is often inconsistent as a foundation for reaching too far into the unknown. Interaction with both peers and adults is essential, as is the involvement in both formal and informal learning opportunities, with structure and freedom juxtaposed, yet available at all times.

Vacillation is common between independence and the desire for regulation, supervision, and direction.

The desire (and growing ability) to make choices releases the adolescent from outside control. Yet freedom is a relative state and the desire for independence will be moderated by the reliance on direction, limited experience, and the erratic loyalties that typify this period. Security and support are important and respect will develop where independence can be expressed within understood parameters. Without these parameters, and on occasion in spite of them, independence will be interpreted by adults as rebellion and disrespect, terms rarely used by adolescents themselves.

Conventions of value, trust, and compromise are put to question and redefined often during this period.

This is, again, a consequence of youth making a transition to adulthood under a cultural framework that is defined, historically, by adults. In order to experience firsthand a skill, emotion, or intellectual understanding, the individual learner must redefine the conventions of that experience. This often occurs on a case-by-case basis and serves as the foundation for life-long social interaction.

The adolescent enters new social institutions such as churches and schools that have rules, constraints, and expectations of behavior to which the individual must accommodate. Prior to adolescence, the family provided a belief system and social support. During adolescence, the family still provides support while simultaneously the individual is testing rules, establishing greater freedom, and developing support systems with peers. This situation of simultaneously separating from and being part of the family, while developing an individual identity and being part of a group, often causes conflicts that challenge those around the adolescent.

The Context

Middle-level educators have long been aware of risk factors among their students that could prevent them from having a successful school experience. Not until recently have they had reliable information to support their contention. Preliminary data from the National Education Longitudinal Study-88 (National Center for Educational Statistics, 1990) suggest that nearly one-half of the nation's eighth graders have enough risks in their lives to jeopardize their success at school. Yet data from NELS:88 also reveal that two-thirds of the 25,000 eighth graders studied have intentions to finish college.

The NELS:88 study lists six indicators of "at risk" and the percentage of eighth graders who exhibited the indicator: living in a single-parent family (22), low parent education (11), low income (21), limited English proficiency (2), being home alone without an adult for more than three hours on weekdays (14), and having a sibling who has dropped out of high school (10). Using these indicators as a basis, 47 percent of the students surveyed have at least one risk factor; 20 percent have two or more. The preliminary data demonstrate that while all middle-level eighth grade students can be affected by these risk factors, the historically underserved and underrepresented students are more significantly impacted: 41 percent of Blacks and almost 37 percent of Hispanics have at least two risk factors contrasted with 14 percent of white students.

Conclusion and Recommendations

The panel concludes this brief discussion by pointing out two pertinent myths that we do not support. The myths are that adolescents should be coddled because of this period of turmoil and that the science program should not be rigorous and challenging for fear of misdirecting personal development. As clarified in later chapters, there are many ways that scientific study can contribute to students' development. Certainly one of the important ways is to build on the questions and problems that concern adolescents. During the development of identity and formulation of personality, adolescents search for meaning in many aspects of the natural and human environment. They are concerned with many questions and problems related to science and technology. Their concern is good reason to provide a middle-level science program that relates to, and provides meaning for, their lives and living. Adolescents enjoy educational activities that are concrete, challenging, and that require critical thinking. Adolescents prefer active involvement, both physically and mentally, rather than passive learning. That adolescents generally find learning interesting when it is related to their immediate concerns, questions, and goals suggests that fundamental scientific and technological concepts and processes, developed in a personal and social context, can be a part of any middle-level program.

Chapter II

Middle-Level Education

This chapter is about education during the middle years, generally from ages 10 to 14. First, there is a vignette intended to introduce the reader to modern middle schools. This introduction is followed by a history of education at the middle level. A review of contemporary education for middle-level students concludes the chapter.

A Walk Through Explorer Middle School

The building was twenty years old but did not look it. The walls were painted light blue and white and the floors were carpeted. Walking down the hall and looking into classrooms, one could see a variety of seating arrangements and student activity. In a few rooms students sat in rows, participating in whole-class discussions or reading. In some rooms students were working in small groups; some involved in discussion, others working with hands-on materials. In another classroom students were working on individual projects. One classroom was apparently a computer laboratory, with about 12 students working at computers, some alone and some in pairs. In another room, a team of three teachers were planning an interdisciplinary unit. Their conversation indicated that the team included science, language arts, and social studies teachers. In the sixth-grade wing students were busily moving from one classroom to another. The 7th graders were having an international day, so students and teachers were dressed in colorful costumes and each classroom was decorated to represent a different country. This brief walk revealed:

- *varied activities in classrooms;*
- *a range of organizational arrangements within classrooms;*
- *different instructional strategies;*
- *an academic wing of the school where "core" courses are taught and a wing of the school with exploratory, "elective" courses; and*
- *teachers planning cooperatively.*

The school climate was not what one imagines in the typical junior high school. There were no bells, no shouting, no teachers monitoring the halls, no running, and no trash on the floor. Students and teachers moved from place to place without the usual noise and disruption; the atmosphere was calm. There was evidence of warmth, caring, and respect among students and all the school personnel.

Several features characteristic of middle schools are evident in this vignette. The daily schedule has blocks of time for interdisciplinary team planning and teaching. The teachers use a variety of teaching strategies, all intended to engage the learner, allow exploration, introduce concepts and skills, and provide opportunities to take action. Education programs for middle-level students offer a range of exploratory units so students can develop their interests. The physical facility is designed to accommodate a core of learning experiences designed for the adolescent. This academic core is required of all students (Alexander and George, 1981).

To understand the place of middle schools, the panel thought a brief history of education at this level is important. There are several purposes for the historical review. Those purposes include 1) a description of the evolution from junior highs to middle schools in this country, 2) clarification of the philosophy and rationale for middle schools, and 3) justification for this panel's support for frameworks designed specifically for the middle level.

The Origins of Junior High School

In 1647, the requirement for compulsory schools was established with the "Old Deluder Law," a statute meant to preserve religious orthodoxy and to encourage the education of youth. Essentially, the law required that townships have schools. Schools were not graded until the mid 1800s when twelve grades were established. Before long, these were divided into primary and secondary grades.

In the latter part of the nineteenth century, most elementary schools included grades one through eight and high schools included grades nine through twelve. This was the eight-four plan. In the early twentieth century, educators recommended the elimination of the eight-four plan in favor of a six-six plan in which elementary school included grades one through six and secondary school included grades seven through twelve. Charles W. Eliot, of Harvard University, recommended the six-six plan in an 1892 address to the National Education Association, of which he was president at that time. Eliot's concern, however, was not in meeting the needs of elementary and secondary students, it was a concern about the age of admission to Harvard University. The National Education Association appointed the Committee of Ten on Secondary School Studies as a result of President Eliot's recommendation. In 1893, the Committee of Ten recommended an introduction to secondary school subjects prior to grade nine, thus setting the stage for a new organization for schools. The debate on the organization of elementary and secondary education continued for three decades. Out of this continuing debate a 6-3-3 plan and the junior high school concept emerged.

In the early twentieth century, G. Stanley Hall's writings on adolescent psychology and several studies on students who drop out focused attention on early adolescents and their educational needs. In 1909-10, several cities, including Columbus, Ohio and Berkeley, California, had separate schools with grades seven, eight, and nine only

The 1918 Commission on the Reorganization of Secondary Education (CRSE) firmly established the junior high school in the American education system. The 1918 CRSE report, *Cardinal Principles of Secondary Education*, stated

> *We, therefore, recommend a reorganization of the school system whereby the first six years shall be devoted to elementary education designed to meet the needs of pupils approximately six to twelve years of age, and the second six years to secondary education designed to meet the needs of pupils approximately twelve to eighteen years of age. The six years to be devoted to secondary education may well be divided into two periods which may be designated as the junior and senior periods.*

The Junior High School

By the 1920s, the concept of junior high schools was established and their numbers were growing. Prominent educators such as Thomas Briggs (1920) and Leonard Koos (1920) published textbooks describing its educational purposes, organizational patterns, and instructional practices. In 1920 there was an estimated 800 junior high schools in the United States; by 1930 there were 1,787. Shortages of facilities and economic restraints placed on schools between World War I and World War II contributed to this rapid increase. Justifications for junior high programs cited the needs of adolescents, the transition to high school, the elimination of dropouts, and vocational preparation. In 1940, William Gruhn and Harl Douglas (1940) published what has become the classic definition and rationale for junior high schools. Gruhn and Douglas summarized the essential functions of junior high schools as:

- **Integration.** Basic skills, attitudes, and understanding learned previously should be coordinated into effective behaviors.
- **Exploration.** Individuals should explore special interests, aptitudes, and abilities for educational opportunities, vocational decisions, and recreational choices.
- **Guidance.** Assistance should be provided for students making decisions regarding education, careers, and social adjustment.
- **Differentiation.** Educational opportunities and facilities should provide for varying backgrounds, interests, and the needs of the students
- **Socialization.** Education should prepare early adolescents for participation in a complex democratic society.
- **Articulation.** Orientation of the program should provide a gradual transition from preadolescent (elementary) education to a program suited to the needs of adolescents.

The reality of the time, however, was that most junior high school teachers were trained for the high school and had neither the background nor the motivation to teach at the junior high level. They perceived a junior high school teaching job as a stepping stone to a high school position. The important goals of education for early adolescents were forgotten or ignored and curriculum and instruction in grades seven, eight, and nine became scaled down versions of grades ten, eleven, and twelve. In science, for example, junior highs implemented life science and physical science classes that were designed as introduction to high school biology, chemistry, and physics. It was clear to many that junior high schools were not living up to their promise. Some of the deficiencies noted were:

- a shortage of qualified professionals (policy makers, researchers, teacher educators, and classroom teachers);
- lack of agreement on purpose;
- failure to meet the needs of early adolescents, resulting in high dropout rates;
- programs (athletics, music, and social) that were inappropriate for early adolescents;
- ineffective discipline;
- teachers who did not understand early adolescents; and
- influences of college entrance requirements.

Why was the junior high school criticized in the 1950s and 1960s? The failure was probably one of practice, rather than misdirected purpose, ill conceived rationale, or lack of policies. The programs and practices were inappropriate for the students. In part, the inappropriate implementation of the junior high school idea could have originated with the name "junior," which implied that new programs and practices were scaled down versions of a "senior" counterpart (Hurd, Robinson, McConnell, and Ross, 1981). While there were other reasons for the criticism and decline, many were directly related to the conceptual and organizational implications of the term "junior." The middle school movement emerged from the floundering junior high school movement. Protest and conflict existed between the middle and junior high school movements; however, that conflict was based on differing programs and practices, not on lack of agreement about the purposes of education for early adolescents.

Emergence of Middle Schools

During the 1960s, several factors contributed to the emergence of the middle school as an alternative to junior high schools. General criticisms of American schools and a need to increase the quality of education; an emphasis on curriculum improvement in science, mathematics, and foreign languages; renewed interest in preparation for college; recognition of Jean Piaget's work in developmental psychology and J. M. Tanner's work in physical development; the need to eliminate de facto racial segregation; restructuring of schools due to overcrowding; and a general desire to improve education were among the factors that contributed to an increase from 100 middle schools in 1960 to over 5,000 in 1980. In 1988, there were 12,000 middle schools with an estimated total enrollment of 8,000,000 students.

The middle school is an important conceptual and physical innovation in the education system. A 1981 report, *The Status of Middle School and Junior High School Science* (Hurd et al. 1981), listed some of the essential characteristics of the middle school that set it apart from the junior high school:

- A program specifically designed for pre- and early adolescents.
- A program that encourages exploration and personal development.
- A positive and active learning environment.
- A schedule that is flexible with respect to time and grouping.
- A staff that recognizes students' needs, motivation, fears, and goals.
- An instructional approach that is varied.
- An emphasis on acquiring essential knowledge, skills, and attitudes in a sequential and individual manner.
- An emphasis on developing decision-making and problem-solving skills.
- Interdisciplinary learning and team teaching.

In light of the criticism of the junior high school, the reader should note the emphasis in this list on programs and practices. This difference is critical to understanding the middle school movement. Middle schools, in structure and function, have many educational advantages; several of these advantages this panel thought important include the following:

- The middle school has a unique status; the school program is not "junior" to another program.
- Specific subjects, like science and mathematics, can be introduced at lower grades (e.g., fifth and sixth) by specialists.
- Developing new middle schools provides the impetus for redesigning goals, curriculum, and instruction for the early adolescent learner.
- Development of middle schools can facilitate changes in teacher certification standards and subsequently in teacher education programs.
- Some discipline problems can be eliminated through different groupings of students, primarily the inclusion of younger students.
- Middle schools can be designed to provide greater guidance and counseling at the time it is most needed.

Time will tell about the role and effectiveness of middle schools in American education. The NCISE panel on curriculum and instruction believes that their time has come, and that they are a prominent educational advance. Table 1 summarizes some of the essential differences between middle school and junior high school, based on the original work of Joseph Bondi (*Developing Middle Schools*, 1972).

The Middle School

Since the mid-1970s, the middle school movement has gathered increasing support and has evolved from the bandwagon stage, through unique innovations, to the model school stage. In 1970, only two states required middle school certification. In 1985, the majority of states (26) had special certification requirements for middle-

Table 1 Middle Schools and Junior High Schools: Some Essential Differences

Middle School Emphasizes	Junior High School Emphasizes
Student-centered program	Subject-centered program
Learning how to learn	Learning a body of information
Creative exploration	Mastery of concepts and skills
Cooperation with other students	Competition with other students
Student exploration with teacher guidance	Student adherence to teachers' lesson plans
Student responsibility for learning	Teacher responsibility for student learning
Student-teacher independence	Teacher control
Flexible scheduling	Structured (six period/day) schedule
Student planning in schedule	Administrator plans schedule
Variable group sizes	Standard classroom sizes
Team teaching	One teacher for a class
Variable materials used in instruction	Textbook-dominated approach

This table is based on the work of Joseph Bondi (1972). Modifications were made in accordance with the contemporary middle school movement.

level teachers (McEwin and Allen, 1985). In 1989, The National Council for Accreditation of Teacher Education (NCATE) issued standards for certification of middle-level teacher preparation programs.

A number of influential textbooks elaborate upon the unique qualities of middle schools and middle-level education. Among the significant textbooks and monographs are Silvester Kohut's *The Middle School: A Bridge Between Elementary and Secondary Schools* (1976), Thomas Curtis and Wilma Bidwell's *Curriculum and Instruction for Emerging Adolescents* (1977), William Alexander and Paul George's *The Exemplary Middle School* (1981), and Jan Wiles and Joseph Bondi's *The Essential Middle School* (1981). The National Middle School Association (NMSA), established in 1973, has also published several important documents such as John

Lounsbury's *Perspectives: Middle School Education 1964-1984* (1984), and a republication of Donald Eichhorn's 1966 work, *The Middle School* (1987).

In the early 1980s John Swaim, then president of the National Middle School Association, formed a committee of prominent educators and gave them the task of developing a clear and complete description of the middle school concept. The committee's work resulted in the publication of *This We Believe* (NMSA, 1982). After a preliminary rationale that centered primarily on the developmental characteristics of the early adolescent, the monograph listed and elaborated on the defining characteristics for a middle school. Figure 1 lists those elements.

Figure 1

Essential Elements of a Middle School

- Educators knowledgeable about and committed to transescents*
- A balanced curriculum based on transescent needs
- A range of organizational arrangements
- Varied instructional strategies
- A full exploratory program
- Comprehensive advising and counseling
- Continuous progress for students
- Evaluation procedures compatible with nature of transescents
- Cooperative planning
- Positive school climate

From *This We Believe*, by the National Middle School Association, 1982.

*The term *transescents* is used in many publications synonymously with early adolescents, young adolescents, and emerging adolescents.

In 1985, the National Association of Secondary School Principals (NASSP) published *An Agenda for Excellence at the Middle Level*. This report stands out among the many reports on middle-level education due to its concise and concrete recommendations. Figure 2 lists the elements of schooling the agenda addressed.

The NASSP report contained this statement about curriculum:

> *. . . the middle-level school curriculum must develop intellectual skills and an understanding of humankind that will permit the student to gather information, organize it in a meaningful fashion, evaluate its veracity and utility, form reasonable conclusions about it, and plan for individual and collective action (National Association of Secondary School Principals, 1985:5).*

This quotation suggests an immediate connection to science and technology education. In what part of the curriculum is there a better opportunity to gather,

Figure 2

Elements of Middle-Level Schooling that Must Be Addressed

- Core values
- Student development
- Learning and instruction
- Technology
- Transition
- Connections
- Culture and climate
- Curriculum
- School organization
- Teachers
- Principals
- Client centeredness

From *An Agenda for Excellence at the Middle Level*, by the National Association of Secondary School Principals. 1985.

organize, and evaluate information and use that information to reach conclusions and take actions?

Following is a summary of some specific recommendations from the NASSP report, with an emphasis on connections to science and technology education.

The middle-level curriculum should:

- Equip students with skills for continued learning.
- Teach students how to organize for action, both as individuals and as members of a group.
- Inform students of the universality of the human condition.
- Inform students of the forces that shape human history.
- Provide for the systematic study of change and its effect on people and societies.
- Engage students in productive thinking, systematic reasoning, and the evaluation of information (National Association of Secondary School Principals, 1985:5-6).

The NASSP's recommendations went beyond consideration of curriculum content and suggested that curriculum organization for young adolescents merits careful attention. Some of their suggestions follow:

- Match instruction to the unique developmental characteristics of young adolescents.
- Relate curriculum content to concerns of young adolescents.
- Provide frequent homework.
- Provide exploratory programs that introduce students to a variety of topics, skills, and content fields without requiring mastery (National Association of Secondary School Principals, 1985:6-8).

The report contained the following recommendations concerning instructional strategies appropriate for middle-level students.

Instruction will be enhanced if teachers:

- use a variety of instructional approaches;
- plan instruction that accommodates different learning styles;
- foster cooperative learning activities;
- use group problem solving to stimulate creative problem solving and productive thinking;
- provide regular feedback on student work;
- adopt material for use in the classroom and do not rely on the textbook as the organizer for the course; and
- capitalize on students' natural activity levels and integrate physical activity and hands-on instruction (National Association of Secondary School Principals, 1985:8-10).

Finally, the section on technology called for the integration and use of technology in the program. The report suggested that technology includes both the use of equipment such as computers and the understanding of technology in society.

In 1987, the California State Department of Education published *Caught in the Middle* to highlight a reform agenda for grades six, seven, and eight. This document contained numerous specific recommendations to guide the reform and to assure the inclusion of unique programs at the middle level.

In 1989, the Carnegie Corporation of New York brought middle-level education to national attention with the report *Turning Points: Preparing American Youth for the 21st Century*. Recommendations from this report can benefit all middle-grade students, but they were designed to benefit mostly those students who are at risk. The goals for middle-level education are based on answers to two questions: What qualities do we envision in the 15-year-old who has been well served in the middle years of schooling? and, What do we want every young adolescent to know, to feel, to be able to do after completing middle school? In answering these questions, the Carnegie Council on Adolescent Development listed the general characteristics they associated with being an effective human being. The effective 15-year-old will be:

- an intellectually reflective person;
- a person en route to a lifetime of meaningful work;
- a good citizen;
- a caring and ethical individual; and
- a healthy person (Carnegie Council on Adolescent Development, 1989:95).

The educational experiences of youth can promote the development of those characteristics. The Carnegie Task Force called for middle-level schools that:

- create small communities for learning;
- teach a core academic program;

- ensure success for all students;
- empower teachers and administrators to make decisions about the experiences of middle-grade students;
- staff middle-grade schools with teachers who are expert at teaching young adolescents;
- improve academic performance through fostering health and fitness;
- reengage families in the education of young adolescents; and
- connect schools with communities (Carnegie Council on Adolescent Development, 1989:9).

An Agenda for Excellence at the Middle Level, *Caught in the Middle*, and *Turning Points* all call for educational reform at the local, state, and national levels. Clear in their purposes, they direct attention to programmatic and instructional changes. The literature on middle schools, including the reports just reviewed, cite science education as essential. A good science education can certainly contribute to such goals as intellectual growth, healthy development, meaningful work, good citizenship, and ethical reflection.

Conclusion and Recommendations

Reports and recommendations for education at the middle level have consistently recognized the importance of the years of transition from childhood to adolescence. So, while the reasons varied, the arguments for special programs for the middle level have been similar across history. For most of the twentieth century, junior high schools served as the transition from elementary to high school. In reality, however, the teachers, programs, and practices were ill-suited for the early adolescent.

In the 1960s the middle school concept emerged. The influence of developmental psychology, economic and demographic shifts, and general reform of education all contributed to an increase in middle schools and a decrease in junior high schools. In the 1980s several key reports gave strong support to the middle school concept and made specific recommendations for curriculum and instruction.

Based on those reports, the following recommendations can be made. Curriculum at the middle level should:

- have exploratory components;
- reflect a balance of academic and developmental goals;
- provide opportunities to gather, organize, and evaluate information, and use the information for personal actions;
- be meaningful to the early adolescent;
- inform students of the human condition and the forces that shape history; and
- engage students in systematic problem solving, productive and creative thinking, and higher levels of reasoning.

Instruction at the middle level should:

- consist of varied strategies;
- accommodate different learning styles and developmental levels;
- foster cooperative learning;
- use group problem solving;
- provide regular feedback; and
- use hands-on, activity based approaches.

Chapter III

Science Education at the Middle Level

This chapter begins with a review of junior high school science programs. A section on science curriculum in the 1970s and 1980s follows. The chapter concludes with a brief look at some middle-level programs for the 1990s.

General Science in Junior High Schools

Science in the junior high school has faced perplexing problems since its inception. General science was the course offered in the 9th grade of 84 schools when the first junior high schools came into existence. Begun in the decade 1910–1920, the course was designed to satisfy the needs and interests of students in early adolescence. Several problems surfaced in junior high school science. One was a shortage of well-trained general science teachers. Many teachers at this level formerly were high school physics, chemistry, and biology teachers whose primary concern was not the problems of junior high school science. Second, teachers in other disciplines such as English, mathematics, and physical education were recruited to teach science. The general science texts for junior high schools were first written to ameliorate these problems. The variations in school organization such as six-three-three, eight-two-two, and eight-four necessitated the repetition of science topics to produce marketable textbooks. There were also deficiencies in equipment and facilities for teaching science. Many science classes were taught in classrooms without water or gas outlets and without adequate facilities for demonstrations and experiments. All of these problems contributed to a science curriculum mismatched for the rationale originally developed for junior high schools.

There was no clear consensus of what junior high school science should actually accomplish. Objectives ranged from "preparation for the rigorous science courses in the senior high school" to "general education for good citizenship." Some felt that general science should be exploratory in nature. Courses designed on this premise became rapid surveys of chemistry, physics, astronomy, meteorology, biology, and geology. Others believed that students should study the applications of science in the world around them. Courses with this theme focused on home appliances, transportation, communication, health problems, and natural resources. Enrollments in general science grew to about 65 percent of the ninth-grade classes by 1956, then declined as new courses began to permeate the ninth grade and as the seventh and eighth grades took over more of the general science offerings (Brown and Obourn, 1961).

New Science Courses for the Junior High School: 1960s and 1970s

In the early years of the national curriculum studies of the 1960s educators and scientists centered their attention on the senior high school courses. With time, attention turned to the junior high science curriculum. Curriculum reform in the 1960s, however, made no effort to improve general science. In fact, the unstated assumption among science educators was that by implementing new life, earth, and physical science programs, the traditional general science course would eventually be replaced. This has not occurred. In one sense the contemporary approaches to middle-level education can be seen as an extension of general science more than of junior high school science. For example, general science textbooks had all disciplines in one text, and attempted to relate the study of science to meaningful topics.

Early in 1963, the American Geological Institute received a grant to develop a curriculum, Earth Science Curriculum Project (ESCP), for the ninth grade. This course was interdisciplinary, involving geology, meteorology, astronomy, and oceanography. Curriculum emphasis was on laboratory and field study, with students actively participating in the process of scientific inquiry.

Materials of the ESCP included a textbook, *Investigating the Earth*; the laboratory was augmented by the text, teacher's guide, films, laboratory equipment, maps, and a pamphlet series. After three years of testing and preparation of materials, the course was published commercially.

Preparation of persons qualified to teach the course was a serious problem for ESCP. Many earth science teachers were recruited from other disciplines and lacked sufficient background. The advances made in the design and implementation of *Investigating the Earth* were commendable. The text design, integration of concepts from life and physical sciences, and the careful presentation of knowledge, process, and skills were unprecedented. Subsequent revisions of the text have replaced many topics and realigned the book with other standard earth science texts.

The Introductory Physical Science (IPS) program, developed by Educational Services Incorporated with support from the National Science Foundation (NSF), was a one-year course in physical science designed for use in junior high schools. Laboratory work was emphasized and equipment was designed to allow students to perform the experiments in ordinary classrooms.

The IPS course was tested in several centers throughout the United States. The materials, which included textbooks, teachers' guides, laboratory notebooks, and comprehensive apparatus kits, were eventually made available through commercial sources. Realizing that the success of a new course depends on well-qualified teachers, the National Science Foundation supported a program to locate qualified science teachers and to prepare them to instruct others in the use of IPS. The program was successful; in IPS workshops, teachers were trained by their peers in the local, school environment.

Several integrated courses were developed in the 1970s. One of them was the Intermediate Science Curriculum Study (ISCS), financed by the U.S. Office of Education and National Science Foundation, and developed at Florida State University. The fundamental assumption underlying the ISCS plan was that science at the junior high school level serves essentially a general education function. Level I for seventh grade, *Energy: Its Forms and Characteristics*, permitted students to delve into physical science principles by dealing with science in their environment using a structured program. Level II, *Matter and its Composition and Model Building*, gave students increasing independence in designing experiments and recording and interpreting their data. Level III for the ninth grade dealt with biological concepts and was designed to use laboratory blocks six to eight weeks long. The student was expected to apply the concepts and investigative skills acquired in the seventh and eighth grades. All of the class activities in the ISCS course were designed for students working alone. The teacher's main duty was assisting students to work on their own; the course did not use large-group lectures or information-dispensing sessions. Another innovative feature of the ISCS program was the development of a complete course on Computer-Assisted Instruction (CAI). The ISCS program was a serious attempt to balance the personal goals of junior high school with the academic goals of the sciences.

There were other, smaller-scale projects for revising junior high school science. Among them were the Interaction Science Curriculum Project (ISCP), *Ideas and Investigations in Science (IIS)*; and a BSCS program, *Patterns and Processes in Science*. Junior high school science received an impetus similar to that enjoyed by senior high school science in the 1960s. Since the basic philosophy in junior and senior high schools was the same, it is likely that pupils who participated in these courses at both the junior and senior high school levels experienced the disciplines of science but were denied the personal development goals of middle/junior high school education.

