ED 288 783 SO 018 537

AUTHOR Hickman, Faith M.; And Others
TITLE Science/Technology/Society: A Framework for Curriculum Reform in Secondary School Science and Social Studies.
INSTITUTION Social Science Education Consortium, Inc., Boulder, Colo.
SPONS AGENCY National Science Foundation, Washington, D.C.
REPORT NO ISBN-0-89994-313-6
PUB DATE 87
GRANT 847-0585
NOTE 56p.
AVAILABLE FROM Social Science Education Consortium (SSEC) Publications, 855 Broadway, Boulder, CO 80302.
PUB TYPE Guides - Non-Classroom Use (055) -- Reports - Descriptive (141)

EDRS PRICE MF01/PC03 Plus Postage.
DESCRIPTORS Core Curriculum; Course Content; Curriculum Design; Curriculum Development; High Schools; Interdisciplinary Approach; *Science and Society; *Science Curriculum; *Sciences; Scientific Literacy; *Social Studies; *Technological Literacy; *Technology; Unified Studies Curriculum
IDENTIFIERS *Society

ABSTRACT

The Science/Technology/Society (STS) theme describes a contemporary trend in education which focuses on the teaching of issues such as air quality, nuclear power, land use, and water resources but justification for including STS in the high school core curriculum has a precedence based on historical connections among science, technology, and society. Maintaining social order, perceiving contemporary events accurately, and advancing science and technology require secondary school students to understand the nature, concepts, and processes of these disciplines in a social context. While educators have stressed a need to implement STS-based core curriculums, their recommendations have not become trends in curriculum development or reform, and curriculum reformers estimate that more than 90 percent of high school graduates have reached only the lowest levels of scientific and technological literacy. Chapter one describes a curriculum framework organized into the categories of acquisition of knowledge, utilization of cognitive skills, and the development of attitudes. Chapters two to four discuss topics, concepts, issues, attitudes, and cognitive processes that can be used as integrative threads. Chapter five examines curriculum options and alternatives, such as developing interdisciplinary courses. Chapters six and seven focus on the infusion of STS content into social studies and science courses. The concluding chapters, eight and nine, describe underlying teaching concepts, cognitive process skills, and guidelines for curriculum reform. (JHP)

SCIENCE/TECHNOLOGY/SOCIETY:

A FRAMEWORK FOR CURRICULUM REFORM IN SECONDARY SCHOOL SCIENCE AND SOCIAL STUDIES

By

Faith M. Hickman
John J. Patrick
Rodger W. Bybee

Social Science Education Consortium, Inc.
Boulder, Colorado

1987

ORDERING INFORMATION

This book is available from:

SSEC Publications
855 Broadway
Boulder, Colorado 80302

ISBN 0-89994-313-6

This work was written as part of the SSEC project, Building Support Networks for Improved Science/Technology/Society Education. the project was supported by the National Science Foundation, grant no. 847-0585. Any opinions, findings, and conclusions or recommendations expressed herein are those of the authors and do not necessarily reflect the views of the National Science Foundation.

CONTENTS

Prologue 1

1: Introduction 5

The STS Trend Among Curriculum Reformers 5
Needs and Problems in STS Curriculum Reform 6
A Framework for STS Curriculum Reform 7

2: Knowledge in Education on STS 11

STS Interactions 11
Major Topics and Concepts 13
STS Issues 14
Guidelines for Education on Knowledge in STS 17

3: Cognitive Process Skills in Education on STS 19

Information Processing 19
Problem Solving 20
Civic Decision Making 20
Guidelines for Education on Cognitive Process Skills in STS 22

4: Values and Attitudes in Education on STS 23

Values, Attitudes, and Assumptions About Knowledge 23
Values, Attitudes, and Assumptions About Persons Engaged in Scientific Inquiry 24
Values, Attitudes, and Assumptions About Citizenship in a Free Society 25
Guidelines for Education on Values and Attitudes in STS 26

5: Alternatives for the Design of STS Curricula 27

Identifying the Options 27
Assessing the Options 28

6: STS in Secondary School Science 31

Guidelines for Infusing STS into Secondary Science Courses 31
Application of Guidelines to Secondary Science Courses 32
STS in Earth Science 33
STS in Life Science 34
STS in Physical Science 35

7: STS in Secondary School Social Studies 37

Guidelines for Infusing STS into Secondary Social Studies Courses 37
STS in World History 39
STS in American History 40
STS in Civics/Government 40
STS in Geography 41
Case Studies of Civic Decision Making About STS Issues 42

8: An Interdisciplinary Approach to STS 45

9: Summary of Guidelines for Curriculum Reform 53

PROLOGUE

Discussions of the science/technology/society (STS) theme often focus on such contemporary issues as air quality, nuclear power, land use, or water resources. The educational theme is problem solving leading to political action relative to the science-related social issue. Indeed, this immediate, practical understanding and application of the STS theme is important to educators, especially classroom teachers of science and social studies.

Educators must realize, however, that while the phrase STS describes a contemporary trend in education. justification for teaching about STS is found in a deeper, more fundamental set of connections among science, technology, and society. A brief examination of these fundamental connections is important to understanding of the place and value of this monograph. The examination requires us to go back in history.

The Age of Enlightenment, the late 17th century to the late 18th century, had a profound influence on both science and society. For example, ideas from The Age of Enlightenment--balance, order, continuity in physical and political systems--are evident in our personal and social lives. Two aspects of the Enlightenment are important to the STS theme. During the Enlightenment, scientists accepted what we have come to know as scientific methods or, more appropriately, that science is a way of knowing about the world. A second important aspect of the Enlightenment is that there was a deliberate effort to use ideas from the Newtonian synthesis as a conceptual framework for the organization of societies.

The Enlightenment, sometimes referred to as the age of science and revolution, blossomed in the 17th century, but the seeds were planted much earlier. During the Middle Ages, there was some scientific study, albeit for religious purposes. In the 13th century, a Franciscan monk named Roger Bacon suggested a scientific method of investigation and experimentation. In the 16th century, the work of Nicholas Copernicus, *Concerning the Revolution of the Heavenly Bodies*, changed society's view of the solar system from an earth-centered to a sun-centered system. These ideas also changed society's world view by demonstrating the important scientific principle of questioning authority--in this case, Ptolemy's concept of the solar system--via an appeal to actual observations of heavenly bodies. In biology, Andreas Vesaluis' *Concerning the Fabric of the Human Body* contributed to the revolution in scientific thinking. The works of Copernicus and Vesaluis were both published in 1543.

The 1687 publication of *Mathematical Principles of Natural Philosophy* by Sir Isaac Newton serves as the symbolic beginning of the Age of Enlightenment. While Newton's achievements built on the past, they were in their own right scientifically and socially significant. In the short period from 1665 to 1667, Newton developed the mathematics of calculus, worked out the optical law that white light is a mixture of colors, and described the universal law of gravitation. The larger synthesis was that there is order within the universe and the order of events can be explained through natural laws. Alexander Pope's couplet recognized the magnitude of Newton's contribution:

> Nature and Nature's Laws lay hid in Night:
>
> God said, "Let Newton be!" and all was light.

Newton's reputation rests on his discussions of scientific methods as much as it rests on his scientific discoveries. A social, as well as scientific, heritage is associated with the method of observation, generalization, and experimentation as a way of knowing about the world.

Newton's ideas and laws about the natural order also influenced philosophic conceptions about social organization. Philosophers such as Francois Voltaire, Jean Jacques Rousseau, and David Hume devoted aspects of their political philosophies to the search for an ideal society. Because European countries already had societies with extant governments, economies, and social orders, the philosophers' ideals were not to be realized in Europe. On the other hand, colonial America presented an opportunity to use Enlightenment ideas in establishing a new social order. Two of the principal architects of the new social order were Benjamin Franklin and Thomas Jefferson, both of whom spent time in Europe, were interested in science, and contributed to society through their participation as citizens.

The *Empire of Reason*,[1] written by historian Henry Steele Commager, presents the thesis that the Old World imagined, invented, and formulated the Enlightenment and that America realized and fulfilled the Enlightenment by writing its principles into law and formalizing them into institutions. For example, the opening paragraph of the Declaration of Independence, drafted by Thomas Jefferson and approved in July 1776, contains words and phrases that reveal Enlightenment ideas:

> When, in the Course of human events, it becomes necessary for one people to dissolve the political bonds which have connected them with another, and to assume among the powers of the earth, the separate and equal station to which the Laws of Nature and Nature's God entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation.

Garry Wills, in *Inventing America,*[2] makes the point that these lines are distinctly Newtonian. There is the suggestion of natural law: "When in the course of human events it becomes necessary," "bonds which have connected," "the powers of the earth," "laws of nature," and "causes which impel." All of these phrases lend support to the argument that America, in this case represented by Jefferson, brought Enlightenment ideas to its public documents. These examples illustrate that science and technology are a conceptual heritage in the historical documents out of which this country was born and which continue to influence our social development.

The Constitution includes few direct references to science and technology. Several specific proposals for science and technology were considered by the founding fathers, but were subsequently not included. One can infer that the decision to leave science beyond government control was deliberate. With time and changes in science, technology, and society, the relationship between science and government has become closer and more controversial. Nonetheless, the relationship between science and government was more distant and less critical near the nation's beginning.

The founding fathers provided for a census in Article I of the Constitution. The context of the provision is the appropriation of Congressional representatives and the apportionment of direct taxes among the states. The directive is:

> The actual Enumeration shall be made within three Years after the first Meeting of the Congress of the United States, and within every subsequent Term of ten Years, in such Manner as they shall by Law direct.

> Article I, Section 8 specifies the following: To coin Money, regulate the Value thereof, and of foreign Coin, and fix the Standard of Weights and Measures.

Later in the same article and section is the only direct reference to science:

> To promote the Progress of Science and useful Arts, by securing for limited Times to Authors and Inventors the exclusive Right to their respective Writings and Discoveries.

To summarize, references to science and technology in the Constitution provide for the census, the establishment of a standard for weights and measures, and protection of writings and discoveries through copyrights and patents.

The Preamble to the Constitution and Article 1, Section 8 contain clauses that indirectly relate to historical and contemporary issues related to science and technology. The Preamble states:

> We the People of the United States, in Order to form a more perfect Union, establish Justice, insure domestic Tranquility, provide for the common defense, promote the general Welfare, and secure the Blessings of Liberty to ourselves and our Posterity, do ordain and establish this Constitution for the United States of America.

Article 1, Section 8 gives Congress "Power to provide for the common defense and general welfare of the United States..."

The clauses "provide for the common defense" and "promote the general welfare" have been used to justify government support in areas such as weapons research and frontier exploration whether these are repeating rifles, Strategic Defense Initiative (SDI), the Missouri Expedition, or the space shuttle.

Probably the most important connection between science and society is established in the First Amendment. That amendment ensures the scientific community the independence needed for the free and public exchange of ideas because it prohibits any law "abridging freedom of speech or the press . . . or the right to petition the government for a redress of grievances." Few things are more essential to science than the public presentation and review of discoveries.

Some fundamental connections between science, technology, and society were established in the canons for scientific investigation and definitions of the American social order. Over 200 years, interactions between scientific and technological developments and constitutional principles have increased. Can there be any doubt about the need to maintain the social order? Is there any doubt about the increased rate and varied directions of social change resulting from scientific and technological advances? Here are but a few of the areas of connection between science, technology, and a fundamental social document--the Constitution:

- Scientific Research and the First Amendment
- Information Technology and Freedom of the Press
- Disease Control and Protection of Privacy
- Medical Technologies and Personal Rights
- Science, Technology, and Criminal Justice
- Biotechnology and Public Protection

The relationship between science and society could not be more fundamental Maintaining the social order and advancing science and technology require students to understand the nature of science and technology, and the concepts and processes of science and technology. The same principles--maintaining the social order and advancing science--also require students to understand principles such as constitutionalism, republicanism and representation, federalism, and separation of power.

The topics of this monograph are specific and practical, in order to make them useful to educators at the state and local levels. Still, there is need to recognize and appreciate the origins of, and justification for, the science, technology, society theme because they relate to the foundations of our culture.

Notes

1. Henry Steele Commager, *The Empire of Reason* (New York: Oxford, 1977).

2. Garry Wills, *Inventing America: Jefferson's Declaration of Independence* (New York: Vintage, 1978).

1. INTRODUCTION

Educational reform has ranked high on the public agenda in the United States during the 1980s. Numerous commissions, task forces, and committees have deliberated and issued reports about deficiencies, needs, and recommendations for improving the education of young Americans. The major curriculum reform reports[1] include various recommendations, but all seem to agree that a sound basic education for high school graduates should emphasize:

1. Knowledge of ideas and facts in the sciences and humanities, which yields comprehension of nature and society.

2. Cognitive processes and skills in using knowledge to solve problems and make decisions, which enable independent thinking and learning.