Junior High and Middle School Science Programs: 1980s

In the 1980s, curriculum programs at the middle/junior high school level took one of three forms: (1) a fact-oriented textbook based on the premise that students must develop a background of information before concepts and inquiry can be used; (2) a "middle of the road" textbook full of encyclopedic facts and vocabulary, a separate laboratory guide, and a separate guide for the "inquiry" teacher to use; and, (3) a program that presents science as active involvement by the student. The next paragraphs summarize programs of types (1) and (2), currently in use by about 90 percent of the middle/junior high school science curriculum. Several programs of type (3) are then described. This is followed by a summary of the impact of curriculum revisions since 1960.

The goals of middle-level science programs are typically (1) to present the fundamental concepts representative of biological, physical, and earth science disciplines; (2) to acquaint students with scientific inquiry through observations, recording information, and reporting findings; (3) to foster development of "scientific attitudes," such as curiosity, respect for reliable information, critical thinking, and appreciation of the cultural contributions of science; and (4) to promote acquisition of skills associated with inquiry such as recording observations in tables, charts, and graphs, and doing experiments.

The goal dominating the textbooks is the acquisition of scientific knowledge. The major emphasis is upon obtaining information about the physical and biological world. Scientific knowledge is usually presented as a body of facts, although some textbooks make an effort to have students organize their learning into concepts, such as "living things are related to their environment," or "matter is neither created nor destroyed."

Laboratory activities representing scientific inquiry are usually distributed throughout the textbooks. Only a few textbooks make a special effort to use laboratory activities as an integral part of the curriculum program.

What about the goals concerning social issues and personal needs? Social issues such as population growth, air quality, health and disease, land use, water resources, energy shortages, and environmental pollution are typically presented in a single chapter in the textbook. Science-related social issues are identified but are not explored or investigated in terms of the complexities of the problems; the short- and long-term effects of the problems; appropriate, reasonable, and prudent actions that might be taken; or the role of personal, governmental, or industrial decisions. The goal of personal needs is recognized only in life science programs, usually with such topics as health, nutrition, disease, and drug abuse.

Little effort is made in middle/junior high school programs to develop career awareness. There are occasional photographs of famous scientists, engineers, or individuals working in health professions. The rich variety of career options within the sciences and engineering is usually not presented. However, the extent to which science teachers actually direct attention toward this goal is not known.

Although by the end of 1980 most middle-level schools were using programs of a text nature, several type (3) programs emerged in this decade. Among them were three that characterize this effort: *Task Oriented Physical Science* (TOPS), *Great Explorations in Math and Science* (GEMS), and *Activities that Integrate Mathematics and Science* (AIMS). The TOPS activities lend themselves to several classroom approaches: resource center activities, demonstrations on individualized approach, or use by teachers for traditional class lessons. The GEMS program represents a selection of the best science and math activities developed at the Lawrence Hall of Science over the past 15 years and included such middle-level topics as *Oobleck: What Do Scientists Do?*, *Animals in Action*, and *Bubble-ology*. According to the developers, the activities combine fun and excitement with scientific content and process skills. The AIMS program began in 1981 with a grant from the National Science Foundation. The program encompasses a broad range of activities that focus on the integration of learning experiences, problem-solving activities, and the use of cooperative learning. It is supported, in part, by the AIMS Education Foundation which has established a national leadership training program. These efforts are representative of the approach generally taken by curriculum development groups during the 80s. None is a complete program. Yet all of these efforts recognized the need to have students actively involved in the learning of science rather than passively reading science textbooks.

What about the NSF curriculum and other similar efforts in the past few decades? In 1976-1977, at least one federally funded science program was being used in 39 percent of the school districts. The programs being used in school districts and the percentage of districts using the materials were Earth Science Curriculum Project (ESCP) — 12 percent, Intermediate Science Curriculum Study (ISCS) — 11 percent, and Introductory Physical Science (IPS) — 8.6 percent (Weiss, 1978). In the 1986 National Survey, only one program, Introductory Physical Science (IPS) was used by more than 2 percent of teachers. Dominating the middle/junior high school market are commercial programs that were certainly influenced by, but not developed during, the "Golden Age" of curriculum reform (Weiss, 1987).

In most ways, the middle/junior high school science curriculum is a reflection of high school programs. It is a "junior" version of senior high school science. Reading level is lower, vocabulary is defined more frequently, and there is some recognition of the needs and interests of early adolescents. There is a vital need to redesign middle and junior high school science programs. In 1986, the National Science Teachers Association (NSTA) published a position statement, "Science Education for Middle and Junior High Students," describing the goals and orientation for curriculum and instruction.

> *The primary function of science education at the middle and junior high level is to provide students with the opportunity to explore science in their lives and to become comfortable and personally involved with it. Certainly science curriculum at this level should reflect society's goals for scientific and technological literacy and emphasize the role of science for personal, social, and career use, as well as prepare students academically.*

This position statement continued with a discussion indicating that the science curriculum should fulfil the needs of the early adolescent and address both the personal needs of students and issues of a global society. The position statement recommended that curricula focus on the relationship of science to:

- content from life, physical, earth sciences, and ecology with frequent interdisciplinary references;
- process skills, such as experimenting, observing, measuring, and inferring;
- personal use in everyday applications and in practical problem solving that allow open-ended exploration;
- social issues that involve individual responsibilities and call for decision making;
- all careers;
- limitations of science and the necessity of respecting differing, well-considered points of view;
- developing written and oral communication skills; and
- positive attitudes and personal success.

The NSTA position statement is important for two reasons. First, the clear emphasis on the student differentiates this curriculum from high school programs. And second, there is support for the trend toward the middle school and away from the junior high school. Table 2 displays some characteristics of science curricula for

Table 2 Ideal Middle-Level Schools and Science Programs

Characteristics of an Ideal Middle School	**Characteristics and/or Needs of a New Science Program**
• Teachers knowledgeable about and committed to the education of early adolescents	• Teacher education programs and staff development specifically for middle-level science programs
• A balanced curriculum of academic goals and developmental needs of adolescents	• A balance of knowledge, inquiry with personal needs, social issues, and career awareness goals
• Different organizational arrangements for instruction, e.g., individual, small group, large group	• A mixture of instructional groupings, e.g., individual projects, group activities, and large group presentations
• A variety of instructional methods	• Use of traditional and new methods such as simulations, role modeling, debate, and use of computers
• An active learning environment	• Use of problem solving, laboratory investigations, field studies, and other activities
• Flexible scheduling	• Schedules designed to accommodate class presentations, field trips, individual projects, etc.
• Continuous progress	• A coordinated science program across the middle-level years to provide a smooth transition from elementary to high school
• Students master skills of critical thinking, problem solving, and decision making	• Emphasis on scientific processes, information processing, and decision making
• Cooperative planning and coordinated teaching	• Science, mathematics, and social studies teachers plan the science program and teach units in parallel or as a team
• Exploratory and enrichment studies	• Opportunities to meet and interact with a variety of individuals in the community whose careers are in science, technology, and mathematics
• Interdisciplinary learning	• An integrated approach to science
• Emphasis on the cognitive, affective, and psychomotor domains	• Science programs that emphasize knowledge, attitudes, and skills related to science and technology integrated with personal needs and social issues

Source. The characteristics of an ideal middle school are based on several sources including *The Exemplary Middle School* by William Alexander and Paul George (1981), *The Essential Middle School* by G. Wiles and H. Bondi (1981), *This We Believe* by the National Middle School Association (1982), *The Middle School We Need* by Thomas Gatewood and Charles Dilg (1975), and a 1973 article entitled, "Do You Have a Middle School?" by Nicholas Georgiady and Louis Romano.

middle-level schools and aligns those characteristics with characteristics of ideal middle-school programs.

Middle School Science Programs: 1990s

In 1988, the National Science Foundation (NSF) issued a request for proposals to develop programs for middle-level science. The NSF solicitation contained the following description of the orientation for middle-level programs:

> *In middle school years, they [students] should begin to develop a more disciplined approach to inquiry and experimentation — improving their ability to organize and articulate knowledge, and to approach problems systematically (National Science Foundation, 1988).*

Included in the solicitation were some characteristics of middle-level materials. Those characteristics included the following:

- Integration of science with other subjects.
- Hands-on experiences.
- Establish a coherent pattern of science topics.
- Capitalize on the interests of students.
- Use of recent research on teaching and learning.
- Identification of standards of student achievement.

In 1989, the NSF funded the following organizations to develop middle-level science programs: Biological Sciences Curriculum Study (BSCS), Education Development Center (EDC), Florida State University (FSU), and Education Systems Corporation (ESC). The programs are briefly described elsewhere in this report. They will be available in 1992.

Conclusion and Recommendations

Education for early adolescent students has evolved toward the current middle school. Likewise, the science program has evolved from general science programs to junior high school programs consisting of life, earth, and physical science textbooks — "junior" models of senior high school programs.

The primary recommendation that emerges from this review is to design a framework 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.

The review in this chapter suggests the development of a framework for curriculum and instruction that supports the current middle-school movement. This report is intended to supply the needed academic emphasis to balance the personal emphasis of the existing middle-school literature.


A COMPARISON

Chapter IV

A Conception of Science and Technology for Middle-Level Education

There are two pillars upon which science and technology education at the middle level rests: one is the unique needs of early adolescents, the second is a clear conception of science and technology. Presented in this chapter is a conception of science and technology appropriate for the development of curriculum materials and instructional strategies for middle-level education.

There is a critical point to be made at the beginning of this discussion. Science teachers have been concerned primarily with teaching the facts, information, concepts, principles, and theories *of* science, and to a much lesser degree *of* technology. This chapter is *about* science and technology. What is it about science and technology that is important for students to know and value? Another way to think about this discussion is that it answers questions teachers are frequently asked — What is science? What is technology? The presentation in this chapter also serves to illuminate the relationship between science and technology, a relationship that is becoming increasingly important in society and yet is not made clear in existing science programs.

A Distinction Between Science and Technology

Just as we did in the report on elementary school science, the panel began with the recommendation that all students develop an empirical understanding of the world. The distinction between science and technology provides the basis for this understanding. The panelists distinguish science from technology as follows:

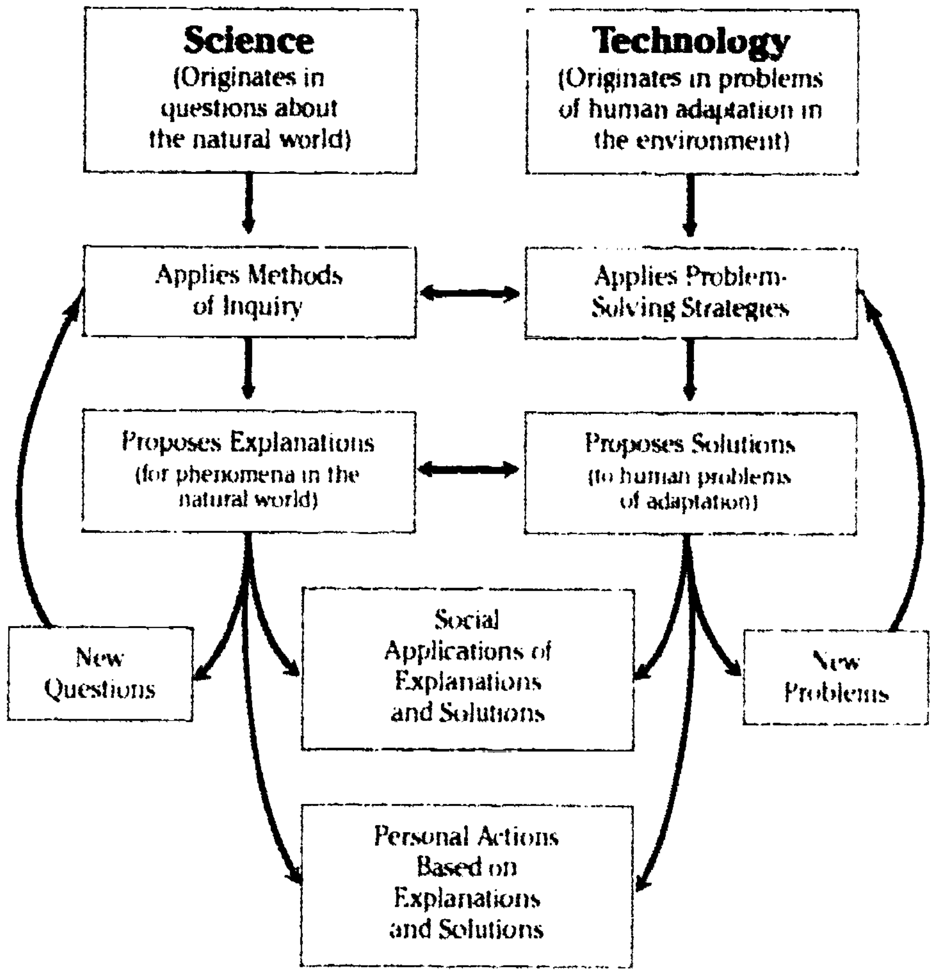
> **Science** proposes *explanations* for *observations* about the *natural* world.
> **Technology** proposes *solutions* for *problems of human adaptation* to the environment.

Figure 3 is a schematic showing the interrelationships between science and technology. An explanation of the connections and the distinctions between science and technology as presented in figure 3 follows.

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? While these questions are simplified for clarity (scientists ask more specific questions), the nature of the questions asked by students and scientists is the same; that is, the questions are about phenomena occurring in the natural world. As scientists proceed to answer these questions, they employ recognized, though variable, methods of rational inquiry. There are "rules of the game" that scientists use. For example, scientific explanations are based on, or derived from, observations. Historically, those observations were direct; now they are often made using technology.

In figure 3, the word *propose* suggests 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. The word *propose* also suggests that scientists make their explanations known to others. That is, the explanations are made public through such means as presentations at professional meetings and publication in refereed journals.

Figure 3
The Relationship Between Science and Technology
and their Connection to Educational Goals



A contrasting view of science is more common in middle and junior high schools. *Science is primarily presented as a body of knowledge* (Weiss, 1978 and 1987; Harms and Yager, 1981; Hurd et al, 1981; Mullis and Jenkins, 1988). The organization of topics and presentation of science in current programs conveys the idea that science is disciplinary, and largely independent of the processes used to develop new scientific knowledge. There is little or no understanding of the tentative and changing nature of explanations in science. Students are left with the idea that scientific knowledge changes by accretion; that is, knowledge in science increases only by the gradual addition of new knowledge.

Technology is seldom presented as a topic of study in science programs for middle and junior high school (Harms and Yager, 1981; Hurd et al, 1981). There is little or no distinction between science and technology in school science programs. When technology is introduced, it is usually defined as the application of scientific knowledge. The traditional definition of technology as "applied science" is simplistic, incomplete, and, in many cases, inaccurate.

The pursuit of science originates in questions about the natural world; technology originates in problems of human adaptation (see figure 3). Humans need air, water, food, and safety. They need to move objects and information, they need to construct shelters and bridge rivers. These, and other historical examples of technology, such as the development and use of tools, agriculture, weapons, and compasses, illustrate the origin of technologies as issues of human adaptation. Technology extends the human ability to change the world (AAAS, 1989) but the changes originate in a need for humans to adapt to the world. The panel also recognizes that some technology is an expression of human aspirations; for example, art. This too can be thought of as adaptation, though not on a survival level.

There are many possible solutions to problems of human adaptation, and inevitably there are objectives and requirements to consider. Some of these are constraints, such as availability of materials, properties of materials, scientific laws, and cultural requirements. Other variables in contemporary society include cost, benefit, risk, and environmental impact. Engineers often complete several designs for a single project so they can assess trade-offs among constraints and variables before making decisions about the best solution. While the methods of scientific inquiry and technological problem solving have many common elements, the latter is distinguished by a focus on such issues as constraints, control, materials, cost-risk-benefit analysis, and decision making. Middle-level curriculum should include the introduction of concepts and skills characteristic of technology. Some examples of those areas might include decision-making techniques, modeling and simulation techniques, information and communication, systems analysis, and technology assessment.

Science and Technology

The distinctions between science and technology are relatively subtle. Simple definitions such as "technology is applied science" no longer sufficiently explain the relationship between science and technology. As the center arrows in figure 3 indicate.

there are interactions between the methods of inquiry and problem-solving strategies and between scientific explanations and technological solutions. Technology depends on accurate scientific information and cannot contravene scientific laws. Science depends on technology to provide instruments and capabilities that enable new or more refined observations (data) to be collected. This panel proposes a model in which the contributions of science to technology and technology to science vary along a continuum.

Current science programs for middle and junior high school present very little information about the relationships between science and technology. Most contemporary science programs for the middle level are based on textbooks designed for junior high, so the topics are aligned with the disciplines; that is, life, earth, and physical sciences. Seldom is there a description or experience that identifies the interactions between science and technology (Piel, 1981; Hurd et al., 1981.)

Although it is not important that middle-level students recognize the subtle difference between science and technology, students at this level can begin to understand the following five principles:

1. Science is an attempt to construct rational explanations of the natural world. Technology is an attempt to provide rational solutions to human problems.
2. Scientific explanations about the natural world are always tentative: they continue to evolve. Technological solutions are always incomplete and imperfect.
3. Technologies exist within the context of nature, that is, no technology can contravene biological and physical principles.
4. All technologies have side effects.
5. Because technologies are incomplete and imperfect, all technologies carry some risk; correspondingly, the degree to which any society depends on technology is also the degree to which the society must bear the burden of risk.

Science and Technology in Society

Scientific and technological enterprises result in socially beneficial products. The direct outcome of science is a better understanding of the world, whereas technological solutions are generally more tangible, taking the form of products or services. In either case, however, individuals and society make decisions and take actions in response to these outcomes (see figure 3). These actions and decisions move science and technology directly into the realm of personal uses and public policy. Since the early 1980s, the connections discussed in this paragraph have been described as the science-technology- society (STS) theme (Bybee, 1987). The STS theme is not prevalent in middle-level education, though it does gain recognition and implementation in policies such as state guidelines. The most widely used textbooks contain little information about the personal and social contexts of science and technology (Hamm and Adams, 1987). Current programs give marginal recognition to the nature and history of science and no recognition to the nature and history of technology (Harms and Yager, 1981). Students in the middle grades are aware of STS issues such as pollution, energy, and disease, but have little opportunity to study such topics as these in school programs (Hamm and Adams, 1987; Hueftle, Rakow, and Welch, 1983; Mullis and Jenkins, 1988).

The influence of science and technology on society is clear in such developments as gunpowder, the compass, and the cotton gin. More subtle are relationships between science and technology and the social power structure. Scientific questions and technological problems chosen for research and development actually support the prevailing power structure, because that structure has the money and influence to induce change. The panel recognizes that a full elaboration of this point is too subtle for middle-level students, but it can certainly be introduced.

Earlier, physical and social changes of science and technology were mentioned. There have also been changes in our perceptions about the natural and designed world. The shift from a geocentric to a heliocentric world view is an example of such a change. In more recent times, as science illuminated our understanding of such processes as photosynthesis and the hydrologic cycle, humans of necessity changed their perceptions about the interrelatedness of life on Earth and about the effects of industrial pollution and deforestation.

Some of the characteristics of science and technology the panel considered important for middle-level students to understand are listed below.

1. The distinctions between science and technology.
2. Scientists and technologists use the same data for different positions on the same issue.
3. Society influences scientific research and technological development.
4. Science requires freedom of information, ideas, and discussion.
5. Science and technology are limited in their capacities to develop explanations and solutions.
6. Scientists and technologists are human.
7. Science and technology are social resources.
8. Science and technology are unique ways of knowing and adapting; there are other ways of knowing and adapting.

Returning to figure 3, we see that scientific and technological outcomes themselves raise new questions and problems. The processes represented in figure 3 are, therefore, interactive. The interactions can develop new explanations and solutions or amend those already developed. These interactions demonstrate the open-ended nature of science and technology.

Conclusion and Recommendations

In the course of history, humans have developed different ways of knowing about the world and solving problems of adaptation. Important examples for this discussion are science and technology. Both science and technology have distinct origins, "rules," and results. Development of scientific and technological literacy at the middle level should include an understanding *about* science and technology and their place in society.

Following are recommendations based on the conception of science and technology presented in this chapter:

1. The program should clearly indicate that science proposes explanations for questions about the world.
2. The program should clearly indicate that technology proposes solutions for problems of human adaptation to the environment.
3. Scientific methods of inquiry and technologic strategies for problem solving should be introduced and developed.
4. The relationships between answering questions and solving problems, and the interactions between proposed explanations and proposed solutions should also be introduced.
5. School science programs should explore the personal and social utility, limits, and consequences of scientific explanations and technological solutions.

Chapter V

Science and Technology Education: Goals for the Middle Level

Education of early adolescents has the dual purposes of providing for their continued personal development and fulfilling the aspirations of society. Early in this century, the literature on junior high schools, and in recent decades, the literature on middle schools (Lawton, 1989) has continuously emphasized the goal of personal development for early adolescent students. While this is appropriate, middle-level educators should not lose sight of the second goal, that of contributing to the society in which the adolescent lives. The goals proposed here incorporate these dual purposes of education.

The National Center for Improving Science Education is attempting to articulate curriculum, instruction, and assessment from kindergarten through grade 12. There are understandable difficulties in articulating the goals since each level — elementary, middle, secondary — has some characteristics that are unique to that level and other characteristics that are common to the other levels. This panel used the following five criteria in the formulation of goals for middle-level science education:

1. The goals should extend and elaborate the goals presented for science and technology education in the elementary school.
2. The goals should portray the conception of science and technology described in chapter IV of this report.
3. The goals should incorporate recommendations from the literature on middle-level education.
4. The goals should emphasize the unique qualities of science and technology education.
5. The goals should provide connections to science education at the secondary level.

Goals for Science and Technology Education at the Middle Level

The goals for science education at the middle level represent general directions for development of curriculum and instruction. While all students may not attain all goals with equal proficiency and understanding, all students should develop some proficiency and understanding in these goals over the period of their education.

Identification of common elements between the goals stated for the elementary years and those stated here should not be surprising since the goals have a common ancestry within science education (Bybee, 1977). The variations between goals for elementary and middle levels are based primarily on the students' developmental differences. Each of the following five goal statements is followed by a brief discussion that is intended to clarify and justify the goal.

Goal 1: **Science and technology education should develop the adolescents' ability to identify and clarify questions and problems about the world.**

Adolescents are, first and foremost, interested in questions and problems that relate directly to them. Constructing a middle-level curriculum could easily begin with general questions such as: "What is normal?" "Why do organisms behave the way they do?" "How are things made?" "Why do things change?" and "What are the relationships among things?" The ambiguity in these questions is intentional. Adolescents seldom state their immediate personal concerns, such as "Why do *I* change?" or "Am *I* normal?." The latter questions are, however, probably closer to the questions of greatest interest to adolescents. The point here is to identify and begin with questions and problems that have meaning for adolescents rather than concepts and skills that have scientific and technological significance. There is the assumption that adolescents will ask few, if any, questions, that are unrelated to science and technology. Support for this assumption is found in the topics of central interest to adolescents, such as sex and drugs.

Asking questions and identifying problems are the first steps in scientific inquiry and technological problem solving. Note that the conception of science and technology presented in the last chapter also begins with questions and problems. Since this is science and technology education, it is appropriate to introduce students to those domains in response to the questions and problems.

Goal 2: **Science and technology education should broaden adolescents' operational and critical thinking skills for answering questions, solving problems, and making decisions.**

In seeking explanations and developing solutions, scientists and engineers utilize cognitive processes and intellectual models that differ from those that people commonly use. Observation, experimentation, and construction of theories in science, as well as consideration of cost, risk, and benefit in technology are examples of the processes and models included in this goal. When students experience the intellectual rigor and demands of scientific inquiry and technological problem solving, they can better understand what and how scientists and engineers think. Furthermore, this experience helps the students to develop problem-solving and decision-making skills that they can apply in their own lives.

The set of goals proposed for middle-level science and technology education includes the acquisition and application of knowledge. Early in this sequence of goals, the emphasis is on conceptual and procedural skills needed for the later applications of knowledge to personal and social issues. Applied logic, critical thinking, analytic reasoning, and technological problem solving are all techniques included in this goal.

Goal 3: Science and technology education should develop adolescents' knowledge base.

The goals for any school science program should include the contributions of science and technology. Among the most important contributions is the general understanding of science as a way of knowing (Moore, 1984) and technology as a way of adapting. These understandings are reflected in the conception of science and technology presented in the last chapter of this report and in the elementary framework.

Knowledge has been a central concern throughout the history of science education. Traditionally, the science curriculum, including that designed for adolescents, consisted of facts, information, and concepts that represent the disciplines of life, earth, and physical sciences. There seemingly were no criteria for selection of content; the curriculum simply represented accumulated information within the discipline. The task of the teacher was to present the information; tests determined what information students retained.

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

The purpose of this goal is to help adolescents understand something *about* science and technology as integral components of past, present, and future cultures. There are three important reasons for including some understanding of history as a part of this goal. The first two reasons were suggested in the report *Science for All Americans* (American Association for the Advancement of Science, 1989). First, conceptual understandings about how science and technology operate would be empty without concrete examples. We propose (and history supports) that new scientific explanations are limited by the social context in which they are presented.

Second, some historical events have significance as a part of our cultural heritage. Consider, for example, the changes in scientific thought spurred by Copernicus, Newton, and Einstein; the contributions of Darwin, Lyell, and Watson and Crick to our understanding of the processes of evolution; and the role of James Watt in the Industrial Revolution. These contributions to western civilization often have significance beyond the scientific content and technological products; indeed they impact culture (Bybee, 1990).

Third, students' conceptual understanding of the world sometimes parallels the historical development of concepts. For example, many students have an Aristotelian view of nature. Presenting different historical perspectives is a way of affirming that others have perceived the world the way they do. But more importantly, historical examples can serve to challenge their current explanations and to provide structures for the reformulation of their explanations.

Throughout history, people have developed explanations for events in their world. For some people, myths provide a powerful explanatory vehicle for organizing their observations. Science, however, presents a particular way of knowing about the world. Likewise, technology is a unique way in which people adapt to their environment. Science and technology as ways of knowing and doing have contributed substantially to cultural progress and will continue to do so.

Adolescents should begin developing an understanding of the nature of science and technology. How do science and technology advance? What constitutes a valid scientific explanation? How is science different from other ways of knowing, such as religion? Is technological problem solving different from other forms of problem solving?

In *Science for All Americans* (American Association for the Advancement of Science, 1989), the authors provide some examples that further clarify both what this goal includes and the conception of science and technology presented in chapter IV. Adolescents should understand that: science assumes the world is understandable, scientific explanations are subject to change, scientific explanations are durable, and science cannot explain all things. Concerning technology, adolescents should understand the interactions between science and technology, that technological problem solving involves design under constraint, that technology involves control, that technologies have unintended consequences, and that technological systems fail.