3. Connections of core ideas and ways of thinking in distinct academic disciplines or fields of study, which bring coherence and unity to the curriculum.

4. Appreciation of values associated with science and democracy, which undergirds a free society.

5. Commitment to responsible citizenship, which combines concern for both individual and community needs--for personal fulfillment within a healthy society.

These common ideas about desirable educational qualities underscore the central place for learning about science/technology/society issues in the secondary school curriculum. One can neither perceive contemporary events accurately, nor think effectively about them, nor act responsibly as a citizen in a modern democracy without learning about science and technology as powerful cultural forces.

Modern societies, such as the United States, are increasingly propelled and changed by advances in science and technology--distinct and synergistic ways of knowing about and altering the world. Sciences (processes of knowing about nature and society) and technologies (ways of using knowledge to satisfy human needs or wants) are combined in modern societies to provide increasing human control over natural and social environments. Tremendous, ongoing achievements have spawned great hopes, fears, and controversies associated with a plethora of developments (e.g., nuclear power, genetic engineering, organ transplantation, robotics, pesticides).

In a democracy, citizens have the right and responsibility--as voters, consumers, workers, and officeholders--to participate in decisions about issues related to social uses of science and technology. The success of individuals and their society is tied to the quality of these choices, which varies with the knowledge and cognitive skills of decision makers. The vitality of our American democracy depends upon widespread ability of citizens to think effectively about developments in science and technology and their effects on the world. Therefore, a central mission of American schools should be education on science and technology in a social context. This kind of general education for citizenship is likely to help students from all social groups understand more fully their own civilization and its connections to the world, to think more effectively, to act more productively, and to participate more responsibly in the democratic process.

The STS Trend Among Curriculum Reformers

Educational leaders and associations agree that the study of science and technology in a social context should be part of the core curriculum of secondary schools--subjects required of all students as part of general education for citizenship. Emphatic supporters of science/technology/society (STS) in the secondary school core curriculum include such prestigious groups as the American Association for the Advancement of Science, National Science Teachers Association, National Science Board Commission, Council for Basic Education, Commission on the Humanities, Carnegie Foundation for the Advancement of Teaching, College Entrance Examination Board, and the National Council for the Social Studies.[2] These advocates include representatives of education in the sciences, social sciences/social studies, and humanities (including history).

The report of a meeting sponsored by the Exxon Education Foundation exemplifies the concerns of leaders in science education about development of scientific and technological literacy in a social context. All participants agreed that courses in the core curriculum should highlight "interconnections among science, technology, and human affairs." Thus, a reformed science curriculum should "provide students with basic concepts and intellectual tools, in an applications context, relevant to their lives." The main reason for this recommendation is that these ideas and cognitive processes are keys "to adjusting to and participating in a world that will continue to change rapidly technologically for the foreseeable future. . . ."[3]

Educators in the social studies and humanities have also called for curriculum improvements to emphasize science and technology as powerful social forces and generators of critical public issues. The Commission on the Humanities, for example, recommends: "Courses in the humanities (including history) should probe connections between the humanities and other fields of knowledge (the sciences). For example, humanistic questions are inherent in--and should foster an awareness of--the moral dimensions of science and technology."[4] Publications of the National Council for the Social Studies (NCSS) have "criticized curriculum patterns that isolate the study of science from the study of society."[5] The NCSS Science and Society Committee urges infusion of "science-related social issues" into core courses of the social studies curriculum.[6]

Ernest Boyer, writing on behalf of the Carnegie Foundation for the Advancement of Teaching, stresses the importance of connecting different basic subjects within a "core curriculum"--the common learning experiences required of all students. He says: "The basic curriculum should be a study of those consequential ideas, experiences, and traditions common to all of us by virtue of our membership in the human family at a particular moment in history. The core curriculum must extend beyond the specialties and focus on more transcendent issues, moving from courses to coherence."[7] Boyer argues that connections between science, technology, and society belong in the core curriculum, because these relationships are among the most important "ideas, experiences, and traditions common to all of us." Furthermore, public controversies generated by advances in science and technology are certainly "transcendent issues" of the modern world. Boyer therefore recommends that all students study "how science and technology have been joined, and the ethical issues" that have been raised. He concludes, "It is increasingly important for all students to explore the critical role technology has played throughout history and develop the capacity to make responsible judgments about its use."[8]

The STS trend among curriculum reformers in the United States reflects an international movement. National reports and curriculum development projects in Canada, Australia, Britain, West Germany, Israel, and Holland have emphasized connections of science, technology, and society in the general education of citizens. For example, a recent report of the Science Council of Canada recommended: "Science should be taught at all levels of school with an emphasis and focus on the relationships of science, technology, and society in order to increase the scientific literacy of all citizens."[9]

Needs and Problems in STS Curriculum Reform

Educators in the sciences and social studies have proposed emphasis on science/technology/society in the core curriculum of secondary schools, but these recommendations have not become trends in curriculum development and classroom practices. There is a discrepancy between "what ought to be," according to major national reports recommending educational policy in secondary schools, and "what is," as documented by various assessments of student achievement, teaching procedures, and curriculum materials.

Several recent studies have revealed scanty coverage of science/technology/society in either social studies or science textbooks or school district curriculum guides. Furthermore, only a small proportion of secondary schools have courses designed to meet science/technology/society goals.[10]

The National Assessment of Educational Progress and other studies of student achievement reveal generally low levels of student knowledge about science/technology/society and values related to scientific inquiry in a free society.[11] Furthermore, investigations of teaching procedures in science and social studies classrooms have revealed a tendency to underemphasize higher level learning and cognition associated with inquiry, problem solving, and decision making. Following his nationwide study of schooling, John Goodlad concluded that "preoccupation with the lower intellectual processes pervades social studies and science as well."[12]

Curriculum reformers estimate that more than 90 percent of high school graduates have reached only the lower levels of scientific and technological literacy; that is, students are only beginning to achieve the objectives of (1) knowing basic concepts in science and their application to technology, (2) understanding interrelationships of science and technology in a social context, and (3) using scientific knowledge and cognitive processes to judge knowledge claims and make reasonable decisions about public issues.[13] Social forecasters say that, in order to meet ongoing economic and civic challenges, citizens of modern societies of the near future will need to develop much higher levels of scientific and technological literacy than is demonstrated by Americans today. The nation's vitality in the 21st century may indeed be tied directly to improvements in education on science/technology/society issues.