Finally, this goal connects back to the second goal concerning operational and critical thinking skills. Adolescents should both understand and develop some of the skills of scientific inquiry, such as the demand for evidence, the use of logic and creativity, the development of sound and coherent explanations and predictions, and the importance of a non-authoritarian, skeptical posture.

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.

Science and technology are directly related to contemporary American life. They serve as agents for social change and in turn they are changed by society. Individuals and nations are increasingly being asked to make decisions about science and technology issues that influence the quality of life. Understanding the limits and possibilities of science and technology bears directly on the goals for general education in the sciences. The need to develop personal decision-making abilities is encompassed in this goal. The reader should note also the connections between this goal and the personal and social dimensions presented in our conception of science and technology. Several other general aims for middle-level education are also incorporated in this goal: expanding the adolescent's potential for meaningful work and careers, and cultivating the adolescent's responsibilities for citizenship.

Conclusion and Recommendations

Taken as a set, the goals are a recommendation for teaching science and technology in a personal and social context. Beginning with questions and problems that have meaning for adolescents is essential (goal 1). Not only is it important to understand the processes (goal 2), the concepts (goal 3), and the history and nature of science and technology (goal 4), it is equally important to recognize what science and technology can and cannot do, what they are and what they are not, and how they do and do not influence individuals and society (goal 5).

The goals and objectives for middle-level education represent an integration of our conception of science and technology and the major orientation of middle-level education. This integrated position implies that curriculum and instruction for school science programs be developed in a personal and social context, or with a science, technology, society perspective.

In *All One System* (1985), Harold Hodgkinson advises that educators view the educational system from the perspective of the people who move through it instead of those who run it. At the same time, our task is to see that adolescents develop the most complete and accurate understanding of science and technology that is possible at their stage of development. The panel thinks these dual perspectives have been incorporated into our goal statements.

In conclusion, the panel recommends five main goals for science and technology education at the middle level:

1. Develop adolescents' ability to identify and clarify questions and problems about the world.
2. Broaden adolescents' thinking skills for answering questions, solving problems, and making decisions.
3. Develop adolescents' knowledge base.
4. Develop adolescents' understanding of the history and nature of science and technology.
5. Advance adolescents' understanding of the limits and possibilities of science and technology in explaining the natural world and solving human problems.

Chapter VI

Science and Technology Education: Knowledge, Attitudes, and Skills for the Middle Level

The vignette at right summarizes a field trip to a river, a typical excursion in many middle-level science programs. What are the goals and objectives of a field trip such as this?

The turbines were huge, shiny, and clean and hummed with an overpowering whine. Ms. Washington and her class have come to see how the electric power plant utilizes the force of the river to make electricity. Engineers in hard hats explain how the water flows into the plant from the dam and spins the turbines, which spin the generators that produce electricity which is sent over the array of powerlines leading from the plant. Outside the plant they see the spectacular stream of water gushing out from below the dam, the huge rocks in the river bed, and people fishing from the shore nearby.

After the plant visit they have a picnic by the dam and then spend some time walking along the river below the power plant. Ms. Washington has asked them to form teams of four and has suggested things to look for along the river. Using maps that Ms. Washington received from the power company, the children go exploring. At the end of their exploration each team of four submits 3x5 cards with questions they have about the river, the reservoir, and the power plant. She also asks the students to list what they like best about the river and what they don't like about the river.

This short vignette sets the stage for this chapter. Later in the chapter we return to this field trip to exemplify the chapter's recommendations.

What should adolescents know, value, and do as a result of an education in science? This chapter answers that leading question. The panel used the following criteria for selecting concepts:

- They are applicable to science and technology.
- They are applicable to other disciplines.
- They accommodate different developmental levels.
- They relate to the personal and social lives of adolescents.
- They are powerful explanatory concepts.

A rationale for the attitudes is different. Many individuals are wary of programs that include values and attitudes, fearful that an individual teacher will inculcate his or her own values. The panel takes the position that science and technology function with a distinctive set of values and that they are influenced by the values of the culture in which they operate. The values and attitudes of science and technology are considered an integral part of education in the sciences.

The learning of skills in science and technology education is justified in two ways. Some skills are essential to the processes of science and technology, and also contribute to the general education of adolescents. The skills of problem solving, critical thinking, and logical reasoning are examples.

Conceptual Themes

Many conceptual themes recommended here were also presented in the report on elementary school science (Bybee et al., 1989). Organizing the curriculum around concepts such as systems, scale, change, and diversity connects the middle-level and elementary-level programs. Such concepts can be developed at a more sophisticated level by the early adolescent. Readers familiar with the National Center's elementary school report will note that where themes in that report were stated individually, conceptual themes in this report are stated in pairs. In some cases, such as cause and effect, the pairing is clear. In other situations, the panel decided that the understanding of one concept is enhanced by the juxtaposition of another related concept, for instance, energy and matter, time and scale, and diversity and variation. Adding new concepts also serves to prepare students for science education in high school, where they encounter a range of disciplines; specifically, the concepts of the earth, life, and physical sciences.

In the following section are descriptions of the conceptual themes that form a sound program for middle-level science and technology education. A later chapter presents a curriculum framework based on the science concepts, attitudes, and skills described here.

Cause and Effect

Nature is not capricious; it behaves predictably. Searching for causes and explanations is the major activity of science; effects cannot happen without causes. A common error arises when individuals confuse correlated events with causal relationships. Some people erroneously assume that events that occur simultaneously or sequentially have a cause-and-effect relationship. Many events happen simultaneously, but there is not necessarily a causal interrelationship. Some events require that several things must happen to cause an effect.

At the middle level, cause-and-effect can be expanded by including the nature of evidence required to demonstrate cause-and-effect relationships. Students will see the need for requirements such as the separation and control of variables. Koch's postulates can be introduced as an example of evidence for cause-and-effect relationships in a contemporary infection such as AIDS.

Technological problem solving requires a functional application of cause and effect relationships. Engineers must predict the risks and benefits of applying a technology. The power of such predictions is based on an understanding of cause and effect.

Change and Conservation

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

Change in the natural world generally tends toward disorganization unless energy is put back into the system. For example, an adolescent's well-organized bedroom will tend to become a mess unless energy is expended to keep the room organized. Similarly, a bicycle will tend toward disrepair and will wear out unless energy is expended to maintain it in good condition. The concept of patterns of change (American Association for the Advancement of Science, 1989) can be introduced at the middle level. Some change is cyclical; that is, the direction of the change is reversed. Diurnal cycles, lunar cycles, seasonal cycles, and menstrual cycles are good examples for middle-level education. Students can recognize that some change is one-directional; physical growth and intellectual development, puberty, and menopause, for example. They can also observe that the rate of change can vary. For example, although most middle-level students will ultimately progress through the same developmental stages, not all of them will reach the same developmental landmarks at the same time.

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

Conservation is introduced at two levels in the middle years. Conservation is a set of exact laws related to changes in matter and energy. The total matter and energy of an isolated system is conserved across transformations of the system. The conservation law is commonly stated as — matter and energy are neither created nor destroyed. Conservation is also introduced as the preservation and wise use of natural resources such as air, water, soil, and forests.

The relationships of technology to conservation are scientifically fundamental and socially appropriate. Technologies cannot contravene the conservation laws, and introduction of technology can have detrimental consequences for the conservation of environments and resources.

Diversity and Variation

Diversity is one of the most obvious characteristics of the natural world. Not only are there many differences among objects (including those constructed by humans) and species, but there also is considerable variation within those objects and species. As scientific understanding of the natural world has improved, humans have come to see that maintenance of diversity is important to natural systems. For example, trees, rocks, and people all play important parts in the ecological balance of a tropical rain forest. Altering or eliminating any one component is likely to impact the entire rain forest.

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

All organisms and objects have distinctive properties. Variation in properties is a universal characteristic of the natural world. Some properties are so distinctive that no continuum connects them. Examples of such discontinuous properties are living/nonliving and saltiness/sweetness. Most properties in the natural world vary continuously; that is, there is no clear demarcation that distinguishes the variation in a population or the properties of objects. The colors of the spectrum, for example, constitute a continuum. Night and day, height, weight, resistance to infection, and intelligence are all continuous properties.

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

At the middle level it is important to begin to point out the difficulties that arise in trying to draw generalizations when there is continuous variation. Of particular importance are what Marsden Blois calls "the emergent properties of organisms" as one ascends from lower levels of organization, such as atoms and molecules, to considerations of whole organisms and their interactions with external environments. The power of scientific explanations breaks down as one ascends from lower levels of organization to higher, and infinite variation makes the certitude of cause/effect relationships much lower. For example, officials cannot guarantee the uniform positive effects of a new vaccine on the population at large, or guarantee the safety of a complex ecosystem into which genetically engineered microorganisms are released.

Energy and Matter

Middle level is the time to introduce the fundamental concepts of energy and matter. The hierarchies of matter that form objects and organisms and the processes that enable them to move and change are basic to the concepts of matter and energy respectively.

Students should be introduced to the idea that although there appear to be numerous materials in the world, those materials are actually variations on the arrangement of a relatively small number of basic elements. The contemporary explanation for matter is that it consists of limited kinds of atoms that when joined in different configurations, form different substances. Temperature and pressure can account for differences (states of matter) in a particular substance.

Energy is recognized in different forms, such as radiant energy, energy of motion (kinetic), and energy of position (potential). Explanations for change in the natural and constructed world inevitably involve transformations of energy from one form to another.

Using a defined system as the unit of analysis allows scientists to say that unless energy crosses the boundaries of a system (goes in or out), the total energy, of all forms, within a system remains constant.

Evolution and Equilibrium

Juxtaposing evolution and equilibrium confronts individuals with a paradox of science and technology. The paradox is trying to understand the simultaneity of changing and maintaining systems. Understanding the concepts of evolution and equilibrium helps resolve this paradox.

Evolution is usually considered a series of more or less gradual and continual changes that accounts for the present form and function of objects, organisms, and technological designs, societies, and so on. Because of the controversy initiated by creationists, evolution is usually perceived as relating to life, in particular the evolution of human life. In fact, evolution is used to explain changes in stars, the solar system, geological features, thunderstorms, political thought, societies, and more.

Equilibrium is a physical state in which forces and changes occur in opposite and off-setting directions, or of the same magnitude, or at equal rates. Steady state is also used to describe equilibrium. Equilibrium can be demonstrated by economic trends or by a balanced ecosystem.

Models and Theories

Introduction of models and theories in middle-level education demonstrates the importance of understanding the larger category — the nature of science and technology.

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

The earth's history is often modeled in the classroom by describing geologic time as distances on adding machine tape. Such a model is usually to scale for geologic time. A mathematical model of the solar system might describe the shape of a planet's orbit as being elliptical. And finally, a physical model of a cell might consist of a variety of scale-sized objects representing the nucleus, mitochondria, and other parts of the cell.

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

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

A theory is an explanation for a relatively large and diverse group of observations and events. Theories serve to show relationships among phenomena that were thought to be [illegible]. Theories should also enable prediction. In short, theories explain and predict.

For middle-level science education, the notion of hypotheses can be introduced. Theories have more predictive power than do hypotheses, but each is a model. Hypotheses derived from a theory continually test the validity of that explanatory model and its predictions. A hypothesis serves as a temporary model for testing a proposed explanation. The statement of a hypothesis in an "if ... then" fashion is related to the notion of evidence with respect to cause and effect relationships.

Probability and Prediction

Probability is the relative certainty (or uncertainty) that can be assigned to certain events happening (or not happening) in a specified time or space. Probability is directly related to the scientists' and technologists' need to predict, that is, to use knowledge to identify and explain observations or events in advance.

The work of science and technology is largely directed toward the reduction of uncertainty. As Jacob Bronowski pointed out, tolerance of uncertainty is an essential attribute of scientists. Reduction of uncertainty occurs through 1) the development of adequate knowledge of factors influencing an event, 2) increased observations, 3) better, more precise observations, 4) better explanatory models, and 5) better computations from models.

Science and technology education at the middle level provides an ideal opportunity to introduce probability and prediction. The integration of materials and the nature of science and technology is easily achieved in the context of questions and problems that are meaningful to the adolescent.

Structure and Function

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

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

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

Systems and Interaction

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

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

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

Most technologies can be seen as systems. A common example is the furnace and thermostat. This system is cybernetic; that is, information is relayed and acted upon within the system in a stabilizing way. A properly tuned heating system keeps room temperatures from fluctuating more than a few degrees from the set point. Interaction among two or more systems, or subsystems, is a useful way of studying the effects of systems on one another. The simplicity or complexity of such interactions should be varied at the middle level.

Time and Scale

Time is a nonspatial dimension of the world that separates objects and events. One can consider the succession of events in time, the interval separating events on a time continuum, and/or the duration of events. Time is related to space, as both are used to describe the separation of objects and events in the natural world.

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

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

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

Attitudes

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

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

Scientific and Technological Attitudes

Development of attitudes occurs within a context. Lessons on "the value of specu' tion," "the need for accepting ambiguity," or "evaluating efficiency" are not recommended. Ways of looking at the world develop over time and in the context of participating in and learning about science and technology. The concepts described earlier provide the basis for the development of scientific attitudes.

The study panel reviewed recommendations from the 1966 report *Education and the Spirit of Science*, published by the Education Policies Commission of the National Education Association and the 1989 report *Science for All Americans* (American Association for the Advancement of Science, 1989). The panel concurred with the recommendations that science education should promote understanding of scientific attitudes and the nature of science. A list of some of the most important scientific attitudes follows:

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

Attitudes Toward Science and Technology

Do students like science? Are students interested in technology? Do they perceive science and technology as useful in their lives? Activities that allow students to experience the processes of answering scientific questions and solving technological problems can promote positive attitudes toward science and technology.

At the same time, positive experiences in science class can contribute to the students' self-esteem. Adolescents' experience in school science should help them develop a positive outlook about their integrity, worth, and capabilities. Cooperative groups, laboratory experiences, and meaningful problems can help students achieve a sense of accomplishment.

Skills

Developing skills is an important goal of middle-level education. Science and technology education can help students develop processing skills such as observing, inferring, and classifying. Science and technology education, through answering questions and solving problems, can promote development of the skills of critical thinking, analytic reasoning, and logical thinking. In addition, science and technology education can introduce students to the use of laboratory equipment, such as balances, microcomputer-based probes, and microscopes. Finally, carefully chosen classroom experiences can contribute to the development of reasoning, mathematics, and written and oral communication skills.

Skill development, scientific process and thinking skills in particular, are major goals for science educators. In large measure, this goal can be attributed to the American Association for the Advancement of Science Commission on Science Education (1967). Table 3 lists fifteen AAAS process skills.

Table 3 Process Skills

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

From *Science — A Process Approach*, by American Association for the Advancement of Science Commission on Science Education, 1967.

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

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

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

Asking Questions and Solving Problems. As with information gathering, this category requires skills that are common to both science and technology. These skills include the ability to state questions, identify problems, hypothesize, predict, separate and control variables, infer, design experiments, formulate models, and interpret data. New skills specific to technology include the ability to identify alternative solutions and assess the costs, risks, and benefits of technological solutions.

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

Taking Action. Adolescents should learn various ways to act on the information and decisions. Saying no to drugs, reducing pollution, behaving safely, contributing to local projects, helping individuals in need, and responding to sexual urges are all examples of taking action.

The River: An Example

There are many excellent themes which come to mind that could be used to teach the major points that we recommend in this chapter. Rivers can serve as an illustration of how an integrated approach to science teaching and learning can be accomplished. Rivers are a major part of the water cycle that affects our lives and in turn is affected by our actions. Water running off the lands is much more that just a geological or physical process; rivers create habitats and corridors for many kinds of life, including human life. People utilize rivers for power, transportation, water supply, waste removal, irrigation, and recreation. There is a rich opportunity to integrate scientific study of rivers with history, geography, economics, and physical education as well as technology studies. Here are some examples of how major themes of science and technology are illustrated by the study of rivers in general and a local, nearby river, in particular.

Cause and Effect: Rivers flood at various intervals that depend upon the type of river basin, vegetation, land-use patterns, and geology. Rainfall patterns alone are not enough to predict the flow of rivers, but the correlation is very high. An investigation of the relationships between rainfall, land use, and river flow will help to illustrate cause and effect.

Change and Conservation: The development of waterfalls or rapids can serve to illustrate how rivers change over time. Waterfalls are classically described as retreating headward (upstream) while at the same time conserving their form. Meanders in rivers like the Mississippi are constantly changing but the geometric patterns of the curves is conserved.

Diversity and Variation: Tributaries of streams can be compared to main streams showing the amount of diversity that might exist within one river basin. Some tributaries will be relatively pristine while others will show much change due to human intervention. On a large scale a local stream might be compared to the river to which it is tributary. A study of the major rivers of the world will show how much diversity and variation exists in what we are still willing to call "rivers."

Energy and Matter: The hydrologic (water) cycle is an excellent example of a system in which energy and matter are in constant flux. Heat energy from the sun drives the system by raising water to a higher elevation after evaporation. This energy subsequently does work as the water loses potential energy on its journey to the oceans. The kinetic energy is tapped by humans to run turbines and is used by nature to drive erosion and transportation of sediments. Frozen rivers illustrate an important change, too. When the phase change occurs in spring (melting during spring breakup) dramatic flooding, channel scour, and other phenomena occur.

Evolution and Equilibrium. These themes are illustrated by flora and fauna in and along rivers, the response of the bed to flooding, and the discharge of water. The volume of water moving along the river is constantly changing partly in response to weather and climate and partially in response to other factors such as land use. However, over the long run (many years) a particular river may not change at all. There is a kind of equilibrium established between the input of water and the amount and kind of work done in the river channel. Riverine vegetation may be torn up by floods, but within a few short weeks or months it will re-establish. Rivers that have been dammed undergo major changes in vegetation, fish species present, and channel shapes as a result of the upsetting of the dynamic equilibrium that existed before the dam.

Models and Theories. The hydrologic cycle is a theory illustrated by a model. Anyone who has read an earth science textbook is familiar with the illustration of the water cycle: clouds overhead, mountains in the background, cows and trees in the middleground, a cutaway view of the earth in the foreground with rain and arrows showing the paths which water takes in the cycle. That picture is a model. Simple stream tables are miniature representations of real streams; they are also models. All models are imperfect in important ways. The stream table shows meanders well but not the movement of sediment on the bottom.

Structure and Function. These ideas are best used for living things as well as technology. Shapes and materials of structures are very much dictated by the function which the structures serve. Why is it that boats almost always conform to one of two shapes; either they are long and pointed (canoes, sailboats, passenger liners) or they are wide and flat (hydroplanes, jon-boats, barges). Water wheels and turbines are constrained in shape by the functions that they serve. Materials used for boat building must be insoluble and relatively rigid as dictated by the purposes they serve.

Systems and Interactions. Watersheds occur in hierarchies and obey mathematical rules in their subdivisions. The number of branches and sub-branches, the length of tributaries, and other properties in a river basin follow simple mathematical expressions. Furthermore, rivers are a part of a larger hydrologic cycle and are influenced greatly by climate and weather systems. The dependence of cities on rivers illustrates water supply, waste water, power systems, and transportation.

Time and Scale. Perhaps the first place that scale becomes apparent in studying rivers is when we try to make models in the laboratory. It is very difficult to make a miniature river that has all the properties of a full-sized river and also obeys all the dynamics of real rivers. Some material properties and behaviors only operate at small scale. For example, laminar flow is common in model streams and uncommon in real streams. Viscosity (the "thickness" or "syrupy" nature of the water) is important in a laboratory stream because the shallow nature of the laboratory streams affects the way that sediment is suspended or rolled along the bottom. Although viscosity can be measured in real streams, it is seldom important to understanding how material is transported. It is difficult to model the effect of vegetation in a laboratory stream. Comparing stream-table models to real rivers will illustrate many of the properties affected by scale at the same time that they help explain the dynamics of rivers.

Integration with Other Subjects in School

Language arts: Mark Twain
Fine arts: Hudson River school, rivers as subjects for art
Performing arts: musicals concerning rivers, Ol' Man River
Mathematics: graphs, estimating, progressions, algebra
Social studies: Egypt, Babylonia, Lewis and Clark, location of cities
Health and safety: water-born diseases, industrial pollution, water safety
Technology education: boat design, water wheels and power generation, bridges, dams
Home economics: aquatic foods
Physical education: water sports, canoeing or kayaking on the river, learning to fish

Skill Development

- Computational: computing velocity, graphing discharge (quantity of water equals cross-sectional area times average velocity), determining the area of a watershed

- Observational: map reading, air-photo interpretation, field sketching
- Communications: team reports (written and oral), poster sessions, letter writing
- Critical responses: "Industry ruins rivers." "Our own sewage ruins rivers." "Rivers have many uses and many demands on them."
- Probability: flood-frequency, predictions
- Information management: using several different media, government reports, maps, photos, experts, personal observations

Evaluation and Assessment. A common way for scientists to communicate their research is through a "poster paper." These replace formal oral presentations and are becoming popular in many disciplines of science. Authors create a poster which explains the ideas they wish to communicate about their research. Writing is kept to a minimum and graphs, photos, maps, simple drawings, and other pictorial materials are used extensively. Students in teams could create a poster session which illustrates many ideas about rivers as physical, biological, technological, and social phenomena. A series of arguments explaining how the local river evolved to its present state and how it might be improved and protected could be a theme for a poster session.

Conclusion and Recommendations

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

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

The major organizing concepts recommended by this panel are:

1. Cause and effect
2. Change and conservation
3. Diversity and variation
4. Energy and matter
5. Evolution and equilibrium
6. Models and theories
7. Probability and prediction
8. Structure and function
9. Systems and interaction
10. Time and scale

The study panel recommends that middle-level science and technology programs incorporate the following scientific attitudes:

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

Science programs and science teachers also should attend to the development of adolescents' attitudes toward science and toward themselves. Science curriculum and instruction should encourage the students to develop their skills. The panel has identified four levels of organization for skill development:

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

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

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

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

Chapter VII

Learner-Based Instruction

Science Museums as a Learning Resource

A loud screech emanated from beneath the bus as it entered the science museum parking lot. The students laughed and noted in their field books that "bus brakes" were another sound experienced in the last ten minutes of their ride to the museum. Ms. Lopez smiled, realizing what a success it had been to repeat an earlier classroom activity in which the students had written down all the sounds they heard during a ten minute interval while sitting at their tables. This time, the game-oriented activity took on a whole new dimension, serving to focus the students' excitement and early morning energy prior to arrival at the museum. Unlike her previous trips to the museum as a primary teacher, where keeping kids together with their chaperon and helping them read the directions to the exhibits were Ms. Lopez's biggest concerns, this time the students were already engaged in the topic of "sounds" and had generated a list of sounds before even arriving! Already she realized the planning for this trip was going to pay off handsomely.

As the bus pulled to a stop and the door beside the driver opened, a single loud escaping of gas was heard with the release of the air brakes. This was followed instantaneously with uproarious laughter by everyone on the bus, including the teachers. The obvious joke was delightful. Even though the students had heard the sound of air brakes releasing many times before, this focused attention seemed to magnify the intensity of the sound. Without anyone saying a word, the obvious comparison to intestinal gas was made by everyone, and they quickly wrote notes next to their previous entry on bus brakes.

Ms. Lopez waited for the laughter to subside and then reminded the students that they would meet first, as a whole group, in the welcome auditorium near the museum entrance. The students stuffed their notepads into daypacks and jacket pockets and filed past the driver, snickering and smiling all the way.

Once inside the museum the students assembled in the welcome auditorium for a general orientation and briefing on the morning's activities. First, the students would have free exploration of the museum for one hour. After that, they would assemble in the special exhibits hall where a traveling exhibit on the physics of music was installed. Then they would have another hour, in groups of four, to focus on the sound-related exhibits. Each group was assigned one of the exhibit modules to diagram and explain in class the next day. As a part of this presentation, the students were expected to come to consensus on three questions about the exhibit: first, what was the main point of the exhibit; secondly, which of the basic concepts explored in the classroom previously did the exhibit demonstrate. If it was a new concept it could be presented as such. And thirdly, what was the group's favorite aspect about the exhibit. A recorder, scout, and team leader had already been assigned in each group with the fourth member serving as a presenter the next day. Ms. Lopez had grouped students on the basis of previous student assessment and informal observation, pairing students with different learning styles as well as matching high academic performers with weaker ones. There was little argument from the students, since they were used to small groupings and had the free time during the first hour to interact with best friends, etc.

As the students fanned out across the museum floor, Ms. Lopez walked over to the other two teachers supervising the group to compliment them on how well the experience seemed to be going. Mr. Walker commented that the inservice presented by the museum educator the previous fall had made all the difference in the world. It was there that he had learned about the various exhibits and had been shown the relationships to the school's curriculum. He also had learned of a new agreement between the school and the local museum to allow classrooms two to three visits a year at a reduced rate depending on the match between the special exhibits and the classroom curriculum. When Ms. Lopez suggested the unit on sound, Mr. Walker went back to his museum users guide to check the exhibit calendar. In addition, the music teacher wanted to participate in order to benefit from the field experience, since his classes rarely were involved in trips to a museum.

Through the inservice and advance registration, the teacher team received supplemental activities for classroom use both before and after their visit, a brief description of the exhibit modules in the special music exhibit, and suggestions on student grouping and time management. Ms Lopez was following one of the suggestions by scheduling free time during the first hour of the museum visit, thus providing opportunity for students to explore the exhibits of their choice and to share the experience with their friends.

After an hour had passed, the group interaction with the physics of music exhibit was under way. A crowd quickly gathered at the center of the exhibit, a ten foot long floor mat piano keyboard that you played with your feet! Since many of the students and all of the teachers had seen this commercially available, larger-than-life toy in the recent comedy "Big," there was no hesitation in slipping off their shoes and lining up to perform in pairs. Students with previous piano lessons were especially popular as partners since they could instruct their fellow student which keys to step on in order to hammer out a recognizable tune.

To everyone participating, the exhibit became a kinesthetic experience with music and sound, even without the physics and technological explanations printed on the sign behind the exhibit. The students in the team responsible for presenting this exhibit module to the class the next day were busy writing notes and watching with delight the other students' performances.

Across the room, four students were clustered with Ms. Lopez inside a sound booth, interacting with a voice synthesizer. As students enters the letters of their name on the computer keyboard, the group recorder wrote what he thought he heard the synthesizer "say." Right away, the students discovered that not all letter sounds were synthesized with the same clarity. In fact, the letter "l" sounded more like the letter "r" so that when Sally entered her name, the synthesized response sounded more like "Salery" or "Sarrie." The recorder jotted down the spellings as the group attempted to listen for certain letter sounds. After the third try, David looked up at Ms. Lopez and asked excitedly if this had anything to do with the way Uno, a

Japanese student in class pronounced her "l" sounds. Earlier in the year, Uno was reciting a poem in class that described a little bird in a tree. To most of the students it sounded like she kept saying "riddle bird." Ms. Lopez's response didn't surprise David; she said, "I don't know."

"Maybe a Japanese person invented this synthesizer!" Paul says as he hurriedly types in his name to see if the "l" at the end of his name produces the same effect. Everyone listens intently as the speaker responds with a "Paur" sound. Rodger records the sound, spelling it as the group best describes and then offers, "You know, the advanced band has a music synthesizer back at school and maybe the music teacher will let us experiment with it when we get back." Again, they glance up at Ms. Lopez. "Sounds like a great idea," she says, "You can ask him on the way home."

Before leaving the sound booth, Rodger, as recorder, reminds the group that they need to decide what they like best about this exhibit.

"Let's enter Ms. Lopez's name," shouts David with a big expectant grin on his face. Sally punches the keyboard and silence overcomes the entire group. "Roped" is the name they hear coming from the speaker and they all break out laughing. Ms. Lopez opens the door and backs out smiling, while Rodger writes her synthesized name next to the statement "Best thing about this exhibit."

This vignette exemplifies current knowledge of, and research on, human learning. Moreover, Ms. Lopez has taken that knowledge and used it as she and her colleagues planned their unit of study on sound and then implemented what the panel believes is a successful learning-teaching model for middle-level science and technology education.

The students had started their study of sound several days prior to the museum trip with a simple invitation by Ms. Lopez to the students to write down all the sounds they could hear in the classroom over a short period of time. She used that invitation again on the bus so that as the students entered the museum they were focused on this topic. The museum experience was not one of lecture and listen nor one of free discovery-play. Rather, after finding what exhibits were available to them, the students broke into groups and explored one or more of the exhibits. The exhibits had been designed to encourage the students to actively explore sound. Ms. Lopez and her colleagues would use these experiences to help the students construct a new understanding of the concept, sound.

The panel believes that science as a way of knowing (Moore, 1984) and technology as a way of adapting are important themes for learning. Although science and engineering are separate fields of endeavor with distinctly different approaches, as shown in figure 3, the two are also inextricably bound. Only about 30 percent of current research can be labeled "pure" science, while over two-thirds of recent Nobel prizes have been given for technological, rather than scientific, advances (Hurd, 1989). At the middle level, young adolescents using their developing powers of cognition can begin to understand the rich relationships between science and technology, while simultaneously seeing how the two endeavors are distinct. Students can see science and engineering as ways of asking questions, tinkering, searching for answers, confronting problems, evaluating possible answers, sharing discoveries, all leading to refined conceptual understanding for students. The panel believes that the approach scientists and engineers use to construct new knowledge provides teachers with a model of teaching and learning appropriate for a middle-level science and technology program. The panel believes that all students should become acquainted with science and technology in ways that parallel how scientists know their world and engineers solve their problems.

The teaching-learning model proposed later in this section is based on the panel's assumptions about students and learning. These assumptions are drawn from research, and they are strikingly different from the views held and promoted by many teachers. These new assumptions about students and learning define roles for teachers of science that are quite different from their roles in most middle-level classrooms today. In turn, these new roles require fresh approaches to the development of, and support for, teachers. This latter point is addressed in detail in the National Center's companion report, *Teacher Development and Support for the Middle Grades* (Loucks-Horsley et al., 1990).

What are the assumptions the panel holds for students and learning? What implications do these assumptions have for the role of the teacher? Is there a model of learning and teaching that can serve middle-level science and technology education? This chapter explores answers to these questions.

Emerging Views of Learning

Contemporary curriculum materials and instructional practices reflect the belief that learning consists of receiving information. This information is dispensed by the teacher or through the textbook, with the student taking a largely passive role (Novak, 1988). Teachers present this information through a presumably logical sequence of topics. Students spend most of their time listening to lectures and reading about science. They have few opportunities to explore natural phenomena directly or to discuss the results of their inquiries (Mullis and Jenkins, 1988; Weiss, 1987).

Current science materials and instructional practices reflect the assumption that there is only one style of learning. The dominant teaching model assumes that learning occurs through listening and reading. Current curriculum and pedagogy fail to meet the learning needs and requirements of a population that has diverse learning styles and varied ability to conceptualize (Hodgkinson, 1985; Weiss, 1987; Mullis and Jenkins, 1988; Panel review of materials, June, 1989).

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

Another view of learning, one that has emerged in the past decade or so, takes a cognitive perspective and argues that educators should focus on the mental constructs and organizational patterns that students have and which students use to guide their behavior. This emerging school of thought, which many researchers and educators call cognitive learning theory, or constructivism, proposes that students are active learners who constantly reconstruct their world view, as they try to reconcile past experiences and extant conceptual understanding with new experiences and information (Posner et al., 1982; Resnick, 1983; Linn, 1986; Novak, 1988; Tobin, 1988).

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 construct new conceptual frameworks. There is a growing body of research that supports the validity of the constructivist view (Posner et al., 1982; Driver, 1973, 1978; Anderson, 1987). This research supports the view that knowledge is a network of different concepts in the brain of the learner. Learners, thus, construct knowledge by making connections between new information and their existing conceptual network (Peterson, Fennema, and Carpenter, 1988). If the new information is consistent with a learner's existing conceptual framework, the learner can easily assimilate the new knowledge. However, if the new experience and information is sufficiently discrepant from the learner's conceptual framework, then the learner must accommodate that new information by actively reconstructing his or her framework.

Using the constructivist paradigm, researchers have provided new insights into the important role played by a student's prior knowledge (Linn, 1986; Anderson, 1987). Bartlett (in Champagne and Hornig, 1987) and Ausubel (1963) found that meaningful learning can occur when teachers present new ideas in familiar contexts. Only when the students cannot relate new ideas to already familiar ones will they resort to memorization and superficial learning, which is soon forgotten. Furthermore, research cited by Champagne and Hornig (1987) and research conducted by Anderson and colleagues (Anderson, 1987) demonstrates that students have understandings of science in ways not congruent with viewpoints held by scientists. Driver (1983:3) refers to these incongruent views as alternative frameworks. Additional research indicates that students can cling to their erroneous viewpoints into adulthood (Murnane and Raizen, 1988). How can educators help students develop new, more sophisticated views of scientific concepts to replace erroneous viewpoints?

Posner and his colleagues (1982) have provided us with insight into possible answers to this question, suggesting for example, that students must become dissatisfied with their existing conceptual viewpoint, while also seeing the plausibility of a new conception or construction. It is naive for teachers to believe that they can transmit correct views of scientific concepts to their students through the spoken and written word (Novak, 1988). Even conducting a science demonstration designed to help the students overcome an existing concept is probably not sufficient. Champagne and Hornig (1987) note that students who observed such demonstrations reported observations that were more closely aligned with their existing viewpoints than with what actually happened. Learning that leads to a changed conception takes time, because a student needs to compare and contrast new information (sometimes presented by the teacher while at other times discovered through inquiry) with an existing concept. With time and ample experiences, the student gradually modifies or replaces the pre-existing idea with a new, more sophisticated concept (Anderson, 1987). Teachers have a responsibility to select appropriate, meaningful materials, but it is the student who must bring meaning to those materials. Thus, teachers must consider the processes of learning, as well as the content of science, as they structure the classroom learning environment. Is there a model of learning and teaching that can serve middle-level teachers in the task of guiding students to reconstruct their conceptual frameworks?

A Teaching-Learning Model

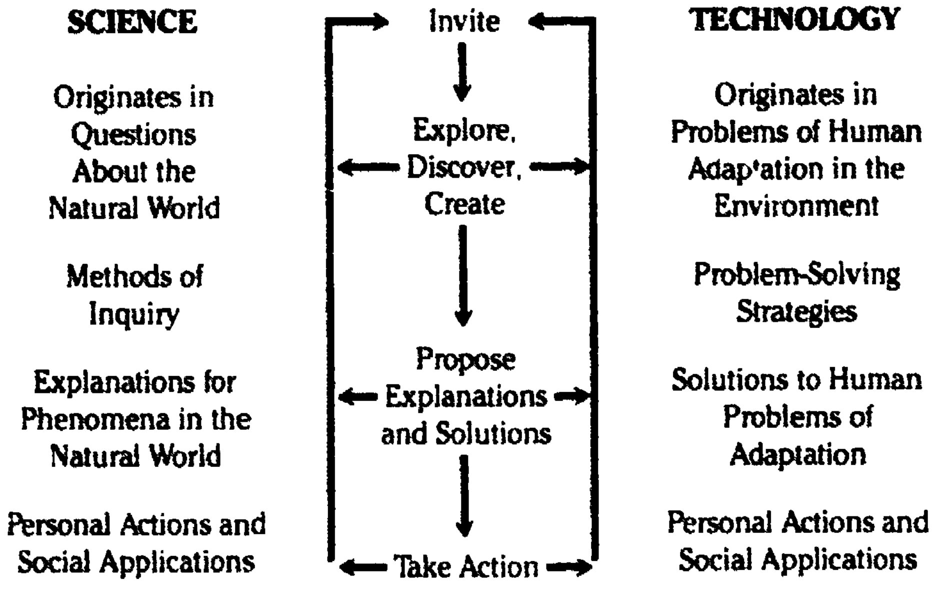
The panel suggests that a teaching-learning model-methods for teaching and learning science — should parallel the methods scientists and engineers use to uncover new knowledge and solve problems. These approaches are consistent with the emerging constructivist view of learning — a view that focuses on enhancing the learner's conceptual understanding of science and technology.

The proposed model is a template that teachers can use to design daily lesson plans and weekly (or longer) unit plans. The panel intends that the model will help ensure that science teaching and learning embodies multiple approaches to learning (tantamount to the experiences of active scientists and engineers), so that learners are asking questions, experimenting, and communicating their new knowledge to colleagues. The students also should have the opportunity and responsibility to act on newly reformulated knowledge and to ask new questions. The model should suggest to teachers and students that science and technology, as fields of study and human endeavor, are dynamic. The model reinforces the generative nature of science and technology: questions and problems lead to tentative explanations and solutions and in turn generate new questions and problems (refer to figure 4).

Components of the Teaching-Learning Model

The proposed teaching-learning model is based on four stages, characteristic of the approach taken by practicing professionals in science and technology, when they learn and apply new skills and information within their fields (figure 4). The descriptive labels for each stage are dynamic, as is the proposed cyclic nature of the model. The instructional model further clarifies for the instructor the dynamic process that is science and emphasizes that although single lessons or units of study may have a beginning (invitation) and an end (taking action), any new skills or knowledge will inevitably lead to new invitations and, therefore, a continuation of the cycle.

Figure 4
Instructional Model



To help the reader better understand the model, we describe what might occur at each of the four designated stages. Figure 5 lists key activities that might characterize each of the stages. These stages represent activities that practicing scientists and engineers might engage in as they learn. The stages, therefore, have parallel suggested activities. The instructional model incorporates the instructor as an active participant in the learning process and provides a guideline for the teacher's learning as well as the students' learning, because many middle-level teachers have limited formal training in science. In fact, the panel considers the model to be universal in describing any learning in science and technology, including learning by professional scientists, teachers, and students. The model is applicable in both classroom and laboratory settings as well as in less formal settings, such as the home, a park, museums, nature centers — literally any place where an invitation to learning may be recognized and accepted.

Invitation. The beginning of any learning process in science and technology is characterized by an invitation. In general terms, the invitation originates with a question about the natural world (science) or a problem in human adaptation (technology). More specifically, an invitation may be quite spontaneous — such as a student discovering an empty eggshell in the park — or it may be elicited by a demonstration of a discrepant event. In both cases, questions emerge immediately, the students and the teachers are observing together, and the stage is set for further investigation. It is important to remember that invitations must engage the learner. Therefore the learner must understand the event, question, or problem well enough to begin actively thinking about the question or problem. If the question, or problem, is not one the students are curious about, or one they initiated, or one they want to address or solve, then further engagement will be difficult and likely will not result in anything but rote learning (Hawkins, 1983).

Figure 5
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
Define parameters of an investigation		Analyze data
	Proposing Explanations and Solutions	
Communicate information and ideas		Construct and explain a model
Construct a new explanation		Constructively review a solution
Evaluation by peers		Express multiple answers/solutions
Determine appropriate closure		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

Although this figure has two distinct columns, a review of examples clearly shows that science and technology are intertwined; many of the examples could easily be placed in both columns. Communicating information and ideas, for example, is as much a part of science as it is a part of technology

Invitations can be made to the entire class. For example, to encourage early adolescents to embark on a study of water organisms and environmental issues, the teacher might bring in a sample of pond water and ask the question, What lives in a drop of pond water? This seemingly simple invitation could well lead students to search for additional information as they struggle with finding answers to more complex questions and issues.

Figure 5 lists suggested activities that are characteristic of this beginning stage of the model. Whereas at the elementary level, teachers and students frequently focused on this stage, with middle-level youngsters, who are developing formal thinking abilities, it is important to spend more time on the next three stages of the model.

Exploration, Discovery, Creativity. 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, to collect data, to begin organizing information, and to think of additional experiments that they might try. The stage is characterized by a strong element of constructive play or informal investigation in which the students try one approach with the materials, share their findings with each other, and try another experiment. They might use analogies or visual imagery to help them think about the new concepts that they are encountering. They begin to explore how new information gained from their investigations relates to previous experiences and their current level of understanding. The teacher is a co-learner and also a facilitator who chooses materials and activities that are likely to lead the students to new discoveries and information. The teacher observes with the students and asks questions with them. Teachers can model many of the responses, such as awe, enthusiasm, curiosity, and the temporary suspension of judgment, that are characteristic of scientists. The teacher also can further informally assess the young adolescents' developing understanding of a concept and pose questions that motivate them to investigate further and try to link the new findings to their current formulations of a concept. At this stage, the students' active reconstruction of conceptual knowledge should be well underway. Figure 5 lists possible activities for this stage of the model.

Proposing Explanations and Solutions. In this stage, the learners continue to refine their developing understanding of a concept. They construct a new view of the concept by integrating their current conception with new information, which they have gained through their explorations and discoveries and through the appropriate use of the textbook, other materials, and information provided by the teacher. The students then analyze data that they began to organize in the preceding stage and consider alternate interpretations prepared by classmates and the teacher. Cooperative learning is an important part of the teaching and learning approach. New explanations can be developed jointly with the teacher and peers by sharing information and actively listening to one another's proposed explanations. The students, guided by the teacher, may decide to perform additional investigations, usually more focused than those they conducted earlier. The results of these experiments will help resolve conflicts that students have between their previous understanding of a concept and a newly emerging view. Each learner, with the assistance of the teacher, brings new meaning to a concept. This cooperation between students and the teacher is an opportunity for the teacher to model qualities that characterize scientists: proposing and accepting alternative points of view, listening and questioning, persistence in seeking solutions, and working together cooperatively. Figure 5 lists activities that are characteristic of this stage of the model.

Taking Action. Once the students have constructed a new view of a concept, they are usually ready to act on that new level of understanding. Figure 5 lists possible ways in which they can take action and demonstrate that they have truly integrated the newly discovered information and proposed solutions into their existing framework of understanding. They might defend a point of view before the class or write a letter to a local authority, 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 through the teaching examples listed in figure 5 and to assist the students in transferring their new knowledge to other fields of study. The teacher also can assess, informally and formally, each student's new level of understanding and gauge the effectiveness of the science program. This will help the teacher plan future activities appropriate to the students.

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

Although this figure has two distinct columns, a review of examples clearly shows that science and technology are intertwined; many of the examples could easily be placed in both columns. Communicating information and ideas, for example, is as much a part of science as it is a part of technology.

Other Models

The panel's teaching model guides teachers as they construct their instructional programs, parallelling the model of science and technology provided in figure 5. The model's stages are presented sequentially so that the model can be more easily interpreted; naturally, the practicing scientist rarely, if ever, follows the model step-by-step. In figure 4, the illustration, with its arrows and possible loops, illustrates the complex nature of scientific investigations. In the classroom, after initial engagement, the children and the teacher may engage in exploratory investigations, propose tentative solutions, and explore concepts several times before coming to the last step, taking action.

The teaching model is compatible with several other models of teaching and learning, such as the Generative Learning Model (Osbourne and Wittrock, 1983) and those models currently under development at the Education Development Center (EDC) and the Biological Sciences Curriculum Study (BSCS).

The Generative Learning Model (GLM), proposed by Osbourne and Wittrock (1983) and recently summarized by Kyle and his colleagues (Kyle et al., 1989) has four steps that closely parallel this report's proposed model of learning and teaching. Prior to any formalized instruction, the teacher assesses students' ideas and conceptual explanations. In the next step the instructor provides experiences related to the particular concept that motivate the students to explore their level of conceptual understanding. In the third step, the teacher assists students to exchange points of view and challenges students to compare and contrast their ideas and support their viewpoints with evidence. Finally, students use their newly refined conceptual understandings in familiar contexts. Thus, the model has four phases: preliminary, focus, challenge, and application.

The EDC framework for instructional strategies also has four phases:

Engaging. The teacher probes the students' prior knowledge, motivates the students, sets goals, and starts experiments. Children ask Why? What is it to me? and What are the goals and expectations? They begin to interact with materials.

2. *Exploring and Discovering.* The teacher is a facilitator who observes, mediates, and assesses. Students experiment, observe, record, and interpret data as they solve problems. At this stage, students work in cooperative groups and share materials, coach and monitor each other, and report findings.
3. *Processing for Meaning.* Together, students and teachers question, hypothesize, analyze data, build models, clarify concepts, bring closure, and apply new knowledge in other contexts.
4. *Evaluating.* Students apply, integrate, extend, and question their knowledge. The teacher evaluates how the students' concepts, process skills, and attitudes have changed and judges the program's effectiveness in promoting changes in students' concepts.

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

1. *Engagement.* Activities in this phase mentally engage the student with an event or question. Engagement activities help the students make connections with what they know and can do.
2. *Exploration.* The students work with each other to explore ideas through hands-on activities. Under the guidance of the teacher, they clarify their own understanding of major concepts and skills.

3. *Explanation*. The students explain their understanding of the concepts and processes they are learning. The teacher clarifies the students' understanding and introduces new concepts and skills.
4. *Elaboration*. Activities in this phase challenge the students to apply what they have learned, to build on their understanding of concepts, and to extend their knowledge and skills.
5. *Evaluation*. The students assess their knowledge, skills, and abilities. These activities also allow teachers to evaluate a student's progress.

The National Center's proposed model, and the three just presented, all have important commonalities. In all the models, students are active rather than passive learners. Additionally, the models attend to the development and refinement of students' conceptual understanding rather than simple rote memorization or accretion of scientific and technological facts and bits of information. Such information can and should be a part of a middle-level science program, but only within a program whose primary focus is major conceptual ideas. All of the models recognize the importance of considering students' current conceptual understandings at the beginning of a unit of study, followed by the provision of experiences that encourage students to explore their understandings. Only after these two stages can teachers facilitate the exchange of viewpoints among students, provide additional information to help them change their viewpoints, and challenge them to defend points of view in an attempt to move students to accommodate their current conceptual frameworks to new information. Finally, students need opportunities to try their reconstructed frameworks in familiar and then different settings. Although the models have been presented as sequential in nature, the panel recognizes that learning is likely not so sequential; rather, "accommodation will be a gradual and piecemeal affair" with false starts, some mistaken paths, and even reversals of direction (Posner et al., 1982).

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

The National Center's proposed model, and the others described herein, represent significant refinements of the discovery learning and inquiry-based instruction that were proposed (and put into practice in some cases) in the 1960s and 1970s. Those approaches frequently did not recognize the importance of students' prior knowledge. In some cases an inordinate amount of time was spent on activities without sufficient time on sharing and challenging viewpoints on major concepts. In other instances, teachers verbalized the concepts prematurely.

The ability of the panel's proposed teaching model (figure 5) to incorporate models, such as those used by current, major curriculum development efforts in middle-level science, demonstrates the robustness of the teaching model, and the power of "science as a way of knowing" as a framework for instruction and curriculum. The frameworks presented in this chapter and the previous one have significant implications for teachers. The National Center's companion report, *Teacher Development and Support for the Middle Grades* (Loucks-Horsley et al., 1990), details the changes in the education of beginning and experienced teachers that are necessary if schools are to implement the findings and recommendations of this report on curriculum and instruction.

Conclusion and Recommendations

In this chapter, the panel has presented a summary of recent research on human learning in science and technology. The emerging view is a constructivist one: students learn by constructing a new view of their science and technology worlds. Based on recent information on human learning, the panel proposed a learning-teaching model, which is patterned after the ways of knowing and problem solving used by active scientists and engineers.

Invitation. This stage initiates the instructional sequence. The object of the invitation phase is to engage the learner with a question, problem, or event related to the concepts or skills of the learner. The teacher solicits from students their current understandings and exploration of concepts.

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

Proposing Explanations and Solutions. This stage allows the students to express their explanations and solutions. It is also a time for the teachers to introduce concepts and vocabulary and for teachers to challenge students to defend emerging viewpoints with supporting evidence.

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

The panel recommends that:

1. Educators and schools adopt a learning-teaching model, such as that proposed by the National Center, that is consistent with the emerging constructivist view of human learning.
2. Educators and schools adopt instructional practices that reflect a constructivist view of human learning and that are also consistent with the cognitive, physical, social, and emotional development of young adolescents.

Chapter VIII

The Learning Environment

The title expresses the panel's vision of middle-level classrooms; they should be environments where students are engaged in learning. The chapter begins with two vignettes, one that centers on the physical environment and one that elaborates the learning themes.

The classroom vignette at right exemplifies some of the recommendations from this chapter. The classroom has adequate facilities, equipment, and materials; instructional technology is available and used; and students work in cooperative groups.

In the vignette below, each student has chosen a science project, designed an "experiment," collected data, and presented the results. The students are studying a topic in-depth, using technology, building on their interests, and acting like scientists.

A Learning Environment

Students were reporting on their projects. Most students displayed their projects in ways one sees at science fairs. The teacher, Ms. Washington, was video taping each 3-4 minute presentation. Several students listened to the presentations while other students silently played board games. Indeed, the room was particularly quiet since students were using hand signals to communicate.

Reports by these 6th grade students revealed a variety of interests, sophistication, and methods. One student answered the question, "What is horsepower?" Another answered the question, "Where do drugs come from?" One student tried to answer the question, "How many people are familiar with acid rain?" Other projects included an experiment with liquids on plants, water transpiration, extra sensory perception, the amount of vitamin C in different fruits, and the corrosion of nails in different liquids.

Ms. Washington focuses the video camera on Thomas' data table enumerating responses from his adult subjects to his question "Have you heard of acid rain?"

"I wanted to find out if people had even heard about acid rain," he narrates, "I found out that less than one half of the adults I asked knew anything about it."

Ms. Washington asks the rest of the class if anyone has a question or comment for Thomas. One student wants to know where he got his idea for his project.

"Well, we studied about acid rain in science and it seemed pretty important. And if we're going to have to change things like cars and maybe use genera-

A Middle-Level Science Classroom

On the wall were two pictures, side by side; a detailed pictorial chart of "organelles of a typical plant" and a Garfield cartoon with the caption, "I'm learning by osmosis." Standard items for a science classroom — bones, glassware, models, and materials — filled the shelves. The room was equipped with laboratory tables, sinks, and a hood. On the chalkboard was a formula, $D = r \times t$; also on the board was an inspirational poster with the caption "You don't know what you can do until you try." A teddy bear was sitting on top of a computer in the front of the room.

The lesson was an introduction to longitude and latitude. The teacher introduced the terms, and had students review the definition, "lines of longitude are north/south and measure east/west." The lesson continued with the students working in cooperative groups and identifying different locations on maps. This introduction was background so the students could collect and share data on their pets with students all over the country. The class was using a new science program, the National Geographic Kids Network, which gives the students the opportunity to collect and analyze data locally, and then share data with students all over the country through telecommunications *tors instead of gasoline or at least a different kind of fuel, then everybody should know about how acid rain is hurting the environment."*

Ms. Washington has filmed Matt's investigation of his hypothesis about nails: the iron nails will disintegrate faster than galvanized nails when in contact with water, salt water, vinegar, and Coca Cola. He has observed his nails in their jars of different solutions for 42 days and has concluded: "I wasn't right and I wasn't wrong." He has noted that disintegration was decisively faster in one case, but not in another. He has also become intrigued by the growth of green, slimy stuff in the Coca Cola jars but not in the others and now his attention has turned from the chemical reactions of nails to what allows or prevents growth of living things in solutions; if the jars were closed where did the mold and slimy stuff come from in the first place?

Ms. Washington takes this opportunity to point out that some of the great scientific work developed from noticing and questioning unexpected results. She mentions the discovery of penicillin and Marie Curie's work with radioactivity. She encourages Matt to continue his investigation and praises him for being willing to modify his original idea based on his own experimental data, for being willing to live with indecisive results, and for noticing unanticipated patterns that led him to a new set of questions.

Ms. Washington's invitation to her sixth graders was to choose a question about their world and to pursue an answer using some scientific practices. The questions they chose tell the observer something about the students themselves:

"How do people react if you ask them how they feel about rocks, dirt, and slugs down their shirts"?

"Which fruit juice contains the most vitamin C?"

"What makes electromagnets stronger or weaker?"

The students were invited to identify questions that have meaning for them and to investigate those questions using scientific models. Topics of interest included drugs, human behavior, and ordinary objects and phenomena. The students have practiced asking questions, collecting data, organizing, presenting, and communicating their findings for themselves, to their peers, and to that impartial observer, the camera.

For Thomas, his prior study of acid rain led him to understand that answers to questions about acid rain have implications for him personally and also for society. These realizations led to his question, "Have adults even heard of acid rain?" Clearly, he has a number of questions that he cares about

While perhaps less profound, Myra's investigation of student responses to her question about dirt down the shirt allowed her to work within the realm of her choice. She has been successful in taking her investigation through to completion. While her oral report was somewhat sparse and halting, and she was apparently somewhat uncomfortable communicating her findings, familiarity and comfort with her topic, and the objectivity of the camera enabled her to give a short but lucid account.

Ms. Washington wanted her class to practice some of the attitudes and skills of scientists. She enabled all students to do so successfully by giving them choice, limits that insure success (advising prevented overly broad or complex questions), time to work on a topic in depth (the nails had been immersed for 42 days), active learning through assembling materials, doing interviews, and practice communicating in formats appropriate for sixth graders, to and in the presence of their peers. Even at the presentation stage mistakes were allowable:

Ms. Washington: "I'm turning the camera off. Would you like to say something about...?"