The American Association for the Advancement of Science (AAAS) points to the appreciable difference between new recommendations for curriculum reform and old realities in schools and urges action now to reform the curriculum. If deficiencies are not remedied soon, an AAAS report warns, "the gap between the public's understanding of science and technology and the requirements of citizenship in a participatory democracy will continue to widen."[14]

In view of current assessments and forecasts, curriculum reform is required. Effective action, however, must recognize and respond to complex problems. How can distinct fields of knowledge--the social studies and sciences--be connected or integrated in the core curriculum? Reformers urge both secondary school science and social studies teachers to emphasize interactions of science/technology/society in their core courses. But how can science educators who lack experience and expertise in civics, history, economics, and geography be expected to teach facilely or effectively about science and technology in history, or about public issues related to advances in science and technology? Likewise, how can social studies teachers accurately treat public issues raised by advances in science and technology without detailed knowledge of basic principles of physics, chemistry, biology, geology, and engineering?

Collaboration between secondary school teachers of sciences and social studies is needed. But is there sufficient common ground to sustain effective partnerships between educators from such disparate fields of study? What common concerns, shared concepts, and compatible ways of thinking might be used to connect studies of science/technology/society in two distinct, but complementary, areas of the secondary school curriculum--the sciences and social studies?

What is the best approach to collaboration between educators in the sciences and social studies in teaching about STS? Should special interdisciplinary courses be created? Or should content on STS be integrated into standard courses in the sciences and social studies? Or should some combination of interdisciplinary and infusion strategies be used? In any case, what content and cognitive processes should be selected and emphasized by teachers and students of the sciences and social studies?

A Framework for STS Curriculum Reform

A prerequisite to resolution of problems in curriculum reform is construction of a framework to guide design of courses or units of study. A framework for curriculum reform consists of interrelated categories and criteria to guide selection and organization of content, cognitive processes, and affective processes to be taught and learned. Furthermore, these categories and criteria can be used to guide development of learning activities and materials that are integrated into standard courses or comprise new courses or units of study.

Construction of a framework for curriculum reform involves definition or development of boundaries for a field of study, thereby enabling users of the framework to identify content that fits a field of study and to distinguish it from subject matter that does not belong. Construction of a curriculum framework also involves setting priorities for selection of content and processes for a course of study, permitting users to decide which content or processes to emphasize in developing learning experiences and materials.

A framework for curriculum reform should be a general and flexible guide to decisions about curriculum reform, not a detailed blueprint. Different curriculum developers should be able to use the same framework similarly and variously. Some choices should be clearly prohibited by a soundly constructed framework, but different curriculum developers should be able to make various justifiable choices within the guidelines of the same framework. The "acid test" of a curriculum framework is its utility as a generator of ideas for goals, content, learning activities, and, ultimately, workable lessons and materials for use in secondary school classrooms.

Our curriculum framework for science/technology/society is organized into three categories: (1) acquisition of knowledge, (2) utilization of cognitive process skills, and (3) development of values and attitudes.[15] Each category guides formulation of particular educational goals, means of instruction, and content and learning activities, as indicated by the labels on the left side of Figure 1.

FIGURE 1
FRAMEWORK FOR CURRICULUM REFORM

A. GOALS	1. ACQUISITION OF KNOWLEDGE	2. UTILIZATION OF COGNITIVE PROCESS SKILLS	3. DEVELOPMENT OF VALUES AND ATTITUDES
	Related to Science/Technology/Society	Based on Inquiries in Science Technology/Society	About Practice of Science and Technology and Democracy
B. MEANS	Through Study of Content in Three Areas of Emphasis	By Means of Three Types of Intellectual Activity	As an Outcome of Educational Experiences that Emphasize Two Kinds of Affective Orientations
C. CONTENT AND ACTIVITIES	STS Interactions	Processing Information	Values in Processes of Science
	Concepts/Topics	Problem Solving	Values in Democracy
	STS Issues	Making Civic Decisions	

The three primary categories in this framework should not be considered separately in curriculum development and teaching. The primary categories neither refer to separate courses nor distinct units of study. Rather, they are interrelated and interdependent elements of a comprehensive and coherent view of education on science/technology/society; they should be treated interactively in developing learning materials. For example, a major unit of study should emphasize all three goals--acquisition of knowledge, utilization of cognitive process skills, and development of values and attitudes. Particular lessons within a unit might also interactively treat all the dimensions of the framework.

Each of the primary categories in the framework is the subject of a subsequent chapter of this work. Acquisition of knowledge on STS (interactions, concepts/topics, issues) is the topic of Chapter 2. Chapter 3 treats cognitive process skills based on inquiries in science/technology/society: information processing, problem solving, and civic decision making. Development of values and attitudes about practices of science, technology, and democracy is the topic of Chapter 4.

In each chapter, criteria and ideas fitting a major category of the framework are defined and explained as essential elements of education on science/technology/society in the curriculum of secondary schools. Furthermore, criteria and ideas in each category are justified as common concerns or shared goals of educators in the sciences and social studies.

A special challenge in construction and use of this curriculum framework is identification of "integrative threads"--topics, concepts, principles, sets of attitudes, or cognitive processes that link teaching and learning within or between separate academic disciplines or broad fields of study.[16] Useful integrative threads are generalizable. They can be applied broadly, cumulatively, and flexibly to various learning experiences in different courses of study. They can be elaborated upon and modified to fit various students and topics at different levels of complexity.

Chapters 2, 3, and 4 discuss topics, concepts, issues, attitudes, and cognitive processes that can be used as such integrative threads. Chapter 5 examines curriculum options: the use of integrative threads to infuse STS into standard courses in the social studies and sciences or to develop special interdisciplinary courses. Chapters 6 and 7 discuss infusion of STS content into standard social studies and science courses. Chapter 8 explores interdisciplinary approaches to education on STS. Chapter 9 summarizes the main ideas and recommendations for curriculum reform presented in this work.

Notes

1. Beatrice Gross and Ronald Gross, *The Great School Debate: Which Way for American Education?* (New York: Simon & Schuster, 1985).

2. Representative educational reform reports that advocate emphasis on science/technology/society in the core curriculum of secondary schools include: Paul DeHart Hurd, *Reforming Science Education: The Search for a New Vision* (Washington, DC: Council for Basic Education, 1984); National Science Teachers Association, *Science-Technology-Society: Science Education for the 1980s* (Washington, DC: NSTA, 1982); Ernest L. Boyer, *High School: A Report on Secondary Education in America* (New York: Harper & Row, 1983); National Science Board Commission, *Educating Americans for the 21st Century* (Washington, DC: National Science Foundation, 1983); Educational Equality Project, *Academic Preparation for College: What Students Need to Know and Be Able to Do* (New York: College Entrance Examination Board, 1983); Educational Equality Project, *Academic Preparation in Science* (New York: College Entrance Examination Board, 1986); Rustum Roy and W. F. Williams, *STS: The Megatrend in Education* (University Park, PA: Pennsylvania State University, 1984); American Association for the Advancement of Science, *Education in the Sciences: A Developing Crisis* (Washington, DC: AAAS, 1982).