Thomas, Matt, and Myra will soon be introduced to National Geographic Kids Network. They will be asking questions about pets, but this time they will take the process of data collection and organization to a higher level, integrating the use of another technology into their repertoire. The appeal of real questions close to home, group interaction, and new technologies such as video and computer, compel the Thomases, Matts, and Myras to engage in some real science and to appreciate the role of data in the answering of questions.

Learning environment is an elusive concept. Difficult to describe, most educators "know it when we see it." Central to the learning environment is the teacher, then the curriculum, and finally materials, equipment, and facilities. This chapter concentrates on the latter components of the learning environment.

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

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

We usually think of the classroom as the main influence in science education, but recent research suggests that out-of-school activities, such as visits to museums and zoos, are highly correlated with science learning. Experiences outside the classroom are essential to the curriculum. The panel recommends that teachers use the community as a classroom and laboratory. Museums, nature centers, zoos, and wildlife reserves are ideal extensions of the classroom. The panel also encourages use of these extensions to make learning personally meaningful for early adolescents. To maximize learning situations, the teacher should give ample preparation for the goals and purposes of these experiences. Communication, in the form of discussions, writing, reading, and thinking, will help teachers and students answer the questions: Where are we going? Why are we going there? and, What will we learn?

The home is another influential setting in which science learning can take place. Parental involvement and television are methods of promoting science learning. Homework is a valuable complement to classroom instruction, particularly if it is checked and discussed within the family (Murnane and Raizen, 1988). By using a variety of media, the students expand their imaginations and have extended opportunities to apply a concept or skill.

Flexible Scheduling

After studying a national survey of middle-level schools, Alexander and McEwin (1989) concluded that good middle-level schools exhibit an interdisciplinary organization, with a flexibly scheduled day. The researchers found considerable increases between 1968 and 1988 in the percent of schools using interdisciplinary team organization. However, approximately two-thirds of schools for early adolescents do not use this plan. Departmentalization is the most common organization in middle-level schools. The survey by Gordon Cawelti and the Association for Supervision and Curriculum Development (1988) found similar results.

In 1984 Joan Lipsitz published a book entitled *Successful Schools for Young Adolescents*. The Lipsitz study was guided by the question, "What is a good school for young adolescents?" Lipsitz completed case studies on four middle-level schools in order to answer the guiding question. What did Lipsitz conclude?

> *The most striking feature of the four schools is their willingness and ability to adapt all school practices to the individual differences in intellectual, biological, and social maturation of their students (Lipsitz, 1984:167).*

Later, Lipsitz addresses the issues of organization and structure. The lesson about structure is seen in words like organic and evolving. The principals had a vision of what schooling should be like for young adolescents; organizational decisions resulted from the school's philosophy.

Major reports such as *Caught in the Middle* (1987) and *Turning Points* (1989) have followed these studies with policy recommendations. The recommendations from *Turning Points* follow.

> *Students need time to learn, especially to learn material in depth. When the time allotted for classes is always limited to 40 or 50 minutes, many youth will not master all the material.*
>
> *A key feature of the transformed middle grade school should be flexibility in the duration of classes. Teacher teams should be able to change class schedules whenever, in their collective professional judgement, the need exists. They should be able to create blocks of time for instruction that best meets the needs and interests of the students, responds to curriculum priorities, and capitalizes on learning opportunities such as current events (Carnegie Council on Adolescent Development, 1989:52).*

Flexible scheduling may consist of extended blocks of time for science activities, alternating emphasis on core subjects, elective studies, shared planning time for teachers, and different assignments for difficult students.

The panel members thought it important to add a note on grouping of students. A recent national survey revealed that approximately two-thirds or more of the nation's schools serving early adolescents use some between-class ability grouping, and more than twenty percent assign students to all their classes according to ability. Ability grouping for all subjects is more prevalent in schools with large (more than twenty percent) enrollments of Black and Hispanic students. Research strongly suggests that students in the lowest ability groups are often stigmatized by teachers and peers as poor learners. The students then internalize these negative expectations and develop poor self-images and a lack of confidence in their abilities as learners (Braddock, 1990).

This panel agrees with the conclusions of Harold Johnston and Glenn Markle (1986).

> *The practice of grouping students by ability for instructional purposes is not supported by research. Even though a majority of teachers believes that ability grouping improves the effectiveness of schooling, the studies reviewed suggest deleterious effects on teacher expectations and instructional practices (especially for students in lower-ability groups), students' perceptions of self and others, and academic performance of lower-ability students. [Ability grouping] interferes with opportunities for students to learn from — and learn to accept — peers of different socioeconomic backgrounds, and may perpetuate notions of superior and inferior classes of citizens. The practice is especially antithetical to the goals and objectives of the middle school (Johnston and Markle, 1986:59).*

Between-class tracking has proven to be one of the most divisive and damaging school practices in existence. Cooperative learning and cross-age tutoring have been documented to be far more effective in teaching diverse groups of students (Carnegie Council on Adolescent Development, 1989:49-50).

Facilities and Equipment

To teach science and technology in the middle-level classroom requires plenty of space, tables or desks with ample surface area, running water, and electrical outlets. When these things are not in the classroom, teachers need to make the most of the resources that are available within the school and community, including the physical plant, surrounding grounds, and human services.

A teacher who uses the proposed frameworks for curriculum and instruction will depend on a well-maintained facility. The availability and maintenance of equipment, media, and supplies should be adequate to support the program's requirements. Systems should exist to provide materials, collect and replenish materials for the next use, and offer assistance in getting unusual materials for interested students and teachers. The school should have allocations for a reasonable collection of science-related books in the school library.

Each classroom should allow for flexible seating arrangements. Within the school, there should be space that allows for display of science activities, storage of materials and unfinished projects, and interest centers on science topics under study (Pratt, 1981).

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

Communities have resources, such as people, museums, nature centers, zoos, industries, and farms. Middle-level teachers who use these resources must make an extra effort to make the experience meaningful, but the cooperation from community groups is usually obtained easily and the rewards for the students are substantial.

Instructional Materials

Science textbook series designed for the junior high school are the dominant instructional materials in middle-level schools. Textbooks focus on learning about science rather than encouraging active involvement by students. Subjects reflect the disciplines of life, earth, and physical sciences. Textbooks emphasize description, explanation, and identification, and generally neglect higher order processes, such as interpretation, evaluation, analysis, and synthesis (Blosser, 1986; Boyer, 1988; Jacobson, 1986; Weiss, 1978 and 1987).

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

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

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

Instructional Technology

While middle-level schools continue to acquire microcomputers and similar technologies, research indicates that teachers make little use of the equipment to enhance their instruction. Typically, science students spend fewer than 15 minutes per week working with computers. Over 85 percent of students in middle-level schools never use computers. Moreover, research indicates a need to study ways to improve education in science through information technologies (Bybee and Ellis, 1989; Weiss, 1987; Educational Technology Center, 1988; Cawelti, 1988; Alexander and McEwin, 1989; Mullis and Jenkins, 1988).

Technology pervades the students' world, and can be used selectively to enhance the learning process. There are several functions of technology for instruction in the classroom, including the use of computers for organization, presentations, simulations, and data collection. Computer technology also can help the teacher to simplify grade books, to produce posters and banners, to provide access to word processing, and to deal with other classroom management problems. Middle-level schools need to budget for the use of technology in the classroom. First, staff development must be paid for. Second, someone must keep track of the hardware and software, as well as evaluate new products and recommend purchases. Third, the cost of hardware repairs and service contracts must be budgeted for.

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

Bybee and Ellis (1989) have outlined recommendations for the appropriate use of information technologies in elementary science programs that are also appropriate for middle-level schools. The recommendations are divided into two categories: microcomputer courseware and video courseware.

Microcomputer Courseware

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

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

Hypermedia. The recent development of Apple's HyperCard™ and IBM's LinkWay™ provides students with the opportunity to seek and obtain information on numerous and varied topics. In the future, HyperCard and LinkWay could easily replace textbooks as sources of information (both print and visual) in the middle-level classroom.

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

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

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

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

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

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

Video Courseware

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

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

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

Time

Adequate statistics are difficult to obtain concerning the time devoted to science in middle-level schools. Ninety-one percent of middle-level schools report that science is taken all year by all students. In grades four through six about 38 minutes per day is devoted to science. Lecture and discussion dominate 87 percent of the time. Although teachers and principals believe that "hands-on" approaches promote effective science teaching, time devoted to this approach is less than one-third (29 percent) in science classes (Weiss, 1978, 1987; Alexander and McEwin, 1989; Mullis and Jenkins, 1988).

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

We recommend that teachers at the middle level should spend an *average* of 60 minutes per day or five hours per week on science, allowing 50 percent of this time for experiential learning in the form of laboratories and activities. Much of this suggested time for science can be used for integrated activities, such as reading science stories, doing arithmetic related to science, and writing about science.

Increased time spent teaching science in middle-level schools does not, in itself, guarantee higher achievement in science, but greater amounts of time spent by students on active learning does lead to higher achievement (Stallings, 1975). Developing science skills requires time. It is unrealistic to imagine that 45 minutes a week can make anyone a competent measurer or scientific problem solver (Hein, 1987). In addition, learning concepts in depth requires time, so learning opportunities and curricula should have extended time for exploration and reflection (Newmann, 1988).

Groups

Students work alone or listen to the teacher the majority of the time. After direct instruction (used by 98 percent of schools), inquiring (41 percent) and cooperative learning (40 percent), are the strategies most often used in schools that serve early adolescents (Cawelti, 1988).

The proposed program assumes a variety of student grouping arrangements and suggests appropriate teaching strategies for those groupings. For example, suggested groups might include full-class involvement, small-group cooperative learning, and individual projects or independent study. Effective groups are designed to address student interest, management of equipment and laboratory space, abilities, and the need for some random divisions. Grouping should always reflect the best benefit to the learner and avoid convenience or restrictive groupings that foster bias by gender, culture, ability, or handicap. Constructing effective learning groups holds great promise for increasing quality learning time (Cohen, 1986).

Classroom Management

Management of materials and students continues to be a significant barrier to science teaching in middle-level schools. Teachers and principals believe that active hands-on instruction is more effective, but the special materials, equipment, and especially management of students and materials, are commonly cited reasons such approaches are not extensively used (Weiss, 1978 and 1987).

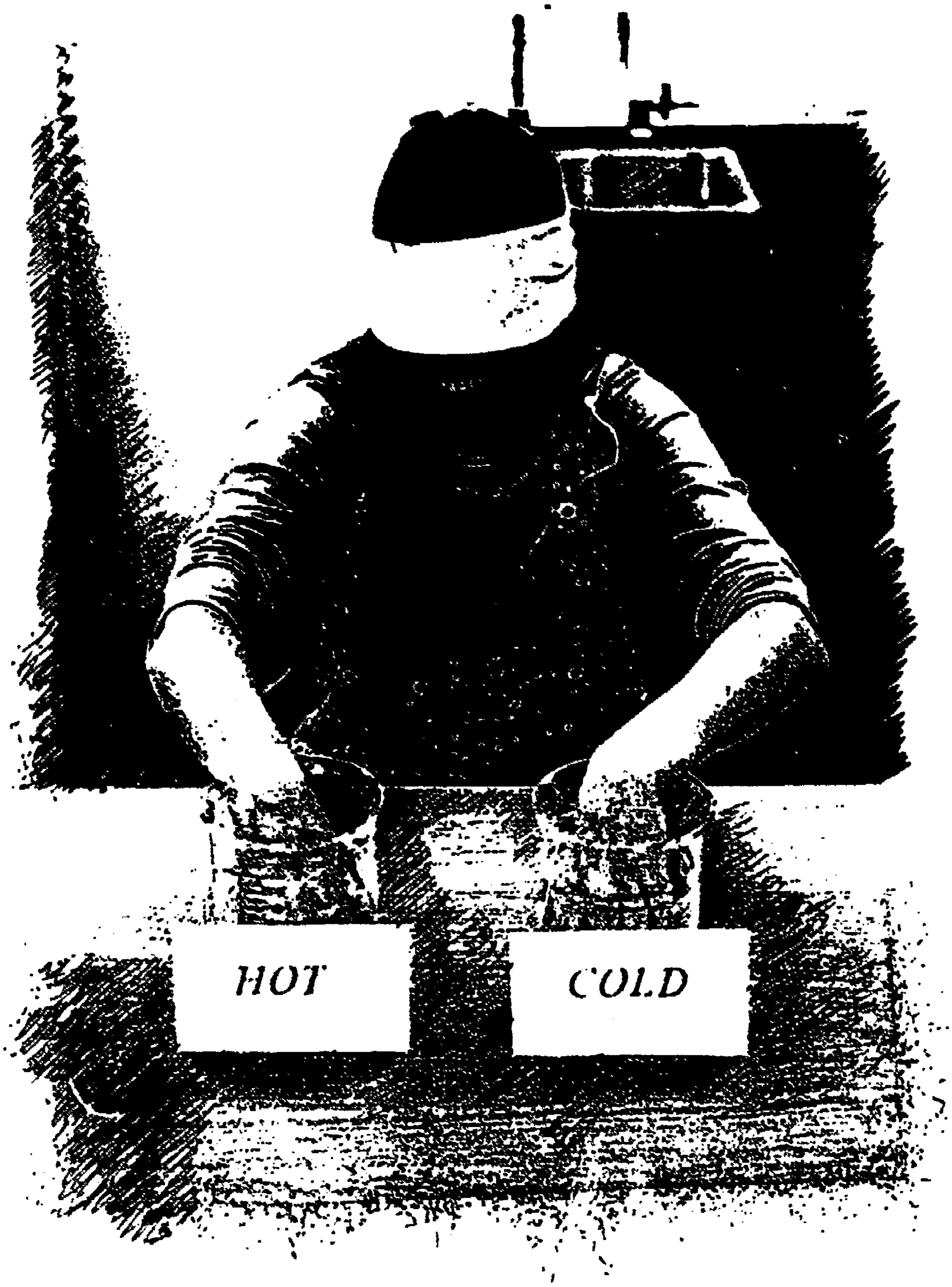
By its nature, the proposed curriculum implies a classroom in which talking, sharing, and movement are not only acceptable, but necessary. By using groups, the middle-level teacher can shift from the role of leader to that of expeditor, facilitator, and co-learner. The organization of tasks and preparation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

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

Conclusion and Recommendations

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. Recognizing these requirements, the study panel made recommendations for a learning environment. Some of the specific recommendations are summarized in the following statements:

- Schedules for the year, units, and day should be flexible.
- Cooperative groups and peer teaching are recommended instead of tracking and ability grouping.
- Facilities should include appropriate flexibility for hands-on activities, peer discussion, cooperative learning, and large-group presentations.
- Facilities should include outdoor environments, resource people, museums, nature centers, zoos, industries, and businesses.
- Instructional materials should include a variety of resources that support instruction which uses a hands-on approach.
- Technology should be a regular part of the curriculum and instruction.
- Computer technology should be used for instructional purposes and for classroom management.
- Teachers should spend an average of 60 minutes a day or five hours a week on science. Fifty percent of this time should be for hands-on activities.
- Use of computers and cooperative groups will contribute to more efficient classroom management.


HOT
COLD

Chapter IX

A Framework for Middle-Level Science and Technology Curriculum and Instruction

Earlier chapters addressed several components of a framework for curriculum and instruction: a conception of science and technology, goals for the curriculum, a rationale for the goals, major conceptual themes, and a learning model. This chapter begins with a vignette that describes a team of teachers as they begin to plan a unit of study. The panel then describes 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 give several examples of programs, units, and lessons that were designed using the framework. We then identify and describe several issues that can impact on the framework and on its implementation.

Ms. Lopez Goes to the Middle Level

In her school system, Ms. Lopez became well-known for her successful teaching of science in her second grade class, for making science a part of the daily elementary program, and for using the interest in and motivation for studying science topics to teach reading, math, and writing. When a science position in a middle-level school became available, Ms. Lopez was invited to fill it. She learned she would be part of a four-teacher team for which subject integration and team planning were vital parts of the curriculum and instruction.

The science course of study for her grade level called for emphasis on process and encompassing conceptual themes and topics related to the lives of students. Science topics were assigned to each grade level. One of these was sound. At her team meeting Ms. Lopez presented sound as the next unit of study.

The team generated a list of questions they must address in planning their teaching.

- *What are the conceptual themes that may be illustrated by a study of sound?*
- *How can this study be linked to math, reading, and writing? Art?*
- *What are some key active and engaging activities that will capture the interest of the students? How do we tie into the interests and knowledge students bring to this study? How do we find out what their interests are while also exposing them to new possibilities?*
- *Is there a way the classroom computers can strengthen the unit?*
- *What do we want the students to learn?*
- *How do we know what they have learned?*

"Let's start with what sound is. I think we often take something as common as sound for granted and we ought to invite exploration of what sound means to the kids."

"Could we start with a sound survey,

have the students find out something about sound, collect data and present it to the rest of the class?"

"Let's have the students sit in one place for 10 minutes, list all the sounds they can hear in one column and try to figure out their source in another column. They can write about their experience and then share with classmates."

"Another activity we could do earlier in the unit would be a trip to the science museum. Remember last fall when the museum director told us about the sound exhibits? Those exhibits would allow the students to explore various aspects of sound."

"We've never tried this before so I am not sure if it would work, but we could have them make a histogram from the results of the sound surveys. It would tie nicely to the work we've been doing on graphing."

"Pretty quickly, I'd like to begin talking about vibrations. It would be great to involve the music teachers at this point, having each student make a simple stringed instrument with a board, string, and screw-eyes, experimenting with changing the length and tension of the string and then looking at and listening to a cello or violin. You can see the strings vibrating so beautifully. In fact, the kids can make wind and reed instruments with straws, hoses, plastic tubing, or bottles. They can make percussion instruments. Bottle xylophones are great for challenging their thinking about why the pitch changes when the amount of water varies."

"It will be possible to know whether or not a student has found a pattern by seeing if they can put an additional bottle into a series already set up according to ascending or descending scale. In fact, there are dozens of ways they can show us their understanding of pitch, volume, and even the meaning of vibration."

"We ought to present use of sound for communication. Animals use sound for finding mates, marking territory, establishing dominance, and echolocation. Use of sonar in mapping the ocean floor, in submarine warfare, and in medicine are examples of technology. We could ask the students to figure out what the problems were that the engineers solved. I think one of the parents in this class is a radiologist and could come in and talk about the use of ultrasound in medicine.

"What about having someone who gives hearing tests come in to explain how they find out if a person's hearing is normal or problematic?"

"How can they generate quantitative data in addition to their sound surveys?"

"If we asked them 'what is too loud?' they could use a tape recorder to test people's definitions. They'd have to grapple with all the issues of controlling the experiment, use the same part of a tape, the same recorder, the same ambient sound, etc. It would make them really think about designing a fair test."

"Technical Education Research Centers has a sound probe and a software package that can be used with a microcomputer that will give some numerical data the kids can use in seeking the answers to some of their questions. They'd love using the computer."

"There are some big health issues related to sound that I know interest kids. When my younger students studied the ear they asked me if it's true loud music really can make you deaf. Sound pollution is a good science-technology-society issue these kids could investigate. For instance, some towns have restrictions on the hours people may run any power tools such as a lawn mower. I'd like to hear the kids plan a town meeting where one group of citizens wishes to limit the amount of noise that can be generated, a gravel operation says it could be economically hurt by such a ruling, and another group objects to limits on their personal freedom, and the town council

has to make a decision. This would be a great problem for research followed by a debate. Kids could choose which group they wanted to represent. We'll brainstorm sources of information, then the librarians can help them find print resources. They can go out into the community to interview citizens and businesses that might be affected by noise restrictions, and to find out about town government by seeing how such an ordinance gets passed or defeated."

"The key themes here seem to be patterns, and cause and effect. I think we should be sure that we point out places in our study of sound where these two themes are exemplified and that we draw parallels with other areas of science where they are relevant."

At the end of this expansive discussion, the team began to block out times for these activities and to assign responsibilities to the team members. The social studies teacher undertook some research on the history of communications which would become the core of her class for the duration of the sound study. The involvement of the music, math, and language teachers assured an integrated approach. The art teacher wished to join in this study and was considering two different projects; a mural depicting the history of communication in America or an assignment for students to represent vibration and sound visually in a way that would convey their understanding of cause and effect or patterns. It was decided to devote four weeks to this topic; to plan the four weeks initially but to review, revise, and redesign at each planning meeting. Assessment would occur throughout based on challenges requiring manipulation of materials, written work such as the sound survey, oral reports such as the debate on sound control, vocabulary tests given at the end of the unit, visual representations and discussion by the artist, etc. Students would evaluate the unit at the end in terms of the goals of the unit and the activities, with questions such as "what did you like the best, the least, what was hardest for you, the easiest, if we planned a sound study for next year's class what would you keep and what would you omit?"

Ms. Lopez and her team mates have many potentially effective ideas for their unit on sound. How successful they will be in designing the unit — that is, how much learning will occur in their students — will largely depend on how they attend to the criteria and guidelines included in the framework the panel describes in the remainder of this chapter. Program design is not a haphazard process; rather, Ms. Lopez and her colleagues have far-reaching decisions ahead of them. They must decide what content is important, which instructional strategies to use and when to use them and, finally, they must decide on which assessment practices will guide their instruction and what type of assessment will give them the maximum information about their students' learning.

What is a Framework for Curriculum and Instruction?

A framework for curriculum and instruction is an intermediate formulation between the idea for a curriculum and the curriculum itself and ideas about instruction and actual instructional practices. The framework specifies and explains the basic components used to design the science program. In the past, it was common for a curriculum framework to specify only criteria for content selection. Little, if any, attention was paid to a learning-teaching model and few curriculum developers attended to assessment practices that were consonant with their beliefs about content and learning. A complete framework provides information needed to make decisions about the content, the sequences of activities, the selection of instructional strategies and techniques that are likely to be effective, appropriate assessment practices, and other specifics of the curriculum. At a minimum, a framework defines enough of the proposed program to differentiate it from other science programs.

A framework is like the broad sketches of an architect's plan. The framework gives an initial picture of the program and it is based on certain specifications. The architect's plan has to fulfill certain requirements. At the same time the more specific details are left to contractors and carpenters. Everyone knows there will be modifications as the framework is developed and implemented, but there should be some fidelity to the original intentions, specifications, and design.

A framework has advantages and disadvantages. An advantage of the framework is that program developers at local, state, and national levels have opportunities to provide specific ideas. One assumes those decisions would be made in terms of the unique characteristics of students, schools, and states, yet still fulfill the program developers' requirements. A disadvantage is that it is incomplete. It lacks a scope and sequence, the precise placement of concepts and skills, the selection of topics and learning activities, and the solutions for assessment, management of materials, and other practical matters. In a sense, the incomplete nature of a framework is a necessity based on the understanding that school personnel must make the final adjustments of the curriculum in terms of the unique characteristics of the school, community, and students

Selection and Incorporation of Instructional Strategies

There are numerous instructional strategies and approaches that educators can incorporate into a science program. Which strategies are appropriate and during which parts of a unit of study, for example, should they be used? In this section we provide answers to these and related questions. First we re-examine the learning-teaching model presented earlier and then we look at the multiple roles teachers must take at the middle level and the implication of those roles for instruction.

The Learning Model and Teaching

A constructivist learning model was presented in chapter VII. In that section, we described a learning model based on how scientists and engineers discover new knowledge. The model is also consistent with recent research on human learning that asserts that learners — middle-level students in this case — construct new levels of concept understanding by actively linking new information to their existing conceptual frameworks ("prior knowledge"). Thus, the model we proposed earlier can provide a scaffold for curriculum developers to use as they decide how to sequence activities. Figure 5 presented an introduction to possible teaching-learning approaches that the panel believes are compatible with each of the four stages of the model. In figure 6 we present a chart that the panel believes can be used by curriculum developers to decide what teachers and students would be doing during each of the four stages. We also point out instructional behaviors and student learning behaviors that the panel believes are inconsistent with each of the four stages.

Multiple Roles for Teachers

Recent recommendations from a variety of sources suggest that middle grade students should be taught:

- to ask meaningful questions about the natural world (American Association for the Advancement of Science, 1989);
- to learn to do science as well as learn about it (Champagne and Hornig, 1987);
- a common core of knowledge that allows students to become healthy, ethical, and active citizens (Carnegie Council on Adolescent Development, 1989; American Association for the Advancement of Science, 1989); and
- to solve problems that affect environmental and human welfare through informed decision making (Hurd, 1986)

These aims require teachers to function in a variety of roles and to use science teaching strategies that de-emphasize the factual and rote approach prevalent in many of today's classrooms. Skillful science teachers effectively fulfill various instructional roles. They facilitate student learning, manage the learning environment, coordinate the curriculum for their students, and assess their students.

Facilitator. Teachers must feel comfortable with their role, not as expert providers of knowledge, but as facilitators of learning. Teachers need to demystify science and change the image many students have of the scientist as a man in a white coat who has all the answers. Teachers can help the students feel confident and successful in science by relating the science activities to the students' personal lives. As facilitators, teachers greatly influence the climate of the classroom. They can model the qualities they wish to encourage in their students by showing curiosity, awe, and enthusiasm. The teacher also is the strategist who plans and provides materials. The lessons must be appropriate for the age and developmental level of the students. Allotting ample time for science activities also is part of the instructional strategy.

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

Figure 6
Interpreting the Instructional Model

Stage of the Instructional Model	What the Teacher Does	
	That is Consistent With This Model	**That is Inconsistent With This Model**
Invite	• Creates interest • Generates curiosity • Raises questions • Elicits responses that uncover what the students know or think about the concept/topic	• Explains concepts • Provides definitions and answers • States conclusions • Provides closure • Lectures
Explore, discover, create	• Encourages the students to work together without direct instruction from the teacher • Observes and listens to the students as they interact • Asks probing questions to redirect the students' investigations when necessary • Provides time for children to puzzle through problems • Acts as a consultant for students	• Provides answers • Tells or explains how to work through the problem • Provides closure • Tells the students that they are wrong • Gives information or facts that solve the problem • Leads the students step-by-step to a solution
Propose explanations and solutions	• Encourages the students to explain concepts and definitions in their own words • Asks for justification (evidence) and clarification from students • Formally provides definitions, explanations, and new labels • Uses students' previous experiences as the basis for explaining concepts	• Accepts explanations that have no justification • Neglects to solicit the students' explanations • Introduces unrelated concepts or skills
Take action	• Expects the students to use formal labels, definitions, and explanations provided previously • Encourages the students to apply or extend the concepts and skills in new situations • Reminds the students of alternative explanations • Refers the student to existing data and evidence and asks: What do you already know? What do you think . . . ? (Strategies from *Explore* apply here also.) • Looks for evidence that the students have changed their thinking or behaviors • Asks open-ended questions, such as: Why do you think . . . ? What evidence do you have? What do you think about x? How would you explain x?	• Provides definitive answers • Tells the students that they are wrong • Lectures • Leads the students step-by-step to a solution • Explains how to work through the problem

Figure 6

Interpreting the Instructional Model

What the Student Does		
That is Consistent With This Model	**That is Inconsistent With This Model**	**Stage of the Instructional Model**
• Asks questions such as: Why did this happen? What do I already know about this? What can I find out about this? • Shows interest in the topic	• Asks for the "right" answer • Offers the "right" answer • Insists on answers or explanations • Seeks one solution	*Invite*
• Thinks freely, but within the limits of the activity • Tests new predictions and hypotheses • Forms new predictions and hypotheses • Tries alternatives and discusses them with others • Records observations and ideas • Suspends judgment	• Lets others do the thinking and exploring • Works quietly with little or no interaction with others (only appropriate when exploring ideas or feelings) • "Playing around" indiscriminately with no goal in mind • Stops with one solution	*Explore, discover, create*
• Explains possible solutions or answers to others • Listens critically to one another's explanations • Questions one another's explanations • Listens to and tries to comprehend explanations offered by the teacher • Refers to previous activities • Uses recorded observations in explanations	• Proposes explanations from "thin air" with no relationship to previous experiences • Brings up irrelevant experiences and examples • Accepts explanations without justification • Does not attend to other plausible explanations	*Propose explanations and solutions*
• Applies new labels, definitions, explanations, and skills in new, but similar, situations • Uses previous information to ask questions, propose solutions, make decisions, design experiments • Draws reasonable conclusions from evidence • Records observations and explanations • Checks for understanding among peers • Demonstrates an understanding or knowledge of the concept or skill • Asks related questions that would encourage future investigations	• "Plays around" with no goal in mind • Ignores previous information or evidence • Draws conclusions from "thin air" • Uses in discussions only those labels that the teacher provided	*Take action*

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

Teachers can help students construct new knowledge through the following:

- Function as facilitators of learning or "guides on the side" (Wiles and Bondi, 1981:49 in ERIC, 1982).
- Capture students' interest and intrinsic motivation by giving them opportunities to make choices about the topics, methods, and learning materials (Wadsworth, 1987 in ERIC, 1982; Reynolds et al., 1985).
- Provide opportunities for student movement, small group, large group, and independent work (Wiles and Bondi, in ERIC, 1982).
- Match learning experiences to students' cognitive growth stages usually beginning with the concrete and moving toward the abstract, verbal, and reflective experiences (Kindred et al., 1976:47-48 in ERIC, 1982; National Science Board Commission, 1983).
- Include both laboratory work and projects (ERIC, 1982; National Science Teachers Association, 1986).
- Vary the type and rate of activities by using resource centers and modular materials (Eichhorn, 1966 in ERIC, 1982).
- Minimize abstractness with a variety of materials such as models, films, visual media, and computer simulations (National Science Teachers Association, 1986; National Science Board Commission, 1983).
- Consider the implications of questioning for middle-level students (Johnston, Markle, Haley-Oliphant, 1987). Teachers should:
  - allow for more than one correct answer so that many students can give successful answers;
  - provide opportunities for students to talk, argue, and answer questions/solve problems in small groups of their peers;
  - recognize the relationship between the diversity of students and their potential responses.
- Pose questions which:
  - utilize more open question and response strategies that intentionally elicit divergent and evaluative thinking (Blosser, 1986) and specific cognitive behavior beyond memory recall (Costa, 1985).

Learning Environment Manager. Learning is best facilitated when teachers can create and manage flexible, diverse, and rich classroom environments. A primary goal is to create an environment of trust where the students feel safe in trying new approaches to learning and feel confident in sharing their viewpoints about the concepts under study.

Teachers who are effective learning environment managers:

- create a community for learning where honest, open dialogue can occur among students and with the teacher (Carnegie Council on Adolescent Development, 1989; Anderson, 1989);
- involve multiple resources so responsibility for learning is shared with families and community resources (Carnegie Council on Adolescent Development, 1989; Beane, 1985);
- encourage personal and group relationships, interaction, and discussion among students and adults through small group work, learning, and similar organization structure (Carnegie Council on Adolescent Development, 1989; Eichhorn, 1966); and
- pay attention to major management themes:
    - do long-range task analyses to predict and trouble shoot possible problems for student learning
    - define clear and detailed rules, procedures, and expectations
    - establish a system to have students be responsible and accountable for academic work and classroom behavior
    - monitor and keep students appraised of the appropriateness of their behavior and work (Squires, Huitt, and Segars, 1984).

Curriculum Coordinator. The classroom teacher is not a passive recipient of, or participant in, the curriculum. Rather, teachers need to be actively involved in curriculum decision making and development just as we saw with Ms. Lopez and her colleagues at the beginning of this chapter. Teachers function as effective curriculum coordinators when they:

- help define a core of knowledge to be learned (Carnegie Council on Adolescent Development, 1989; American Association for the Advancement of Science, 1989) that will engage students in doing science as well as learning about it so that they can make decisions and apply science to their lives (Hurd, 1986).
- coordinate carefully defined objectives for thinking and process skills, conceptual development, attitudes, learning experiences, and assessment strategies (Squires et al., 1984).
- organize an exploratory program of all the sciences, issues in science and society, career awareness, historical aspects, and the nature and community of scientists (National Science Board Commission, 1983; Reynolds et al., 1985).
- work with colleagues to plan both discipline-based and interdisciplinary curriculum (Jacobs, 1989).

- include learning experiences that teach with and about new technologies, information processing skills, and the stimulation of higher level thinking (Fleming, 1989; Matsumoto, 1985).

Assessor. Assessment is an important and integral part of teaching and learning (St. John, 1987). It is especially important within the constructivist paradigm, for how are teachers to know what questions to ask of students, what new experiences and information to provide, and how much time may be required for the students to interpret new information and integrate it with prior knowledge? The National Center's companion document, *Assessment in Science Education [illegible] the Middle Years* (Raizen et al., 1990), presents an extensive discussion of issues in assessment, in assessment of learning, and in assessment of program quality. In this section, we describe how assessment can serve instruction. The panel urges the readers to consult the companion document for a detailed discussion of issues surrounding the role of assessment in science education. All science educators should be concerned about assessment for four reasons:

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

As mandates for assessment grow, it becomes imperative to establish correspondence between the goals of science and technology education, the curriculum, and the test, and to establish other means of assessment that might be used for correlating what students have learned and accomplished in the science and technology program. Assessments must support the teaching of professionals like Ms. Lopez, not undermine them. Ideally, teachers like Ms. Lopez use tests for a variety of reasons, including: (1) finding out about the students' prior knowledge so that they can help students build upon those conceptions; (2) establishing, after a period of instruction, what the students have learned so they can shape subsequent teaching; (3) placing the students in productive learning groups; (4) motivating the students to attend to assigned materials; (5) communicating to the students the teachers' expectations of what they are to learn; and (6) documenting what the students have learned in order to inform them, their parents, and subsequent teachers of individual and group progress.

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

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

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

> *The desirability of using a range of techniques is based on an assumption that much of the knowledge acquired in a hands-on and minds-on science program is tacit and has not been verbalized. Accordingly, although students can apply certain knowledge when they do science, they cannot necessarily reproduce that knowledge in verbal form on a pencil and paper test or in a discussion with the teacher (Tobin 1988:15).*

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

Design and Development of Curriculum Materials

Following are some guidelines for development of a middle-level science and technology curriculum framework. These guidelines will help define your framework and assist in the development of a unique program for your middle-level school:

- Design the science program so it builds upon the middle school concept. For example, at each grade level, science should be integrated and not be discipline based. The latter is a junior high model.
- Base the program on both science and technology. Use the unifying themes recommended in this report to provide linkages across units and topics of study.
- The science and technology curriculum should span the entire middle level, usually two or three years. As you design the new program it is usually a good idea to conceptualize the entire two-three year scope and sequence.
- Decide on the number of units that would be best for your school system. Does your school have four quarters? Two semesters?
- As units are designed, be sure to include an instructional model. There is a model described in chapter VII of this report. However, your school district may be using a model such as the Madeline Hunter or Bernice McCarthy models.

Decide the level at which the instructional model will be used. That is, will lessons or units be the level at which the instructional model is functional?

- Decide on the curriculum emphasis for each unit. Curriculum emphasis is the primary goal of the unit. Examples of curricular emphases are: understanding scientific and technological concepts, presenting information and facts, knowing about the history of science and technology, understanding the nature of science and technology, and studying the interactions of science, technology, and society (STS).
- Include a variety of activities for the middle-level student. Laboratories, reading, simulations, and cooperative learning are all recommended.
- Decide what and how disciplines such as mathematics, social studies, English, health, and art might be included.
- There are several principles that should be followed as the programs are designed. In general, the units and activities 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), and include scientific and technological processes and skills.
- Include both informal and formal assessment approaches that are consonant with your philosophy of curriculum and instruction and which produce information that will inform your decisions when revising your curriculum.

Criteria for Selection of Content

If schools and curriculum developers are to respond to recommendations that less be taught in greater depth, how is one to select from among the myriad topics in science and technology? At the middle level there are several criteria which should help curriculum designers make appropriate choices:

- *Content should relate to the life and world of the early adolescent.* Topics such as magnetism or plants which engross the third or fourth grader may not be as compelling to the sixth or seventh grader. However, topics related to their own bodies or which touch their lives, such as acid rain or violent weather, inventions, or value-laden issues are more compelling.
- *New knowledge, skills, and attitudes should be understandable in a context.* If sound is to be studied, it should be presented as another example of a pattern that allows one to predict. It should be illustrated with examples from their world, their music, sound technology, their own hearing, as part of communication which is so vital to students of this age. If one has to stretch to find a context, then one should consider choosing different content.
- *Conceptual themes should be the focus for content; specific subject matter is learned as exemplifications of these themes.* A study of rivers can integrate several conceptual themes such as change, cycles, cause and effect. These themes, as well as more specific content, such as erosion, solubility, pH, and fresh water food chains, when learned as part of a study of a single topic, the river, are seen as related and integrated and are therefore apt to be assimilated by middle-level students.
- *Science programs should progress from concrete to abstract.* There is considerable agreement that despite the ability of some young adolescents to deal

successfully with abstractions, most remain concrete learners. Therefore, concrete, first-hand experience must be the foundation of science and technology curriculum and instruction. The idea that sound is due to vibrations must be accompanied by real objects to vibrate, a variety of materials to use to make sounds, and a way for the learner to experiment with controlling sound by changing vibrations and the materials set in motion. Only after seeing a tuning fork splash water or a plucked cello string move back and forth, or a wave move through a Slinky will the abstraction be comprehensible. If a topic cannot be illustrated by a concrete, first-hand example or experience, it should be discarded in favor of another.

- *Topics which allow in-depth, extended learning should be used.* A topic, such as light, lends itself to many, many weeks of study and could encompass experiments illustrating the nature of light, reflection, refraction, absorption, taking light apart with prisms, mixing colored light, mixing pigments, the eye, optical illusions, adaptations of sight in animals, responses to light in plants, human use of light in inventions and technologies, the telescope and astronomy, the microscope and microbes, controlling and using light in photography. These many separate topics become woven into the understanding of one topic, light. The richness of experiences are close-at-hand. The potential for engaging students in the study of light are many.

Teachers and administrators must be mindful of requirements that students will be expected to meet. It will be incumbent upon them to responsibly include the materials necessary to meet requirements within a format that will prepare students for life; not just for a test, the next grade, or a high school science class.

Examples of Science Curriculum Material for Middle-Level Education

This report is not intended as a *curriculum*. The intention is to assist curriculum design, development, and implementation at the local level. Seeing examples is, however, always helpful. This section includes examples ranging from a three-year scope and sequence to individual lessons. We remind the reader that vignettes throughout the report also exemplify curricular and instructional approaches.

The one-year-plan in Table 4 illustrates an emphasis on human (early adolescent) interests and topics. There is inclusion of conceptual themes, health concepts, and technology across the year.

Building a Unit on Primates

The beginning points for the development of this three-month unit on primates were:

(1) building a course that would intrigue middle-level students, growing from their interests and preoccupations while at the same time addressing some of the issues central to their lives at this age, providing useful insights, (2) focusing on some important attitudes and skills, (3) selecting a topic that naturally lends itself to integrating earth, life, and physical science, and (4) making activities and museum

Table 4 Scope and Sequence: One-Year-Plan

A Year Curriculum on Science and Technology: Living in the World

Unit 1: ***Living in the Natural World***
This unit begins with the exploration of a natural system such as pond, vacant lot, or plot of ground. Students investigate the various components of the system. The conceptual themes of order, diversity, and energy are developed.

Unit 2: ***Living in Human Environments***
Students investigate the school as an example of a human environment. Students investigate the technological issue: What are the problems of human adaptation that are solved by the school?

Unit 3: ***Living with Myself***
What changes occur as humans grow and develop? Using the human as the type-system, biological and psychological changes are studies. Such topics as moods, feelings, and perceptions are explored.

Unit 4: ***Living with Others***
What does it mean to be a friend? This unit centers on relationships between two people. The unifying idea — friends — is used to examine such topics as truth, "secrets," relationships, dating, social pressure, and commitments. Secondary goals of the unit are to introduce health related topics such as substance abuse, family relationships, and sexual intimacy.

and zoo visits the central learning experiences; i.e., there must be rich, substantive activities suitable for students this age that will underpin the learning.

Chimpanzees, monkeys, and gorillas capture the interest of middle-level students. Their behavior is both familiar and novel to the young adolescent. Watching Jane Goodall's films on chimpanzee infant development, feeding, food sharing, and tool use invites students to look at ways humans relate to each other, care for their offspring, communicate, and teach their children to live successfully in their environment. In addition, primate studies provide an ideal focus for a science course that aims to integrate life, earth, physical, and behavioral science as well as other disciplines.

This topic — primates — lends itself to examining some important scientific concepts, attitudes, and skills.

Concepts. Major concepts include: animals can be grouped or classified according to similarities and differences. We belong to a group of mammals called primates. Sharing this group are lemurs, monkeys, chimps, orangutans, gibbons, and gorillas.

Beginning A Unit on Primates

The day following a trip to the zoo, Ms. Lopez writes on a large chart labeled "behaviors" as students report their observations of the day before. Hooting, grooming, holding babies, chest-thumping, brachiating, eating, peeling. The list grows. Ms. Lopez instructs her students to work in their cooperative groups and try to group these behaviors. "Remember what you learned about birds last year; why do birds sing?" The students call out. "To find a mate, to scare away other males so they can have the female to himself, to protect their young, to distract enemies to keep them from the nest, to mark their territory." In their groups students go over their lists. "Grooming is taking care of each other so the whole group will be healthy. One monkey was feeding her baby. I think taking care of others should be one category." "How do you know it was a female any way and maybe it wasn't that monkey's baby, but taking care of each other fits anyway, let's go with it." "What about when the monkeys hooted at each other? I thought they were trying to keep the others away, maybe so they could prove they were the boss or the bully or the strongest monkey. What would you call that?" "How about 'aggressive behavior' "? "Maybe they were trying to attract a mate instead of being a bully; I couldn't tell, but I think the hooters were holding the babies so either they could be females or else the males take care of the babies too." "I don't think male primates take care of babies. I saw a TV show on monkeys and the mothers took care of the babies." "What about the swinging from branch to branch? I think it was males showing off." "It could be they were exploring or happy or needed exercise."

After working on their categories for 15 minutes and writing their headings on a large sheet of paper, Sally, who was designated reporter for her group for this week, prepared to explain her group's categories to the class.

Ms. Lopez was as intrigued as her students by the variety of interpretations the groups had made using the same set of observations as starting points. This was the first year she had tried this activity with her students and she was delighted with an opportunity to point out that scientists observing the same phenomena often interpreted them in different ways.

In the days that followed Ms. Lopez' students would generate a list of human behaviors and then predict what they would observe when they went in pairs to a kindergarten class. They role-played interactions they thought they would see being unobstrusive observers. When Ms. Lopez asked them to pick one area to look at closely, the students decided that little kids argue a lot and they would look at ways to resolve their conflicts.

The next step for Ms. Lopez' class would be a look at communication and behavior amongst their peers, but with a backdrop of looking carefully at communication among several other groups of animals

We can better understand ourselves by looking at similarities and differences among primates. Animals are interrelated and interdependent. Communication allows primates to reproduce and protect themselves. Generally animals avoid conflict. The welfare of all members of the group is critical to the survival of the individual. Extinctions may occur either naturally or by human deeds. There is evidence for evolution of both the earth and primates.

Attitudes. There are three general attitudes that are central to this unit. Many people with a variety of backgrounds and skills can become scientists; for example, Jane Goodall, a woman not originally trained as a scientist, has done some of the most important work in the field of primates. There are plenty of unanswered questions left that will be important to answer; students today could be the scientists of tomorrow. The Earth is both awesome and fragile. Individuals can make a difference in preserving it; groups of individuals can make an even greater impact.

Skills. In this unit students should develop the following skills: learning to ask questions, finding patterns, making and recording observations, organizing and presenting data, evaluating, determining if their observations support their ideas, and finding ways to take action.

The Outline for the Unit

Finding the Great Rift Valley: Students make a paper mache model of the Earth, putting on major global features, locating plate boundaries and the Great Rift Valley, working from flat maps to spherical, reviewing and discussing axis, tilt, rotation, and revolution, season, time zones, and climate.

Evidence for the theory of plate tectonics is presented, a geologist whose specialty is volcanoes talks to students about the geology of volcanoes and his research, and students in teams use the computer simulation "Volcano" to collect data and learn to predict the likelihood of a volcanic eruption on a mythical island group (successful prediction produces more funding for further research, cooperation between teams of volcanologists, and sharing of information benefits all teams).

A museum visit to observe and draw primates acquaints students with similarities and differences in this group. Field study is illustrated by reading Irven Devore's booklets and viewing film loops on baboon study written for young adolescents. Chimps are introduced by viewing Jane Goodall's films.

There are several other topics of study. The human skeletal system is studied; bones, teeth, their structure-function relationships as well as issues of health are studied; and the pattern of human skeleton and dentition compared to chimps. Evidence for evolution is presented through work with fossils, writing a possible life story for a fossil-bearing piece of rock based on clues from the rock itself and knowledge of rock formation and fossilization. Students make a clay animation to illustrate a scenario called "From Death to Discovery" that chronicles the death of an African animal at the water hole, the process of fossilization, the earth changes that result in a deeply-buried fossil being exposed and thus able to be found by an anthropologist. Students photograph six scenes from their animation which they will then put in order and narrate as a slide show. A stratigraphy project using nuts, bolts, nails and screws, and buckets multi-layered with different materials (sawdust, sand, etc.) challenges students to excavate and reconstruct the history of "life on earth" of these simulated "species," using the concept of relative dating.

Fundamental to understanding of fossil evidence are some ideas about the nature of the earth itself. Sedimentation, erosion, volcanism, the theory of plate tectonics and evidence that supports this theory, climate and topography of the Great Rift Valley for example, are topics that help students appreciate the clues that scientists use to answer questions that they have about the history of life on Earth.

Middle-level students' frequent challenge to science—how do they know—leads in a natural way to a careful look at the human body, particularly the skeletal system and teeth. How can you tell a human bone from a chimp's bone, or a modern human jaw from the jaw of a hominid predecessor? Museums provide a place to carefully observe and draw primates, zoos may be sites to observe living primates and study ways they communicate with each other. Drawing closer to self, a middle-level classroom can be a site for a structured observation and report on ways that humans resolve conflicts. Having looked at primate behavior somewhat removed from self, middle-level students can examine their own communication, conflict resolution, and social behavior in a new light.

There is a richness of opportunity for hands-on learning in science in such an integrated unit. This extended discussion only hints at the diversity of topics and activities that are possible for middle-level education.

The three examples in this chapter are quite different in scope and sequence. The diversity is instructional. There is more than one curricular organization for middle-level programs.

Issues for Middle-Level Education

Although the panel has described a detailed framework for curriculum and instruction that should guide curriculum developers, there are important issues that can and should influence the curriculum. In this section, we describe those issues.

Demographics

For whom are we designing science curriculum? For whom are we teaching science? We are designing curricula for all students and we are teaching the majority of students. And, we must recognize that the majority is a diverse group, with different needs, perceptions, and aspirations. Science programs should be designed for all students: those who are college bound, and those who will enter the work force when they exit high school.

It is absolutely essential to consider the demographics of education as we look at the reform of science education. In *All One System,* Harold Hodgkinson (1985) presents demographic trends, changes in population groupings that will move through the educational system. Hodgkinson (1985:7) summarizes his findings:

> ...*what is coming toward the education system is a group of children who will be poorer, more ethnically and linguistically diverse, and who will have more handicaps that will affect their learning. Most important, by around the year 2000, America will be a nation in which one of every three of us will be non-white. And, minorities will cover a broader socioeconomic range than ever before, making simplistic treatment of their needs even less useful.*

The students Hodgkinson describes have struggled, historically, to achieve success in our schools, and in the sciences they are underserved and underrepresented. It is far too common for girls and minority students to turn away from the sciences and mathematics during the middle-level years. Yet, the NELS:88 study of eighth grade students, which this report described in chapter I, revealed that nearly 75 percent of the students studied plan to enter college. At the same time, however, the study found that many of these students, particularly girls and minorities, are not completing studies at the middle level that will enable them to enroll in high school courses that are prerequisite for college entrance. Moreover, because of their mathematics and science deficiencies, these students will also not be adequately prepared for the workplace they will enter when they exit high school.

How do we keep more of our youngsters on the achievement train? Indeed, among those youngsters considered at-risk, how do we get more to climb aboard that train? Long standing social and economic disadvantages are difficult to overcome. Evidence is accumulating, however, that a concerted, systemic, school reorganization effort can be successful (Dryfoos, 1990; Oakes, 1989; Earle, 1989). The panel believes that part of this effort lies in restructuring middle-level science programs. The content of science must become more personal to the students, and less abstract and disconnected. Science teachers must understand and value different cultures, their learning styles, world views, and ways of approaching problems. Instruction must capitalize on our knowledge that members of minority groups generally fare better in cooperative learning situations than in competitive ones. The panel encourages middle-level educators to become aware of the changing demographics of our school population and to examine ways in which the needs of their students can be met while simultaneously attending to the curriculum and instruction recommendations in this report and to the other issues delineated in subsequent pages of this chapter.

Science Textbooks and Lectures

To say that the science textbook is the organizing framework for the curriculum and reading the textbook is the dominant method of instruction is not an overstatement. Over 90 percent of science teachers use published textbooks (Weiss, 1978; 1987). And, science instruction tends to be dominated by teacher lectures and reading the textbook (Weiss, 1987; Mullis and Jenkins, 1988). Any consideration of reforming science education at the middle level must examine the role of the textbook and lectures in instruction.

There is a fundamental problem associated with the use and review of textbooks. A majority (76 percent) of science teachers do not consider textbook quality to be a significant problem (Weiss, 1987). On the other hand, many educators do consider textbook quality and usability to be problems (American Association for the Advancement of Science, 1985; Armbruster, 1985; Carter, 1987; McInerney, 1986; Moyer and Mayer, 1985; Muther, 1987; Rosenthal, 19[illegible]).

In a national survey of science education, Iris Weiss (1987) asked several specific questions about the quality of science textbooks. Some of the items that received favorable ratings by a majority of science teachers follow:

- Appropriate reading level (87 percent).
- Interesting to students (52 percent).
- Clear and well organized (85 percent).
- Develops problem-solving skills (61 percent).
- Explains concepts clearly (74 percent) and
- Has good suggestions for activities and assignments (74 percent).

The problem is clear. Science teachers use textbooks extensively and they perceive the quality of their textbooks as adequate. Yet, others evaluate textbooks as inadequate. The solution is not clear. Many states require textbooks and provide guidelines for acceptable materials. While California has provided leadership in the revision of the state guidelines, there still remains the issues of teacher selection of and satisfaction with textbooks. At the middle level these issues are even more complex because there are no programs designed to address the needs of young adolescents. Most textbooks used for school science programs in middle-level schools are based on the junior high model; namely, life, earth, and physical science for each of three years. The policies recommended in this document are intended to remedy the current situation, but the textbook problem is quite complex and requires a systemic solution. The panel believes that educators can start the process by considering how textbooks and lectures can be used within the constructivist learning paradigm presented earlier in this chapter and in chapter VII.

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

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

In an attempt to improve text materials with a goal of bettering student achievement, a team at Michigan State University rewrote a sixth-grade science textbook unit using a constructivist approach. The new unit developed out of a conceptual change approach that began with an assessment of students' prior knowledge and of the conceptual difficulties associated with the new concepts and phenomena. This approach is time-consuming and requires working directly with students and teachers (Institute for Research on Teaching, 1988).

The panel's own review of textbooks led to the conclusion that current textbooks emphasize coverage of material, rather than student understanding. The proceedings of a recent national conference on improving textbooks (Education Development Center, 1987) recommended that a textbook program should

- get students ready to learn new information;
- actively engage students in integrating and organizing new information and old information; and
- accommodate the students' diversity and tap their strengths and interests when helping them extend new knowledge.

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

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

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

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

Learning Styles and Teaching Styles

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

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

Clearly, research on learning styles tells educators that students have diverse approaches to learning. While the American educational system has been successful for the first half of this century, traditional educational practices no longer meet the needs of a population that is becoming increasingly diverse. Evidence is mounting to support Anderson's (1988) conclusion that different cultures produce different learning styles. He points out that the curriculum and instruction in most schools reflects the Euro-American analytical, detached, non-affective field-independent style of teaching and learning. These approaches are dysfunctional for many students, particularly minority students who are more likely to exhibit a field-dependent style of learning. Recently, Bell and McGraw-Burrell (1988) reported data that low-achieving black children have culturally specific learning styles that make it difficult for them to succeed in schools dominated by monotonous and repetitive, rather than varied, tasks. Finally, Cole and Griffin (1987) reported on several studies involving Native Americans, Native Hawaiians, Blacks in southeastern United States, and Hispanic children in the southwest. All of the studies lend credence to Anderson's conclusion. More importantly, the studies suggest ways in which "reorganization of lesson formats to make them sensitive to linguistic and cultural variations can promote educational excellence" (Cole and Griffin, 1987:35).

In view of the changing demographics of the student population in this country, the emerging research on learning styles begins to "point the way to making instruction more responsive to youngsters who do not learn and retain information in ways that conventional education provides" (Dunn and Dunn, 1987:55). Our increasing knowledge of student learning styles suggests that teachers must adopt a variety of parallel teaching styles. While the research is not at all clear about the effects of matching or mismatching student style to teaching style, what is evident is that multi-modal approaches—where learners engage in auditory, visual, tactile, and kinesthetic activities—assist learners in gaining greater understanding of concepts. The constructivist learning paradigm can be used as a structure for suggesting different modes of teaching (and learning) that might be effective.