3. *Science Education in the United States: Essential Steps for Achieving Fundamental Improvement* (New York: Exxon Education Foundation, 1984).

4. Commission on the Humanities, *The Humanities in American Life* (Berkeley: University of California Press, 1980), p. 46.

5. Cheryl Charles and Bob Samples, *Science and Society: Knowing, Teaching, Learning* (Washington, DC: National Council for the Social Studies, 1978), p. 1

6. Science and Society Committee of the NCSS, "Guidelines for Teaching Science-Related Social Issues," *Social Education* 47 (April 1983), p. 258.

7. Ernest L. Boyer, *High School: A Report on Secondary Education in America* (New York: Harper & Row, 1983), p. 302-303.

8. *Ibid.*, p. 109.

9. This recommendation of the Science Council of Canada is quoted in Gerry Popowich et al., *Integration of Technology in the Alberta Science Curriculum* (Edmonton: Alberta Education, 1984), p. 7.

10. E. Joseph Piel, "Interaction of Science, Technology, and Society in Secondary Schools," in Robert E. Yaeger, editor, *What Research Says to the Science Teacher*, Volume 3 (Washington, DC: National Science Teachers Association, 1982); John J. Patrick and Richard C. Remy, *Connecting Science, Technology, and Society in the Education of Citizens* (Boulder, CO: Social Science Education Consortium. 1985), pp. 19-36.

11. Stacey J. Hueftle, Steven J. Rakow, and Wayne W. Welch, *Images of Science: A Summary of Results from the 1981-82 National Assessment in Science* (Minneapolis: Science Assessment and Research Project, 1983; Jon D. Miller, Robert W. Suchner, and Alan M. Voelker, *Citizenship in an Age of Science* (New York: Pergamon Press, 1980).

12. John I Goodlad, *A Place Called School* (New York: McGraw- Hill, 1984), p. 236.

13. Audrey B. Champagne and Leopold E. Klopfer, "Actions in Times of Crisis," *Science Education* 66 (July 1982), pp. 503-514; Stephen R. Graubard, "Nothing to Fear, Much to Do," *Daedalus* 112 (Spring 1983), pp. 231-248; Robert E. Yaeger, "The Major Crisis in Science Education," *School Science and Mathematics* 3 (March 1984), pp. 189-198.

14. *Education in the Sciences: A Developing Crisis* (Washington, DC: American Association for the Advancement of Science, 1982), p. 2.

15. This framework reflects the ideas and writings of Rodger W. Bybee; see, for example, Rodger W. Bybee, "The Sisyphean Question in Science Education: What Should the Scientifically and Technologically Literate Person Know, Value, and Do--As a Citizen?" in Rodger W. Bybee, editor, *Science/Technology/Society* (Washington, DC: National Science Teachers Association, 1985), pp. 79-93.

16. Ralph Tyler, *Basic Principles of Curriculum and Instruction* (Chicago: The University of Chicago Press, 1949); Hilda Taba, *Curriculum Development: Theory and Practice* (New York. Harcourt, Brace and World, 1962).

2. KNOWLEDGE IN EDUCATION ON STS

Education on science/technology/society begins with knowledge. If students are to understand the interrelationships of science and technology in society, then education in this area must incorporate the concepts, principles, and theories of the sciences (physical and natural sciences) and social studies (history and social sciences). Finally, science/technology-related social issues, and the ideas and information that pertain to them, are the essential context of this field of study.

Paul DeHart Hurd, a leading science educator, emphasizes breadth, rigor, and academic integrity in selecting and organizing subject matter in courses or units of study that treat science/technology/society. Hurd writes: "Knowledge confined to one discipline is too narrow in scope to be the sole basis for dealing with higher science and technology, social problems, or problems of the individual . . . A fair amount of the subject matter for a science course . . . should include that which illustrates the basic principles, theories, methodology, and conceptual nature of its parent discipline. Without this background, students have no way to judge the validity of the information they will be using."[1]

Hurd's viewpoint applies equally to education that includes science/technology/society in social studies courses. Unless students know basic concepts and facts in history and the social sciences, they are not able to meaningfully examine social issues or understand the interactions of science and technology in a social context.[2]

In this chapter, three categories of knowledge are discussed as essential elements of a framework for curriculum reform: (1) STS interactions, (2) major topics and concepts of academic disciplines in science and the social studies, and (3) STS issues. Curriculum developers, science and social studies supervisors, and secondary teachers can use these categories as guidelines to selection and organization of subject matter.

STS Interactions

Science is a systematic, objective, empirical approach to asking questions and looking for answers. Science is limited to inquiries into physical and social realities. Whenever possible, science seeks its answers through replicable means, usually involving the determination of correlations and the design and conduct of controlled experiments.

Technology is the application of knowledge to the solution of practical problems. In modern time, science has fueled and driven technology, and technology in turn has influenced scientific endeavors. The two enterprises, often viewed as different sides of the same coin, may be thought of as complementary or combinatory, rather than as independent.

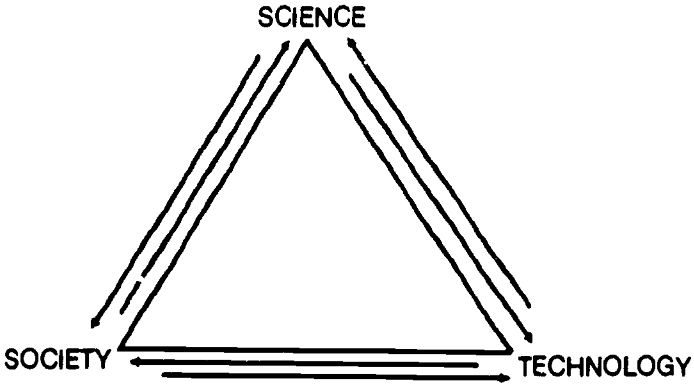
Scientific and technological endeavors occur within society, the collective interactions of human beings at local, national, and global levels. Societies are comprised of interrelated institutions created to serve various human needs and wants. Societies and institutions are distinguished and shaped by the values of their members. As values change, so do the institutions and the directions of a society. Science and technology affect and are affected by the institutions and values of a society, as indicated by Figure 2. Education on STS in science and social studies courses should emphasize these interactions, which are discussed below.

Interaction: SCIENCE—>TECHNOLOGY. The knowledge generated by the scientific enterprise plays an important role in shaping technologies. Our technological limitations are more often products of limited knowledge than inadequacies in engineering skills.

Interaction: SCIENCE—>SOCIETY. The knowledge generated by science influences individual and collective action. Examples of this extremely obvious and infinitely powerful relationship abound. Consider, for example, the social consequences of the compass or gunpowder. In a more contemporary sense, the social consequences of advances in physics, biology, and health are evident.

Interaction: TECHNOLOGY—>SCIENCE. New technologies shape the scientific enterprise, often determining the questions that are asked and the means that are employed in seeking answers. This often-overlooked or underestimated interaction has grown to unanticipated proportions in recent decades. Just as Leeuwenhoek could not observe unicellular organisms until he developed sophisticated magnifying lenses, so scientists today are limited in their in-

FIGURE 2
STS INTERACTIONS



quiries by the tools available to them. On the brighter side, we sometimes develop tools that expand our vision into undreamed-of domains--the use of computers for brain scanning being only one of the many recent and notable examples. For better or for worse, "pure science" is becoming increasingly rare. While some scientists are still seeking knowledge for its own sake without regard to possible future applications, their work is seldom funded without an eye to future technologies. For example, today's basic research in cell biology is a direct result of concerns about cancer. Work on light is supported by interests ranging from the medical applications of fiber optics to the military applications of laser weapons.

Interaction: TECHNOLOGY—>SOCIETY. Technology has profound influences on how people act and interact locally, nationally, and globally. Perhaps the most misunderstood and maligned of all the interactions, this is perhaps also the most visible and the most rapidly changing from the viewpoint of the average citizen. Care must be taken to avoid one-sided, emotional indictments when, for example, modern fertilizers are blamed for polluting the water while their contribution to increased food production is overlooked or discredited. Technology per se is neither friend nor foe--but positive and negative consequences are unavoidable. The challenge is to anticipate both and then take steps to minimize undesired outcomes. Such choices fall within the decision-making purview of individuals (e.g., safe use of contraceptive technologies), organized groups (e.g., citizens' action and lobby groups for environmental or consumer protection), and nations (e.g., the debate over nuclear weapons systems sent orbiting in space).

Interaction: SOCIETY—>SCIENCE. Individual and collective opinion and action often determine how the course of scientific research will proceed. In any human system. the total available resources are always less than the total required to meet the needs and wants of all the components of the system. Thus. much scientific research goes unfunded, because society believes some questions to be more important than others. Often, a concern for possible future applications is the arbiter, and promising areas of inquiry that could generate significant leaps in understanding lay idle and forgotten. Public opinion also restrains research procedures. Examples include the action of the Cambridge City Council to ban recombinant DNA research in that municipality and the continuing efforts of animal protection groups to outlaw research on mammals, vertebrates, or all animals.

Interaction: SOCIETY—>TECHNOLOGY. Individuals and groups of human beings make choices about what new technologies will be developed and how they will be employed. From the perspective of the average citizen, this interaction may appear magical if it exists at all. In fact, new technologies frequently seem to arise from nowhere--absent one day and mysteriously omnipresent the next. Only upon careful, detailed examination of histories, trends, and decision trails does it become possible to delineate the chain of human-controlled causes and effects that lead to the deceptively "overnight" appearance and widespread adoption of new technologies.

What must be emphasized with students is that, at every point along the way, people make decisions to create and disseminate new technologies. Scientists select a single research area from the thousands available to them. Companies, government agencies, or both invest in engineering, development, and testing. Financial institutions arrange venture capital. Marketing specialists identify those most likely to buy, and advertising experts determine ways to persuade the potential buyer. Manufacturers determine cost-effective production schemes. Distributors identify means of bringing products to the retail marketplace. Finally, consumers decide whether, when, and how they will use new technologies. The decision of the user provides the feedback that completes the system. This scheme of bringing consumer technologies to market differs only slightly from the pattern employed to deliver large-scale technologies, most notably weapons and defense systems, for collective uses.

Interaction: SCIENCE—TECHNOLOGY—> SOCIETY. These interactions may be either mutually reinforcing or mutually exclusive and may, furthermore, create desirable or undesirable outcomes seen as risks, benefits, gains, losses, advantages, or disadvantages. The patterns of thought typically described by "cost-benefit analysis" and "risk-benefit analysis" are no longer seen as complex, technical tools accessible to only a few. Seeking answers to such questions as "What do I have to gain?" and "What do I have to lose?" is an activity of merit for every citizen and every student. The answers to these questions can be ascertained only through detailed study of situation-dependent interactions between and among science, technology, and society.

Major Topics and Concepts

In addition to understanding STS interactions, students need to know topics and concepts in science and the social studies that pertain to studies of science/technology/society. For example, the concepts of continuity and change, from the academic discipline of history, can be applied to lessons on the origins and effects of new ideas in science and their applications to social institutions. Furthermore, the concept of system, used in science and social science disciplines, can be used to illuminate developments in technology and their effects on societies.

The concepts of power, authority, and freedom, derived from political science, can be applied to relationships of science and government and the effects of these relationships on citizenship in free societies and authoritarian systems. For instance, developments in science and technology may provide government officials in an authoritarian regime with vastly greater power to control people subject to their authority. By contrast, the same developments in science and technology in another social context may be viewed as liberating forces, giving more power to achieve desired ends to various groups and citizens of a free society.

Several core concepts relevant to studies of STS are applicable to education in both the sciences and social studies. These concepts might serve as organizers for information on STS within standard secondary school courses in the sciences and social studies. Or, they might be foundations for interdisciplinary courses or units of study. Figure 3 presents a list of these concepts.[3] This list is *not* definitive; rather it is indicative of the kinds of ideas that can be developed in the sciences and social studies.

FIGURE 3
UNIFYING CONCEPTS FOR SCIENCE, TECHNOLOGY, AND SOCIETY

SYSTEMS AND SUBSYSTEMS

ORGANIZATION AND IDENTITY

HIERARCHY AND DIVERSITY

INTERACTION AND CHANGE

GROWTH AND CYCLES

PATTERNS AND PROCESSES

PROBABILITY AND PREDICTION

CONSERVATION AND DEGRADATION

ADAPTATION AND LIMITATION

EQUILIBRIUM AND SUSTAINABILITY

STS Issues

A third knowledge component of education on STS is science/technology-related social issues. These issues involve both factual and value judgments; while rooted in science/technology, they cannot be resolved solely by scientific or technological means. Indeed, value positions, rather than technical considerations, often dominate decision making about STS issues. In various STS controversies (fetal research, nuclear power plant placement, use of life-support systems, in vitro fertilization, disposal of industrial wastes, and so forth), no amount of data can resolve the fundamental value conflicts. Furthermore, different experts may interpret the data variously. Thus, knowledge produced by scientific inquiry is necessary, but not sufficient, to the resolution of complex issues of public policy.