Educational Technology

The use of educational technology has great potential for improving instruction in science. According to a national survey (Weiss, 1987), computer use increases with grade levels, with approximately 36 percent of science classes in grades 10-12 using computers. Although the amount of time computers are used is low, at grades 10-12 computers are primarily used for drill and practice, simulations, learning content, and as a laboratory tool (Weiss, 1987). In contrast to 1977, the 1987 National Survey indicates that computers are a part of science education. This panel assumes the trend toward increased use of computers will continue. Among the justifications for greater use of computers are the demands of an increasingly information-oriented and technological society and use of computers in the work place (Ellis, 1984).

There have not been sufficient quantities of good software and affordable hardware to have a widespread impact on curriculum and instruction in science. Individual pieces of software are used as supplements to instruction. But, the occasional application of a tutorial or simulation is not enough to bring about the reformation of thinking required to fully incorporate technologies into the science program. As hardware and software evolve beyond the phase of application-specific packages, there is reason to believe the next phase of hardware and software will serve as an integral component of science education (Tinker, 1987). There are four types of software that have immediate and important implications for the curriculum in science: Apple's HyperCard, or IBM's LinkWay, microcomputer-based laboratories (MBL), modeling (Kaehler, 1988), and telecommunications. All of these approaches can be important components of the constructivist learning paradigm (Tinker, 1989-90).

At least two projects are underway that promise to assist teachers in using new technologies to enhance student learning. Florida State University's "Interactive Middle Grades Science" project and Educational Systems Corporation's "Explorations in Middle School Science" project are developing computer-based programs for the middle grades. The Florida State University project will integrate teachers, textbook, and laboratory with applications of the microcomputer and laser videodisc, resulting in a system for science instruction, classroom management, and student evaluation. The Educational Systems Corporation plans to provide a set of 50 computer lessons in life, earth, and physical science that use computer-simulated laboratories to involve students in "doing" science with a number of on-line tools (that is, notebook, data base manager, and calculator).

The Integrated Curriculum

Chapter II summarized the recommendations for middle-level education set forth by several prestigious groups. Those recommendations, as well as the panel's own framework for curriculum and instruction, led the panel to conclude that middle-level educators should consider implementing an integrated curriculum, rather than one based solely on separate disciplines. This conclusion is supported by additional observations. Jacobs (1989) argues that at least four factors create a need for integrating the curriculum. First, knowledge is growing exponentially while the length of the school day has remained largely unchanged since the turn of the century. Second, can we really condone cramming a subject into a series of 45 minute blocks? Third, 25-40 percent of our students are dropping out of school each year, prompting us to wonder what is wrong with the current organization of the curriculum. Fourth, an integrated curriculum more closely resembles the workplace in which our youngsters will find themselves someday. In the workplace, workers must confront problems using knowledge gained from several disciplines and problem-solving strategies that cross traditional discipline boundaries.

Middle-level educators have a range of possible options as they consider the issue of integrated curriculum. Curriculum developers can select planning models that range from strictly departmental orientation to a fully integrated approach: parallel disciplines, clustering of disciplines, interdisciplinary units, and interdisciplinary programs. In the first approach, parallel teaching, two or more instructors examine their respective scope and sequences to see when sub-topics can overlap or interrelate. By carefully sequencing instruction in each subject, what the students learn in each class becomes mutually reinforcing. For example, a physical education teacher might plan to focus on respiratory (fitness) activities at the same time the classroom teacher focuses on the cardiovascular system. The only change in teaching that is required is timing what is already taught.

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

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

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

The panel urges middle-level educators to consider which of these four scenarios seems best suited for their school and students and for which part of their instructional program. Interdisciplinary units are manageable in most middle-level schools, particularly since teaming is usually part of the middle school philosophy. But how does a team of teachers drawn from several disciplines, including science, design an interdisciplinary unit of study?

Jacobs (1989) suggests a four step process for designing interdisciplinary units. First, the design team must select a "managing center" or topical theme around which they can design the unit. Conceptual patterns — light, world hunger, pioneers, change — are examples of some that might work. Next, the team needs to brainstorm possible associations of disciplines to the agreed upon theme. Third, the team establishes guiding questions that will serve as a framework or kind of scope and sequence. As Jacobs notes, the questions cross disciplinary boundaries and serve as organizers just like chapter headings do in a textbook. Fourth, the team begins to generate possible teaching-learning activities.

The panel suggests the following criteria for selecting appropriate themes or topics for units of study:

- They build upon students' prior experiences and knowledge.
- They capture students' interest.
- They lend themselves to interdisciplinary study so that students can see that reading, writing, mathematics, and non-science disciplines are part of science and technology.
- They are vehicles for teaching major conceptual themes in science and technology, as well as scientific and technologic attitudes and skills.
- They allow a balance of science and technologic activities.

The panel also suggests that science educators examine the criteria set forth by Jacobs (1989). A theme deserves selection when:

- It has validity within each discipline under consideration because it applies broadly and pervasively within each discipline.

- It has validity across the disciplines for it points out similarities and contrasts across the disciplines so that a concept, for example evidence, is better understood than if approached through one discipline only.
- It has validity beyond the disciplines so that the whole is greater than the sum of its parts. A theme, such as pollution, gains validity because the design team has reason to believe that the science "content" will be better understood when the students see it interrelated to technical, moral, and political issues.

The panel believes that middle-level educators must examine the issue of curriculum integration closely. In the past, many efforts at integrating the curriculum have failed or encountered resistance. According to Jacobs (1989), two problems characterized these earlier efforts. Many units only sampled content from the disciplines, did not have a carefully constructed scope and sequence, and did not aim for depth of understanding. In other instances, design teams failed to recognize that both discipline-based and interdisciplinary experiences are required — it is not an either/or polarity. Carefully constructed integrated units, however, can be an important avenue to meeting the learning and developmental needs of *all* middle-level youngsters.

Conclusion and Recommendations

This chapter presented information and examples that curriculum developers and school personnel can use to develop a scope and sequence and units of study for a middle-level science program. The scope and sequence and units of study should be characterized by major conceptual themes that provide linkages across grade levels and among units, attitudes, and skills described in earlier chapters, and an emphasis on topics and themes that engage the early adolescent learner. Recommendations for the design of programs include the use of:

- the middle-school concept as the basis for design;
- a program based on both science and technology;
- a program for the entire middle-level sequence;
- an instructional model;
- a curriculum emphasis for each unit;
- a variety of activities;
- an integration of other disciplines;
- a progression from personal to social, local to global, questions to explorations, problems to solutions;
- an articulation with elementary and high school programs;
- assessment that is consistent with the goals of the curriculum; and
- assessment that includes evaluation of higher-order thinking, attitudes, and problem-solving skills.

Recommendations for the selection of content include:

- a relation to the life and world of the student;
- a context for presenting new knowledge, skills, and attitudes;
- a use of major conceptual themes to link subjects, topics, and disciplines;
- a focus on depth of study rather than breadth of topics;
- an extensive use of laboratory-oriented activities, field studies, and informal educational environments, i.e., museums, zoos, nature centers; and
- an opportunity to learn basic reading, writing, speaking, and mathematical skills in scientific and technological contexts.

Unfortunately there are few contemporary science programs designed specifically for the middle level. However, there are programs being developed at the Biological Sciences Curriculum Study (BSCS) and Education Development Center (EDC) that incorporate many elements of the framework for curriculum and instruction described in this report. Both programs focus on depth of student understanding of science concepts rather than breadth of coverage, employ constructivist learning models, and use a variety of active learning approaches to meet the learning and developmental needs of all middle-level youngsters. The BSCS and EDC programs will be available in 1992.

Chapter X

Summary and Conclusion

The panel's recommendations for science education at the middle level presents a vision that is essential to American education. Historically, early adolescents and middle-level education have been neglected. The contemporary reform provides an opportunity for science educators to change the curriculum and instruction for early adolescents.

This report began with views of early adolescents and their developmental characteristics. The intention was to displace popular myths about adolescents and to present recommendations for school science and technology programs appropriate for this age group. Curriculum and instruction in science and technology should contribute to personal, social, and cognitive development.

Chapter II is a brief history of middle-level education. The point of the review is that the rationale for a unique education for adolescents has been consistent across most of educational history. But, the implementation of recommendations, in the form of junior high schools, did not represent the unique needs of adolescents; rather, they were scaled down versions of high school programs. In the late twentieth century the middle-school concept emerged as a proposed remedy to the problems of junior high schools. In the late 1980s and early 1990s, middle schools, in the form of philosophical ideas and physical facilities, emerged. There is, however, a discernible lacuna between the ideas and facilities, and curriculum programs and instructional practices.

Science education at the middle level is reviewed in chapter III. The discussion confirms and elaborates the points made in chapter II. While the curriculum reform of the 1960s and 1970s largely neglected middle-level education, those programs that were developed supported the junior high model of earth science (ESCP), physical science (IPS), and life science. In the 1980s, junior high textbooks were being used in middle schools. Recently funded NSF programs may provide programs supporting the middle-school concept. This report, and National Center reports on assessment and teacher education, provide policy recommendations aligned with the middle-school movement.

The National Center's report on curriculum and instruction for elementary schools used a conception of science and technology as the basis for recommendations. The panel made that conception fundamental to this report. A revised discussion of science and technology is in chapter IV.

Goals for science and technology education in middle-level schools are presented in chapter V. The goals are closely aligned with the concept of science and technology. The panel recommended five goals for science and technology education in the middle years:

- Develop adolescents' ability to identify and clarify questions and problems about the world.
- Broaden adolescents' thinking skills for answering questions, solving problems, making decisions, and taking action.
- Expand adolescents' knowledge base.
- Develop adolescents' understanding of the history and nature of science and technology
- Advance adolescents' understanding of the limits and possibilities of science and technology in explaining the natural world and solving human problems.

Chapter VI answers the question, "What knowledge, attitudes, and skills should be included in middle-level programs?" Major concepts should provide connection among science disciplines and between topics. Conceptual themes in the report include: cause and effect, change and conservation, diversity and variation, energy and matter, evolution and equilibrium, models and theories, probability and prediction, structure and function, systems and interaction, and time and scale. Scientific attitudes include desiring knowledge, being skeptical, relying on data, accepting ambiguity, willingness to modify explanations, cooperation, respecting reason, and honesty. Skills are grouped in the categories of asking questions and solving problems, gathering information, making decisions, and taking action.

In chapter VII, the panel recommends that middle-level educators follow a teaching-learning model that is constructivist in nature. The four-step model, patterned after the way scientists and engineers approach their work, begins with an invitation to learning and is then followed by activities that encourage students to explore, discover, and create. Only after these steps can teachers realistically introduce students to new information and concepts and expect students to link this new knowledge to extant knowledge. Together, teachers and students can then propose solutions and explanations. The last step in the model, taking action, reflects the panel's belief that students should demonstrate their new, developing conceptual understandings.

The learning environment, the context within which the curriculum and instruction is implemented, is explored in chapter VIII. Here, the panel sets forth important recommendations concerning instructional materials, the use of educational technologies in the classroom, flexible scheduling, grouping of students, and classroom management.

In chapter IX, the panel concludes its report by setting forth a framework for curriculum and instruction. The framework is an intermediate structure between broad recommendations and an actual curriculum. The framework is intended to give guidance to middle-level educators who wish to take the next step in implementing the panel's recommendations in curriculum and instruction. The framework is punctuated by the panel's belief that middle-level educators must delve into several important issues as they restructure middle-level science education: the country's changing demographics, the development of science textbooks that are constructivist in nature, the implications of research on student learning styles, and the importance of implementing an integrated curriculum.

A variety of people and groups must work together to meet the challenge of this report. Fulfillment of the panel's vision requires teachers who can orchestrate classrooms for success. These teachers, both new and experienced, must recognize the needs of adolescents, understand science and technology, see the interrelationship between the two, and know how to teach science through technologies. The changes require more than taking a workshop or a college course. While science and technology coursework is necessary, the courses must be designed in ways that allow the prospective teachers to interact with the materials and their colleagues, in a manner similar to what we have proposed for children. Teachers, like children, must actively construct new conceptual understandings.

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

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

The panel is recommending dramatic changes in what science we teach and how it is taught to early adolescents. We hope that you share our vision of the future and that you will work toward improving science education in middle-level schools by implementing the recommendations contained in this report.

Science and Technology Education for the Middle Years

An Annotated Bibliography

Aldridge, B.G. (1989). Essential changes in secondary school science: Scope, sequence and coordination. Paper written for National Science Teachers Association. Washington, D.C.

We never give students the chance to understand science, claims Aldridge. In other countries, all students take several years of biology, chemistry, and physics and learn these subjects successfully. Furthermore, the dropout rate in these countries is only about 2 percent compared with our 25 percent. Aldridge proposes increasing the exposure of U.S. students to the sciences by raising total instructional time in secondary science from 540 hours to 1512 hours, and dividing it into descriptive studies (grades 7–8), empirical studies (grades 9–10), and theoretical studies (grades 11–12).

Alexander, W.M., & McEwin, C.K. (1989). *Schools in the middle: Status and progress.* Columbus, OH: National Middle School Association.

A status report on middle schools. Compares data from surveys of middle schools conducted in 1968 and 1988 to identify likenesses and differences between features characteristic of middle level schools then and now, and between today's schools of different grade organizations. Following is a list of what the authors consider to be critical elements of good middle schools: (1) Interdisciplinary organization with flexible scheduling. From 1968 to 1988, considerable increases occurred, but approximately two-thirds of the schools do not use this plan. Flexible scheduling is less common than interdisciplinary teaming. (2) A guidance program with a teacher advisory plan. In 1988, 39 percent of the schools surveyed had such a program. (3) A full-scale exploratory program. (4) Emphasis on personal development, continued learning skills, and basic knowledge areas. (5) Varied and effective instructional methodology for young adolescents. (6) Continued orientation and articulation for students, parents, and teachers.

The authors conclude that much progress has been made in the implementation of desirable characteristics, but most middle level schools still have a long way to go.

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

This report recommends that schools focus on what is essential to scientific literacy and teach it more effectively. The basic dimensions of scientific literacy include: Being familiar with the natural world and recognizing both its diversity and its unity; understanding key concepts and principles of science; being aware of some of the important ways that science, mathematics, and technology depend on one another; knowing that science, mathematics, and technology are human enterprises and knowing what that implies about their strengths and limitations; having a capacity for scientific ways of thinking; using scientific knowledge and ways of thinking for individual and social purposes. The report recommends reducing boundaries between academic disciplines and emphasizing linkages among them.

Recommendations to science teachers: Start with questions about nature; engage students actively; concentrate on the collection and use of evidence; provide historical perspectives; insist on clear expression; use a team approach to reinforce the collaborative nature of scientific and technological work; do not separate knowing from finding out; deemphasize the memorization of technical vocabulary.

In addition, science teaching should reflect scientific values, suggesting that teachers do the following: Welcome curiosity, reward creativity, encourage a spirit of healthy questioning, avoid dogmatism, promote aesthetic responses. To counteract learning anxieties, teachers can: Build on success, provide abundant experience in using tools, support the roles of girls and minorities in science, emphasize group learning. Also, teaching should take its time. Students learning science need time for exploring, for making observations, etc. Students need to encounter concepts periodically in different contexts and at increasing levels of sophistication if those concepts are to take hold and mature.

Anderson, C.W. (1987). Strategic teaching in science. *Strategic teaching and learning: Cognitive instruction in the content areas.* Alexandria, VA: Association for Supervision and Curriculum Development; Elmhurst, IL: North Central Regional Educational Laboratory.

Science teachers decide what it is about science that is worth understanding. Three common perspectives among science teachers and educators are: (1) Teaching science as facts, rules, and definitions. Learning facts puts the students in a passive rather than active role, encourages memorization rather than the active construction of knowledge, and fails to connect science content with students' prior knowledge of the world. Teaching science as facts, rules, and definitions typically produces little understanding and less retention. (2) Teaching science as process skills. Research findings suggest that hands-on activities or instruction in process skills does not ensure meaningful learning, alone or combined with conventional fact-based instruction. (3) Teaching science as explanation. Science is fundamentally an attempt to describe and explain the natural world. Scientific progress involves constructing more powerful descriptions and explorations, not simply discovering more facts and laws according to the "scientific method." Teachers emphasizing the explanatory functions of science ask questions calling for explanations and help students construct scientific answers to those questions.

To help science teachers become more successful at strategic teaching in science, we can: (1) improve science textbooks and other teaching materials; (2) improve preservice and inservice teacher education to help teachers become aware of the issues presented in this chapter, master cognitive instructional strategies, and continue professional growth and development; (3) improve the conditions of teaching.

Atwater, M.M. (1989). Including multicultural education in science education: Definitions, competencies, and activities. *Journal of Science Teacher Education, 1*(1), 17-20.

The author recommends the inclusion of multicultural education in science teacher education programs, pointing out that science teachers need exposure to certain philosophies, knowledge, and skills to most effectively instruct culturally diverse students. Multicultural science teachers must have democratic attitudes and values, and a belief that society can be composed of diverse ethnic groups and still function effectively.

Becker, H.J. (1990). Curriculum and instruction in middle-grade schools. *Phi Delta Kappan, 71*(6), 450-457.

Data gathered in *Education in the middle grades: A national survey of practices and trends*, conducted by the Johns Hopkins University Center for Research on Elementary and Middle Schools, helped answer questions about curriculum and instructional practices actually used in the middle grades. In science classes, memorizing the "facts" discovered in scientific investigation uses much more instructional time than does engaging in any learning activities that would teach students how to think and learn as scientists do. Fifty-seven percent of the principals surveyed reported that their typical science teachers teach basic science facts every day; only 33 percent said that discussions of scientific methods are part of nearly every lesson. 10 percent of the teachers have students do hands-on laboratory work daily, and computer or video technology is used to provide scientific explanations by 3 percent of the teachers daily, 30 percent weekly. A school's structure and location, and economic backgrounds of a school's students affect the kinds of opportunities provided to the students.

Braddock, J.H., II. (1990). Tracking the middle grades: National patterns of grouping for instruction. *Phi Delta Kappan, 71*(6), 445-449.

Research bears out that used wisely, instructional grouping practices help schools meet the varying needs of students and create a positive learning climate; used unwisely, such grouping practices exaggerate differences. Use of ability-grouping was reported by approximately two-thirds of the middle-grade principals surveyed. This type of grouping has repeatedly been found to be ineffective for increasing student achievement and to exert the greatest potential for harm of all grouping plans. Cooperative learning, the most widely recommended and best-documented instructional strategy for addressing the problem of student diversity in heterogeneous classrooms, was reported in use in 34 percent of the middle schools, 16 percent of the 7-8 schools, and 15 percent of the 7-9 junior high schools. Braddock concludes that if schools serving early adolescents are to achieve the goals of reform, they must find effective alternatives to tracking.

California State Department of Education. (1987). *Caught in the middle.* Sacramento, CA: Author.

This well-researched report contains recommendations for curriculum and instruction, student potential, organization and structure, teaching and administration, leadership and partnership in the middle school. Excellent list of characteristics (intellectual, physical, psychological, social, and moral and ethical development) of middle grade students is in the appendix.

Carnegie Council on Adolescent Development. (1989). *Turning points. Preparing American youth for the 21st century.* Washington, DC: Author.

An outstanding description of the conditions of adolescents in the 80s. Recommendations target at-risk students. The core academic program should result in students who are literate, including in the sciences; who can think critically, lead healthy lives, behave ethically, and assume responsibilities of citizenship in a pluralistic society. Part of this core program is youth service to promote values for citizenship. Recommended flexibility in the duration of classes to permit learning material in depth, use of cooperative learning, and elimination of tracking by achievement.

Cawelti, G. (1988, November). Middle schools a better match with early adolescent needs, ASCD survey finds. *ASCD Curriculum Update.*

A recent ASCD survey found that the middle school organization of grades 6-8 is a better match with early adolescent needs than other grade organizations. Cawelti includes statistics about how schools organize for instruction, teaching strategies, student-reported uses of computers, and enrollment patterns in exploratory courses.

ERIC Information Bulletin #2. (1982). Teaching science to middle school students.

Based primarily on the 1981 yearbook of the Association for the Education of Teachers in Science, Improving Practices in Middle School Science. Examines characteristics of middle school students, the relationship of those characteristics to science teaching, the middle school curriculum, needs of middle school students with implications for teaching science, characteristics of middle school science teachers, some sample programs for the preparation of middle school science teachers, and inservice activities for middle school science teachers.

Epstein, J. (1990). What matters in the middle grades—grade span or practices? *Phi Delta Kappan, 71*(6), 438-444.

In this article, Ms. Epstein reports selected results from *Education in the middle grades: A national survey of practices and trends,* conducted by the Johns Hopkins University Center for Research on Elementary and Middle Schools (CREMS). In particular, she focuses on how the range of grade levels connects to school size and to grade-level enrollment, school goals, report card entries, and trends in middle-grade practices. Of the key practices for middle-grade education, the single strongest predictor of higher ratings of the overall quality of school programs is the use of common planning periods for members of interdisciplinary teams. Flexible schedules, common planning periods for departments, eight-period days, extracur-

ricular activities or activity periods for all students, and cooperative learning strategies that include group rewards for mastery of academic skills were other significant predictors of high ratings. The CREMS survey reveals that: (1) Most schools containing grade 7 have not yet developed educational programs based on recommended practices for the middle grades. (2) Overall, middle schools (6-8) and 7-8 schools use more of the recommended practices than do other schools. Principals in these schools, particularly those in suburban and urban settings, give their programs higher ratings. Seven–9 and 7–12 schools use fewer responsive practices than do other types (e.g., K–12) of schools, and principals in these schools give lower ratings to the quality of their programs for early adolescents. (3) Regardless of grade span, good practices make stronger programs. (4) We need more data on how students' learning, attitudes, and behaviors are influenced by different middle-grade practices in schools of different grade spans.

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

Examines major demographic trends and the education consequences. By the year 2000, one of every three Americans will be non-white; children will be poorer, more culturally and linguistically diverse, and will have more handicaps that affect their learning.

Hurd, P., Robinson, J.T., McConnell, M.C., & Ross, N.M., Jr. (1981). *The status of middle school and junior high school science.* Volume I, Summary report. A report prepared for the Center for Educational Research and Evaluation.

Instructional recommendations include: science instruction should reflect the way scientific knowledge is created and grows, its relationship and role in our technological society, and its limitations as a way of knowing. Content for science programs at this level should have a problem-centered and/or thematic approach, omitting subject matter that does not meet the established criteria. Content should be relevant to the students' lives and should be organized into meaningful and participatory learning experiences appropriate to the developmental level of young adolescents. Recognition that change is inevitable and development of anticipatory skills to cope with future events benefits students A science program for middle grade schools should include a core of common knowledge for all students and should meet the needs of a diverse student population by varying instructional procedures.

Lawson, A.E., Abraham, M.R., & Renner, J.W. (1989). *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills.* NARST monograph, number one. Cincinnati, OH: National Association for Research in Science Teaching.

Research on the learning cycle indicates that the approach encourages positive attitudes toward science and science instruction, develops better content achievement, and improves general thinking skills. The authors recommend more research to explore various facets of the learning cycle and to extend and test its effectiveness in new areas and for longer periods of time. They believe that learning cycle instruction will endure because

it follows the way humans spontaneously construct knowledge. The appendix contains five sample learning cycle lessons.

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

The conference members were asked to synthesize the current state of knowledge about science education, and to recommend actions to strengthen the science. This report described problems and obstacles impacting science education, the new thrust in science education research, recommendations, and first steps toward implementation. The report noted that the different perspectives of cultural and population groups require special attention because learners build new understanding upon their previously formed ideas, and different cultural groups have distinct world views. Instructors need skills and information to recognize, respect, and respond to the perspectives of women, hispanics, blacks, and other groups. We need curricula that incorporate what we know about conceptual change to teach all students the fundamental ideas of science rather than serving some students while ignoring the prior learning of others. Special effort should be made to motivate students in grades 4-8, because many lose interest in math and science in these grades. Curricula that respond to students' concerns about the impact of science on society seem especially promising. Research also demonstrates that students tend to develop "ownership" of problems and learn more when they study them over time. Topics selected for in-depth coverage in science classes should reflect the fundamental problems of the discipline. The discipline-specific information learned must have wide applicability.

Lipsitz, J. (1985). *Successful schools for young adolescents.* New Brunswick, NJ: Transaction, Inc.

Lipsitz begins her study by looking for characteristics shared by good schools for young adolescents, and ended by looking at the diverse ways middle-grade schools attained excellence. Opportunities for community engagement by the students, large scale simulations, exciting interdisciplinary units, caring relationships, parents who are informed about and supportive of the school's purposes are some favorable practices noted by Lipsitz. The four schools she studied all exhibited willingness and ability to adapt school practices to the individual differences in maturation (intellectual, physical, social) of their students.

Mac Iver, D.J. (1990). Meeting the needs of young adolescents: Advisory groups, interdisciplinary teaching teams, and school transition programs. *Phi Delta Kappan, 71*(6), 458-464

Numerous task forces have recommended the use of interdisciplinary teams of teachers for effective middle grade education. Data from the CREMS national survey on elementary and middle school reveals that more 6-8 middle schools (around 40 percent) use interdisciplinary teaming than do other types of schools surveyed. However, about 30 percent of the schools that use such teaming do not have officially scheduled common planning time for team teachers and only 36 percent of the schools using interdisciplinary teaming give team members two or more hours of common planning time each week. This makes it difficult for teams to become truly effective. Three conclusions of the data: (1) Good evidence was found, for each of the key practices, that strong implementation results in educationally significant benefits. For example, a group advisory program can play an important role in dropout prevention by helping a school better meet the social and emotional needs of young adolescents. Interdisciplinary teams of teachers, if they have an appropriate leader and sufficient common planning time used for team activities, produced a wide variety of benefits. (2) If a major goal is for most schools to adopt effective implementations of these practices, the movement to restructure middle grade education still has a long way to go. (3) Additional data are needed to study how students' motivation to learn, attitudes, and achievement are directly influenced by these and other key practices.

Malcolm, S. (1984). *Equity and excellence: Compatible goals.* A study conducted for the NSB Commission on Precollege Education in Mathematics, Science and Technology, Washington, DC: American Association for the Advancement of Science.

Reports a study of science and mathematics intervention programs for minorities and females. Successful programs involve students in the "doing" of science and math and convey a sense of their utility. Intervention programs usually use an integrative approach to science, math, and communications and are taught by teachers highly competent in the subject matter who believe that students can learn the materials (as opposed to teachers in rural or inner city schools who often have different and lower expectations for minority students).