Decisions on STS issues emerge from social and political pressures, which involve interaction among experts in science and technology, government officials, interest group leaders, and the citizenry in general. Points of view must be articulated, criticized, and debated. Legislators who reflect the values and attitudes of voters must be elected. Laws must be proposed and debated until compromises are reached that reflect generally accepted values about the issues.

STS issues often involve trade-offs between conflicting values, in which there is no clear view of right or wrong. Many environmental issues, for instance seem to force choices of either clean air and water or industrial production and jobs. Most people agree that industrial pollution is bad; they also tend to agree that unemployment and a depressed economy are bad. Solving the problem may involve a trade-off or compromise among conflicting value positions (e.g., limiting pollution sufficiently to protect health and environment while still maintaining a satisfactory level of production and employment).

Science/technology-related social issues abound in daily newspapers, television news programs, and weekly newsmagazines. Furthermore, they permeate the modern history of America and the world. A few examples of current STS issues are: (1) the technical efficiency and public safety of nuclear power plants, (2) the hazards of recombinant DNA research and genetic engineering, (3) the threats to environmental quality and public health associated with various industrial enterprises, (4) the loss of certain types of jobs to automation/robotics, (5) the depletion or conservation of nonrenewable natural resources needed to sustain or stimulate economic development, (6) the economic and social problems occasioned by rapidly growing human populations, as a consequence of advances in medical care and nutrition, and (7) the perils posed by modern weapons (both nuclear and conventional) and the ever-present threat of their use in acts of terror, rebellion, or war. Of course, this brief list of topics is merely suggestive of the plethora of examples that challenge citizens of modern societies. A more specific list, ranked by science educators is displayed in Figure 4. Figure 5 indicates changes expected in STS issues by the year 2000. These tables provide support for inclusion of STS issues in science and social studies classes.[4]

FIGURE 4
U.S. SCIENCE EDUCATORS' RANKING OF SCIENCE/TECHNOLOGY-RELATED GLOBAL PROBLEMS
(N=77)

GLOBAL PROBLEM	RANK	MEAN
POPULATION GROWTH (world population, immigration, carrying capacity, foresight capability)	1	3.40
WATER RESOURCES (waste disposal, estuaries, supply, distribution, ground water contamination, fertilizer contamination)	2	4.83
WORLD HUNGER AND FOOD RESOURCES (food production, agriculture, cropland conservation)	3	4.94
AIR QUALITY AND ATMOSPHERE (acid rain, CO_2, depletion of ozone, global warming)	4	5.50
WAR TECHNOLOGY (nerve gas, nuclear developments, nuclear arms threat)	5	5.63
ENERGY SHORTAGES (synthetic fuels, solar power, fossil fuels, conservation, oil production)	6	6.09
LAND USE (soil erosion, reclamation, urban development, wildlife habitat loss, deforestation, desertification, salinization)	7	6.50
HUMAN HEALTH AND DISEASE ((infectious and noninfectious disease, stress, noise, diet and nutrition, exercise, mental health)	8	6.63
HAZARDOUS SUBSTANCES (waste dumps, toxic chemicals, lead paints)	9	6.93
EXTINCTION OF PLANTS AND ANIMALS (reducing genetic diversity, wildlife protection)	10	8.51
NUCLEAR REACTORS (nuclear waste management, breeder reactors, cost of construction, safety, terrorism)	11	8 90
MINERAL RESOURCES (nonfuel minerals, metallic and nonmetallic minerals, mining, technology, low-grade deposits, recycling, reuse)	12	9.36

FIGURE 5
U.S. SCIENCE EDUCATORS' INDICATION OF CHANGE FOR SCIENCE/TECHNOLOGY-RELATED GLOBAL PROBLEMS BY THE YEAR 2000
(N=77)

GLOBAL PROBLEMS	BETTER (Includes Better and Much Better) %	ABOUT THE SAME %	WORSE (Includes Worse and Much Worse) %	DON'T KNOW %
POPULATION GROWTH	18.1	31.2	50 7	--
WATER RESOURCES	10.3	22.1	67.6	--
WORLD HUNGER AND FOOD RESOURCES	11.6	29.9	58.5	--
AIR QUALITY AND ATMOSPHERE	29.5	23.1	36.2	11.2
WAR TECHNOLOGY	6.4	21.8	57.7	14.1
ENERGY SHORTAGES	12.8	33.3	52.6	1.3
LAND USE	10.3	39.7	48.7	1.3
HUMAN HEALTH AND DISEASE	52.0	31 2	14.3	2.5
HAZARDOUS SUBSTANCES	21 8	17.9	59.0	1.3
EXTINCTION OF PLANTS AND ANIMALS	3.9	33.8	58.5	3.8
NUCLEAR REACTORS	37.2	38 5	21.7	2 6
MINERAL RESOURCES	5.1	41.0	51 2	2.7

STS issues should be studied within standard secondary school courses in the sciences and social studies. According to a recent report of science educators, "Societal issues must be raised as one integral part of the present courses in chemistry, physics, biology, general science, and earth science, not as separate courses . . . An infusion rate of perhaps 10 percent seemed appropriate and feasible."[5] Social studies educators have made similar recommendations about including STS issues in geography, American history, world history, and civics/government.[6] Other educators in science and social studies have advocated study of STS issues through interdisciplinary courses.[7]

In any case, STS issues should be studied in concert with concepts and topics of academic disciplines that have a bearing on the questions under consideration. In addition, these issues should be connected to STS interactions, which were discussed in the first part of this chapter. For example, suppose students are examining issues about land use--a standard topic in secondary school geography courses. They should examine STS interactions to learn how humans have variously modified their environments by development and application of new technology in farming, mining, stock raising, forestry, manufacturing, etc. Students should also learn how basic concepts in geography (e.g., interaction and change) can be applied to land use issues, such as conservation or development of wilderness areas.

Guidelines for Education on Knowledge in STS

Following are guidelines for supervisors, curriculum developers, and teachers of secondary school who wish to develop lessons, courses, or units of study that treat science/technology/society. These guidelines reflect the basic place of knowledge acquisition in the framework for STS curriculum reform (see Figure 1 in Chapter 1).