Mergendoller, J.R., Marchman, V.A., Mitman, A.L., & Packer, M.J. (1988). Task demands and accountability in middle-grade science classes. *The Elementary School Journal, 88*(3), 251-265.

The study results indicate that, in general, tasks placed minimal cognitive demands on students, as they typically involved copying or simple step-by-step procedures. In laboratory activities, "There was very little emphasis on planning an investigation or interpreting results." ". . . Educational reform must begin with task reform." The authors recommend an in-service support model.

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.

Some of the findings:

- Students' science achievement at age seventeen remains well below that of 1969; at ages nine and thirteen, the declines were smaller. Average achievement at age thirteen remained below that of 1970 and at age nine, simply returned to where it was in the first assessment.

- Data showed substantial disparities in science proficiency between groups defined by race/ethnicity and gender.
- Approximately half of the teachers in grades seven and eleven reported spending three hours or less providing science instruction per week.
- Of the seventh- and eleventh-grade students taking a science class in 1986, 12–16 percent reported spending no time on science homework each week.
- Very few students in this country take advanced science courses.
- About one-third of the seventh graders and slightly more than half of the eleventh graders reported that they were asked to hypothesize or interpret data in their science class on a weekly basis.
- Thirty-five percent of the seventh graders and 53 percent of the eleventh graders reported working with other students on science experiments at least on a weekly basis.
- Over half of the third graders and more than 80 percent of the seventh and eleventh graders reported never going on field trips with their science class.
- Sixty percent of the seventh graders and 41 percent of the eleventh graders said they never had to write up the results of science experiments.
- About 46 percent of the teachers of seventh or eleventh grade reported access to a general-purpose laboratory and only 64 percent of the eleventh-grade teachers reported access to a specialized laboratory for use in teaching science.

National Science Teachers Association. (1986). Science education for middle and junior high students. Washington, DC: Reprint distributed by NSTA.

This position statement provides recommendations for evaluation, teacher preparation, necessary resources, and professional development of middle-level teachers in addition to the recommendations listed below.

A model science curriculum for the middle level involves concrete, manipulative, physical experiences and focuses on the relationship of science to: (1) content from life, physical, and earth sciences, with frequent interdisciplinary references; (2) process skills such as experimenting, observing, measuring, and inferring; (3) personal use in every day applications and in practical problem solving allowing open-ended exploration; (4) social issues that involve individual responsibilities and call for decision making; careers; limitations of technology and the necessity of respecting differing points of view; (5) development of written and oral communication skills.

Activities appropriate to early adolescents' cognitive developmental level should: (1) use laboratory experiences extensively to develop student skills with the tools of science, while stressing lab safety; (2) use models, simulations, computer/student interactions, and other approaches that provide concrete, manipulative experiences; (3) use a wide variety of instructional strategies to accommodate student cognitive levels and learning styles; (4) be responsive to short student attention spans; (5) follow a logical sequence and be based upon familiar elements; (6) provide positive experiences that build student self-confidence and esteem; (7) involve social interaction and allow changes in instructional group size and composition; (8) balance

student- and teacher-directed learning; (9) use community resources through field trips, independent study situations, and interaction with role models and community members; (10) use information from various disciplines of science and humanities; (11) involve students in experiences with the natural world to foster understanding of their relationship to that world; and (12) emphasize that people of both sexes and all cultures can participate successfully in science.

Nightingale, E.O., & Wolverton, L. (1988). *Adolescent rolelessness in modern society.* An invited address for the American Medical Association, National Congress on Adolescent Health: *Charting a Course Through Turbulent Times.* Chicago, IL.
The goals for involving adolescents in youth service are to give them a sense of self-worth and accomplishment, to bring them in contact with adults who may serve as mentors and role models, to provide service to those in need, and to learn responsibility and behaviors appropriate to holding a job and performing well. By relieving the frustration of youth and providing them with constructive values, youth service can help to combat the high-risk behaviors that often result from restlessness and rolelessness.

Porter, A.C., & Brophy, J. (1988). Synthesis of research on good teaching: Insights from the work of the Institute for Research on Teaching. *Educational Leadership, 45*(8), 74-85.
Based on insights from recent research on teaching, the authors view effective teachers as semi-autonomous professionals who:

- have clear instructional goals;
- know their content and the strategies for teaching it;
- communicate to their students what is expected of them—and why;
- make expert use of existing instructional materials in order to devote more time to practices that enrich and clarify the content;
- know their students, adapting instruction to their needs and anticipating misconceptions in their existing knowledge ("Conceptual change teaching strategies are especially applicable to instruction in science, where student misconceptions abound");
- teach students metacognitive strategies and give them opportunities to master them;
- address higher- as well as lower-level cognitive objectives;
- monitor students' understanding by offering regular appropriate feedback;
- integrate their instruction with that in other subject areas;
- accept responsibility for student outcomes; and
- are thoughtful and reflective about their practice.

Rakow, S.J. (1988). Images of science through the eyes of middle school students. *American Middle School Education, II*(1), 1-7.
The evolving nature of middle school students' attitudes toward themselves, peers, adult authority, and their futures provides teachers a special opportunity to have a life-long impact upon the lives of these students. (1) Through hands-on science investigations, students recognize

that they, through their own actions, can gather data and solve problems. By personally discovering the solution, they become the authority rather than the teacher or textbook, thereby developing a stronger sense of control over their own fate. (2) The science teacher can encourage students not to blindly accept the first possible solution, but to explore "what if..." questions that might change the solution. (3) Students practice their problem-solving skills by exploring and debating real-world issues that concern them, such as health, the environment, and energy. This also helps them develop attitudes which may well affect their view of science as they become adults. Comparing national assessment results of 1976 and 1981, Rakow observed what appears to be a growing sense of powerlessness on the part of thirteen-year-olds. Only 38 percent of the students in 1981 felt they could contribute to the elimination of pollution, energy waste, food shortages, overpopulation, disease, destruction of resources, and accidents, compared to 46 percent in 1976. Recent efforts to increase the emphasis on science, technology, and society in the middle school science curriculum may help students appreciate the value of science. "The successful adult of the 21st century will be the one who can use the tools of science to solve current problems as well as problems not even as yet imagined. Teachers who provide these students with such life-long learning skills affect their students long after they have left the classroom . . . (which is) what teaching is all about" (1988:7).

Sachse, T.P. (1989). Making science happen. *Educational Leadership, 47*(3), 18-21. In this article, Thomas Sachse, manager of California's Math and Science Education Unit, points out that from the many reports decrying the sorry state of science education, a consensus is emerging on how to make the goal of science literacy attainable for all students. Science educators largely agree that: (1) Instead of teaching science "factoids," concentrate on things that really matter, and on depth rather than breadth. (2) Science lessons need to be made more relevant to students' daily lives, which often means drawing connections between basic science concepts and their technological applications (STS). In some cases, connections can best be made to students' sense of aesthetics. (3) We need to integrate the disciplines of science and to integrate science with other areas of inquiry. Sachse also reports on three trends in instructional reform: thematic science teaching, constructivist science teaching, and interactive science learning. The overall instructional trend is toward a structured sequence of instructional events, during which students collaborate to build new ideas on existing intellectual foundations, with teachers creating the blueprints for learning and monitoring the execution of the design. Sachse describes school-level change in California. Nearly 100 middle schools are beginning to base the entire science program on "projects" that last from three weeks to three months. Students select a project from a set that the teacher has chosen to interest adolescents. Characteristics of the projects: (1) built in sequence, (2) almost unlimited options for detours (relevant exploratory inquiries), (3) they are as rich and intellectually stimulating as the students make them, (4) they require small-group collaboration. Sachse sees three areas that state and federal agencies can influence—texts, tests, and training—all in need of significant improvement.

Vetter, B.M. (1988). Look whos coming to school: Changing demographics. Implications for science education. *Curriculum development for the year 2000:* A BSCS Thirtieth Anniversary Symposium. Colorado Springs, CO: Biological Sciences Curriculum Study.

Of the youngsters who will comprise the freshman class of the year 2000, 25 percent live below the federally established poverty line; one in eight has physical or emotional handicaps; at least one in twelve does not speak much English; more than half will live at least for a time in a one-parent home before they reach college age. Vetter emphasizes that we need to recognize that we are not good at educating poor children, Black children, and Hispanic children, and that we must learn how, because that is who is coming to school. In 1982, our school population was about one-fourth minority, with blacks predominating. In 1988, our school population was almost 30 percent minority, and by 2020, the Census Bureau predicts that our school population will be about 50 percent white, 20 percent black, 25 percent Hispanic, and 4 percent other (mostly Asian). Our schools need to provide a science education that, by ninth grade, gives students an appreciation for the marvels of science, some indication of how it relates to them, and how the understanding of at least rudimentary facts and principles could give them some control over their lives.

References

Alexander, W.M., & George, P.S.
1981 *The exemplary middle school.* New York: Holt, Rinehart, & Winston.

Alexander, W.M., & McEwin, C.K.
1989 *Schools in the middle: Status and progress.* Columbus, OH: National Middle School Association.

American Association for the Advancement of Science.
1985 *Science books and films, 20,*(5).

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

American Association for the Advancement of Science Commission on Science Education.
1967 *Science—A process approach.* Washington, DC: Author.

Anderson, C.W.
1987 Strategic teaching in science. *Strategic teaching and learning: Cognitive instruction in the content areas.* Alexandria, VA: Association for Supervision and Curriculum Development; Elmhurst, IL: North Central Regional Educational Laboratory.

Anderson, J.A.
1988 Cognitive styles and multicultural populations. *Journal of Teacher Education, 39*(1), 2-9.

Armbruster, B.
1985 Readibility formulations may be dangerous to your textbooks. *Educational Leadership, 42*(7), 18-20.

Atkin, J.M., & Karplus, R.
1962 Discovery or invention? *Science Teacher, 29,* 45-51.

Ausubel, D.
1963 *The psychology of meaningful verbal learning.* New York: Grune and Straton.

Beane, J.
1975 The case for core in the middle school. *Middle School Journal, 6,* 33-34, 38.
Summer

Becker, H.J.
1990 Curriculum and instruction in middle-grade schools. *Phi Delta Kappan, 71*(6), 450-457.

Bell, Y.R., & McGraw-Burrell, R.
1988 Culturally-sensitive and traditional methods of task presentation and learning performance in Black children. *The Western Journal of Black Studies, 12*(4), 187-193.

Blosser, P.E.
1985 Using questions in science classrooms. In R. Doran (Ed.), *Research matters . . . to the science teacher*, Vol. 2, Cincinnati OH: National Association for Research in Science Teaching.

Blosser, P.E.
1986 March Learning as indicated by achievement data from National Assessment of Educational Progress. A paper presented at a meeting of the National Association for Research in Science Teaching, Atlanta, GA.

Boyer, E.
1988 *Report card on school reform*. New York: The Carnegie Foundation for the Advancement of Teaching.

Braddock, J.H., II.
1990 Tracking the middle grades: National patterns of grouping for instruction. *Phi Delta Kappan, 71*(6), 445-449.

Brandt, R.
1988 On learning research: A conversation with Lauren Resnick. *Educational Leadership, 46*(4), 12-16.

Brown, K.E., & Obourn, E.S.
1958 *Offerings and enrollments in science and mathematics in public high schools.* (Bulletin 1961, No. 5; DHEW-OE-29021). Washington, DC: U.S. Government Printing Office.

Bybee, R.W.
1977 The new transformation of science education. *Science Education, 61*(1), 85-87.

Bybee, R.W.
1987 Science education and the science-technology-society (S-T-S) theme. *Science Education, 71*(5), 667-683.

Bybee, R.W., & Ellis, J.
1989 A technology-oriented elementary school science and health program: Implications for teacher education. In J.D. Ellis (Ed.), *Information technology and science education*, pp. 145-162.

Bybee, R.W., Buchwald, C.E., Crissman, S., Heil, D.R., Kuerbis, P.J., Matsumoto, C., & McInerney, J.D.
1989 *Science and technology education for the elementary years: Frameworks for curriculum and instruction.* Andover, MA: The National Center for Improving Science Education.

California State Department of Education.
1987 *Caught in the middle.* Sacramento, CA: Author.

Carey, S.
1986 Cognitive science and science education. *American Psychologist, 41*(10), 1123-30.

Carnegie Council on Adolescent Development.
1989 *Turning points. Preparing American youth for the 21st century.* Washington, DC: Author.

Carnegie Forum on Education and the Economy.
1986 *A nation prepared: Teachers for the 21st century.* The report of the Task Force on Teaching as a Profession. New York: Author.

Carter, J.
1987 Who determines textbook content? *Journal of College Science Teaching, 16*(5), 425, 464-68.

Champagne, A.B., & Hornig, L.E.
1987 Practical application of theories about learning. In A.B. Champagne & L.E. Hornig (Eds.), *Students and science learning.* Washington, DC: American Association for the Advancement of Science.

Cohen, E.G.
1986 *Designing groupwork: Strategies for the heterogeneous classroom.* New York: Teachers College Press.

Cole, M., & Griffin, P. (Eds.).
1987 *Contextual factors in education. Improving science and mathematics education for minorities and women.* Madison, WI: Wisconsin Center for Education Research.

Costa, A.
1985 Teacher behaviors that enable student thinking. In A. Costa (Ed.), *Developing minds. A resource book for teaching thinking.* Alexandria, VA: Association for Supervision and Curriculum Development.

Driver, R.
1973 The representation of conceptual frameworks in young adolescent science students. Ph.D. Diss., University of Illinois.

Driver, R., & Easley, J.
1978 Pupils and paradigms: A review of literature related to concept development in adolescent science students. *Studies in Science Education, 5,* 61-84.

Driver, R., & Erickson, G.
1983 Theories-in-action: Some theoretical and empirical issues in the study of students' conceptual frameworks in science. *Studies in Science Education, 10,* 37-60.

Dryfoos, J.
1990 The achievement train: Can high-risk children get on board? *The Harvard Education Letter, 6*(1), 1-4.

Dunn, K., & Dunn, R.
1987 Dispelling outmoded beliefs about student learning. *Educational Leadership, 44*(6), 55-62.

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

ERIC®
1982 Teaching science to middle school students. Information bulletin no. 2. Columbus, OH: ERIC® Clearinghouse for Science, Mathematics, and Environmental Education.

Earle, J.
1989 *The steps to restructuring: Changing Seattle's middle schools.* Alexandria, VA: National Association of State Boards of Education.

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

Education Development Center.
Undated Improving urban middle school science: A collaborative approach. A proposal to National Science Foundation by EDC & Sunburst Communications, Inc.

Educational Technology Center.
1988 *Making sense of the future.* Cambridge, MA: Author.

Eichhorn, D.H.
1966 *The middle school.* (Special printing, 1987). New York: The Center for Applied Research. Columbus, OH: National Association of Secondary School Principals. Reston, Virginia: National Middle School Association

Ellis, J.
1984 A rationale for using computers in science education. *The American Biology Teacher, 64*(4), 200-206.

Fleming, R.
1989 Literacy for a technological age. *Science Education, 73*(4), 391-404

Florida State University.
1989 Interactive Media Science Project. General information. Tallahassee, FL.

Gatewood, T.E., & Dilg, C.A.
1975 *The middle school we need.* Washington, DC: Association for Supervision and Curriculum Development.

Georgiady, N.P., & Romano, L.G.
1973 Do you have a middle school? *Educational Leadership, 31,* 238-241.
December

Georgiady, N.P., & Romano, L.G.
1977 Growth characteristics of middle school children: Curriculum implications. *Middle School Journal, 8*(1), 12-15, 22-23.

Glaser, R.
1984 Education and thinking: The role of knowledge. *American Psychologist, 39* (2), 93-104.

Gregorc, A.F.
1982 Learning/teaching styles: Their nature and effects. *Student learning styles.* Reston, VA: National Association of Secondary School Principals.

Hamm, M., & Adams, D.
1987 An analysis of global problems: Issues in sixth and seventh grade science textbooks. Paper presented at the Annual Conference of the American Educational Research Association. Washington, DC.

Harms, N.C., & Yager, R.E. (Eds.).
1981 *What research says to the science teacher,* Vol. 3. Washington DC: National Science Teachers Association.

Hawkins, D.
1983 Nature closely observed. *Daedalus, 112*(2), 65-90.

Hein, G.E.
1987 The right test for hands-on learning? *Science and Children, 25*(2), 8-12.

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

Holdzkom, D., & Lutz, P.B. (Eds.).
1984 *Research within reach: Science education.* Washington, DC: National Science Teachers Association.

Holmes, E. (Ed.).
1988 *Integrated curriculum.* Winchester, MA: Winchester Public Schools.

Hueftle, S. Rakow, S., & Welch, W.
1983 *Images of science: A summary of results from the 1981-82 National Assessment in Science.* Minnesota, WI: University of Minnesota.

Hunter, M.
1983 *Mastery teaching.* El Segundo, CA: TIP Publications.

Hurd, P.
1986 Perspectives for the reform of science education. *Phi Delta Kappan.*
January

Hurd, P.
1987 The middle school as an institution: Implications for an education in the sciences. A report prepared for Carnegie Corporation of New York.

Hurd, P., Robinson, J.T., McConnell, M.C., & Ross, N.M., Jr.
1981 *The status of middle school and junior high school science.* Volume I, Summary report. A report prepared for the Center for Educational Research and Evaluation.

Hurd, P.
1989 Personal communication.

Institute for Research on Teaching.
1988 A new model of developing science curriculum. In *IRT Communication*
Fall *Quarterly, 11*(1), 3-4. East Lansing, MI: College of Education, Michigan State University.

Jacobs, H.H.
1989 The interdisciplinary model: A step-by-step approach for developing integrated units of study. In H.H. Jacobs (Ed.), *Interdisciplinary curriculum: Design and implementation.* Alexandria, VA: Association for Supervision and Curriculum Development.

Jacobson, W.
1986 The current status of science curricula: Insights from the Second International Science Study. In A.B. Champagne & L.E. Hornig (Eds.), *The science curriculum..* Washington, DC: American Association for the Advancement of Science.

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

Johnston, J.H., Markle, G., & Haley-Oliphant, A.
1987 What research says—about questioning in the classroom. *Middle School Journal, 18*(4), 29-33.

Kaehler, C.
1988 *HyperCard power: Techniques and scripts.* Reading, MA: Addison-Wesley.

Kagan, J.
1971 Twelve to sixteen: Early adolescence. *Daedalus,* 100(4).

Kerry, S.
1985 *Conceptual Change in Childhood.* Boston, MA. MIT Press.

Kuerbis, P.J.
1987 Learning styles and elementary science. A commissioned paper for the Biological Sciences Curriculum Study. Colorado Springs. CO.

Kyle, W.C., Jr., Abell, S., & Shymansky, J.A.
1989 Enhancing prospective teachers' conceptions of teaching and science. *Journal of Science Teacher Education, 1*(1), 10-13.

Kyle, W.C. Jr., & Shymansky, J.A.
1989 April Enhancing learning through conceptual change teaching. *Research matters . . . to the science teacher,* No. 21. Cincinnati, OH: National Association for Research in Science Teaching.

Lawson, A.E., Abraham, M.R., & Renner, J.W.
1989 *A theory of instruction: Using the learning cycle to teach science concepts and thinking skills.* NARST monograph, number one. Cincinnati, OH: National Association for Research in Science Teaching.

Lawton, E.J.
1987 True middle level education—keeping student characteristics in mind. *NASSP Bulletin, 71*(502), 115-120.

Linn, M.C.
1986 *Establishing a research base for science education: Challenges, trends, and recommendations.* Report of a national conference sponsored by Lawrence Hall of Science and the Graduate School of Education, University of California, Berkeley.

Lipsitz, J.
1977 *Growing up forgotten.* Lexington, MA: D.C. Heath.

Lipsitz, J.
1985 *Successful schools for young adolescents.* New Brunswick, NJ: Transaction, Inc.

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

Matsumoto, C.,
1985 The potential of computers for teaching thinking. In A. Costa (Ed.), *Developing minds.* Alexandria, VA: Association for Supervision and Curriculum Development.

McCarthy, B.
1981 *The 4MAT system. Teaching to learning styles with right/left mode techniques.* Oak Brook, IL: Excel.

McEwin, C.K., & Allen, M.G.
1985 *Middle level teacher certification—A national assessment.* (ERIC Document Reproduction Service No. ED 263 061).

McInerney, J.
1986 Biology textbooks—whose business? *The American Biology Teacher, 48*(7), 396-400.

Moore, J.A.
1984 Science as a way of knowing—evolutionary biology. *American Zoologist, 24*(2), 421-534.

Moyer, W., & Mayer, W.
1985 *A consumer's guide to biology textbooks.* Washington, DC: People for the American Way.

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. (Report No. 17-S-01). Princeton, NJ: Educational Testing Service.

Murnane, R.J., & Raizen, S.A. (Eds.).
1988 *Improving indicators of the quality of science and mathematics education in grades K-12.* Washington, DC: National Academy Press.

Muther, C.
1987 May Textbooks, the key to success: Monitoring and modifying. *Educational Leadership, 44*83-4.

Muther, C.
1987 September What do we teach, and when do we teach it? *Educational Leadership,* 77-80.

National Center for Educational Statistics.
1990 *The National Education Longitudinal Study-88.* Washington, DC: U.S. Department of Education.

National Education Association.
1966 *Education and the Spirit of Science* Washington, DC: Educational Policies Commission, National Education Association.

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

National Science Board Commission on Precollege Education in Mathematics, Science and Technology.
1983 *Educating Americans for the 21st century.* Washington, DC: National Science Foundation.

National Science Foundation.
1988 Programs for middle school science instruction. Program solicitation. (NSF88-11). Washington, DC: Author.

National Science Teachers Association.
1986 Science education for middle and junior high students. Washington, DC: Reprint distributed by NSTA.

Newmann, F.
1988 January Can depth replace coverage in the high school curriculum? *Phi Delta Kappan*, 345-48.

Novak, J.D.
1988 Learning science and the science of learning. *Studies in Science Education, 15*, 77-101.

Novak, J.D., & Gowin, D.B.
1984 *Learning how to learn.* New York: Cambridge University Press.

Oakes, J.
1989 *Lost talent: The underparticipation of women, minorities, and disabled persons in science.* Santa Monica, CA: The RAND Corporation.

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

Osbourne, R.J., & Wittrock, M.C.
1983 Learning science: A generative process. *Science Education, 67*(4), 489-508.

Penick, J., & Krajcik, J.
1985 *Focus on excellence, Vol. 2, No. 2: Middle school/junior high science.* Washington, DC: National Science Teachers Association.

Peterson, P., Fennema, E., & Carpenter, T.
1988, December/ 1989, January Using knowledge of how students think about mathematics. *Educational Leadership, 46*, 42-46.

Piel, J.
1981 Interaction of science, technology, and society in secondary schools. In N.C. Harms & R.E. Yager (Eds.), *What research says to the science teacher,* Vol. 3. Washington, DC: National Science Teachers Association.

Posner, G.J., Strike, K.A., Hewson, P.W., & Gertzog, W.A.
1982 Accommodation of a scientific conception: Toward a theory of conceptual change. *Science Education, 66*(2), 211-227.

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: The National Center for Improving Science Education.

Renner, J.
1986 The sequencing of learning cycle activities in high school chemistry. *Journal of Research in Science Teaching, 23*(2), 121-143.

Resnick, L.
1983 Toward a cognitive theory of instruction. In Paris, Olson, and Stevenson (Eds.), *Learning and motivation in the classroom.* Hillsdale, NJ: Erlbaum.

Reynolds, K.E., Pitotti, N.W., Rakow, S.J., Thompson, T., & Wohl, S.M.
1985 Excellence in middle/junior high school science. In J. Penick & J. Krajcik (Eds.), *Focus on Excellence,* Vol. 2, No. 2. Washington, DC: National Science Teachers Association.

Rosenthal, D.B.
1984 Social issues in high school biology textbooks: 1963-1983. *Journal of Research in Science Teaching, 21*(8), 819-831.

Rowe, M.B.
1983 Science education: A framework for decision-makers. *Daedalus, 112*(2), 123-142.

Sizer, T.R.
1984 *Horace's compromise.* Boston, MA: Houghton Mifflin.

Smith, F.
1989 Overselling literacy. *Phi Delta Kappan, 70*(5), 353-359.

Squires, D.A., Huitt, W.G., & Segars, J.K.
Undated Effective schools and classrooms: A research-based perspective. Alexandria, VA: Association for Supervision and Curriculum Development.

St. John, M.
1987 *An assessment of the school in the Exploratorium program.* Inverness, CA: Inverness Research Associates.

Tinker, R.F.
1987 October Educational technology and the future of science education. *School Science and Mathematics, 87,* 466-76.

Tinker, R.F.
1989-90 MBL is alive and well. *Hands On! 12*(2), 10-11.

U.S. Department of Education, National Center for Educational Statistics
1990 NELS:88, *A profile of the American eighth grader* (NCES Publication No. 90-458). Washinton, DC: United States Government Printing Office.

Weiss, I.R.
1978 *Report of the 1977 National Survey of Science, Mathematics and Social Studies Education*. Prepared for The National Science Foundation (Supt. of Doc. No. 083-000-00364-0). Washington, DC: United States Government Printing Office.

Weiss, I.R.
1987 *Report of the 1985-86 National Survey of Science and Mathematics Education*. Prepared for The National Science Foundation (No. SPE-8317070). Washington, DC: United States Government Printing Office.

Wiles, J., & Bondi, J.
1981 *The essential middle school*. Columbus, OH: Charles E. Merrill.

Curriculum and Instruction Panel

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

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

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

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

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

Carolee Matsumoto
Senior Associate
Education Development Center
Newton, MA

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

Advisory Board Members

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

David P. Crandall
Executive Director
The NETWORK, Inc.
Andover, Massachusetts

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

Douglas Lapp
Executive Director
National Science Resources Center
National Academy of Science
Washington, D. C.

Andrew Porter
Director of the Wisconsin
Center for Educational Research
University of Wisconsin
Madison, Wisconsin

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

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

Laurence Vickery
General Director for
Regional Personnel Administration
General Motors Corporation
Warren, Michigan

Richard M. Berry
National Science Foundation (Retired)
Bowie, Maryland

Sally Crissman
Science Teacher and Lower School HeadT
h)TShady Hill School
Cambridge, Massachusetts

David Kennedy
President
Council of State Science Supervisors
Olympia, Washington

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

Mary Budd Rowe*
Professor
College of Education
University of Florida
Gainesville, Florida

F. James Rutherford
Chief Education Officer
American Association for the Advancement of Science
Washington, D. C.

Mare Taagepera
Director
Science Education Program
University of California
Irvine, California

---

* Currently Professor, School of Education, Stanford University

Index

151

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
Andover, Massachusetts
Washington, D.C.

BSCS
The Biological Sciences Curriculum Study
Colorado Springs, Colorado