1. Develop comprehension of three fundamental concepts--science, technology, society--and the various interrelationships among these three concepts, such as the symbiotic connection of science and technology, occurring in a social context.

2. Emphasize knowledge of major concepts in science and technology that are associated with significant social changes and issues; these concepts and topics, anchored in the traditional academic disciplines of physical and natural science, should be applicable to social issues of continuing importance and relevance to citizenship in a free society.

3. Emphasize knowledge of major concepts and topics in history and the social sciences that are associated with significant social issues rooted in science/technology; these concepts and topics include institutions and human affairs connected with the practices, products, and effects of science/technology in a social context. These concepts and topics should be treated in historical perspective and with vision toward the future.

4. Teach about STS issues in history and contemporary society which illuminate and enhance comprehension of STS interactions; these STS issues should be linked to core concepts and topics of standard secondary school subjects in the sciences and social studies.

5. Develop understanding of the uses, limits, abuses, and variable social consequences of scientific and technological endeavors; the ultimate goal is connecting education about science/technology/society to development of good citizenship in a free society.

Notes

1. Paul DeHart Hurd, *Reforming Science Education: The Search for a New Vision* (Washington, DC: Council for Basic Education, 1984), p. 11.

2. Hazel Whitman Hertzberg, *Social Studies Reform. 1880-1980* (Boulder, CO: Social Science Education Consortium, 1981).

3. The unifying concepts and definitions in Figure 3 are taken from Rodger W. Bybee, "The Sisyphean Question in Science Education: What Should the Scientifically and Technologically Literate Person Know, Value, and Do--As a Citizen?" in Rodger W. Bybee, editor, *Science/Technology/Society* (Washington, DC: National Science Teachers Association, 1985), pp. 87-88.

4. Rodger W. Bybee, "Teaching About Science-Technology-Society (STS): Views of Science Educators in the United States," *School Science and Mathematics* 87, 4(April 1987), pp. 274-285.

5. Phillips Exeter Academy Science Department, *The Exeter Conference on Secondary School Science Education* (Exeter, NH: The Phillips Exeter Academy, 1980), p. 26.

6. Science and Society Committee of the National Council for the Social Studies, "Guidelines for Teaching Science-Related Social Issues," *Social Education* 47 (April 1983), pp. 258-261.

7. Irma S. Jarcho, "Curricular Approaches to Teaching STS: A Report on Units, Modules, and Courses," in Rodger W. Bybee, editor, *Science/Technology/Society* (Washington, DC· National Science Teachers Association, 1985), pp. 162-173.

3. COGNITIVE PROCESS SKILLS IN EDUCATION ON STS

Knowledge about science/technology/society (the first dimension of the framework for curriculum reform) becomes more meaningful and valuable when joined to cognitive process. This combination of educational priorities involves both acquisition of knowledge and its application to questions, issues, problems, and decisions.

Cognitive processes in both the sciences and social studies consist of skills in using knowledge to describe, explain, evaluate, and decide. In history, social sciences, and natural sciences, for example, scholars marshal information to formulate and test hypotheses--to support or reject competing claims about reality. Significant differences in ways of thinking and knowing distinguish academic disciplines within and between broad fields such as the sciences and social studies, but public standards of scholarship (shared beliefs about how to conduct and resolve conflicting or alternative claims about knowledge) are generally agreed-upon. These broad common concerns and approaches to inquiry can be emphasized in both science and social studies courses to bring coherence to studies of STS in different parts of the secondary school curriculum.

The overriding purpose of teaching *all* students to use certain cognitive processes and skills is to help them become literate and critical consumers and users of knowledge on science and technology in a social context, *not* to urge them to become scientists or engineers. The ability to gather, organize, interpret, evaluate, and apply knowledge to everyday concerns is an expectation of citizenship in a free society. Thus, these cognitive process skills should be embedded in the core curriculum of secondary schools.

When inquiring about STS issues, three kinds of cognitive processes can be stressed in both social studies and science courses: (1) information processing, (2) problem solving, and (3) decision making.[1] In this chapter, these three types of cognitive processes--and cognitive skills associated with them--are defined and connected to other parts of the framework. Furthermore, the cognitive process skills are justified as important aspects of education on STS. Finally, guidelines for developing these cognitive process skills are presented. Note that use of the terms STS issues and problems implies that problem identification is included as part of the acquisition of knowledge and utilization of cognitive processes. Specific discussion of problem identification is provided in the section on problem solving.

Information Processing

We live in an era of information explosion and overload, which is driven by computers with enormous capacity for storage and retrieval of data. But the construction and use of systems for organizing, inputting, accessing, and interpreting information depend upon human capacities. Unlike previous eras, when a minority of educated people could maintain the system, modern societies need very large numbers of individuals with basic skills in information processing. These skills in gathering, organizing, interpreting, and communicating information are basic, both to inquiry in the sciences and social studies and to solving daily problems. They are at least necessary, if not sufficient, to problem solving and decision making in both academic and practical affairs.[2]

Skills in gathering information involve systematic collection of data in natural, social, and laboratory settings through unmediated use of the senses or extensions of them provided by various kinds of instruments. In addition, skills in gathering information involve abilities in using reference sources and information storage facilities, such as libraries and computerized data bases.

After information has been gathered, it is made meaningful through skills in organization, interpretation, and communication. These skills, first of all, involve analysis and classification of phenomena--the use of definitions to distinguish data that fit a concept (category) from data that do not belong to the category. From classification, one moves to measurement, comparative analysis, synthesis, and appraisal. On the foundations provided by sound conceptualization, one is able to measure and compare variations in different categories, to make relationships between categories, and to construct generalizations that describe and explain various aspects of reality.

Persons skilled in processing information are able to gather data empirically in various settings, to use concepts to classify these data, and to communicate descriptions and explanations about these data in written and graphic form. Furthermore, they can gather data from various reference sources, which involves skills in finding and interpreting messages in writing and in graphic formats, such as tables, diagrams, charts, graphs, and pictures.

Skills in gathering, organizing, interpreting, and communicating information about science/technology/society can be treated emphatically in both the science and social studies curriculum of secondary schools. Variations in these treatments will necessarily occur because of differences in the data and the methods of investigation that distinguish inquiry in the sciences and social studies. Nonetheless, emphasis on cognitive processes and skills--systematic ways of processing information in any field of study--can reinforce and integrate learning in the two different but complementary areas of the sciences and social studies.

Problem Solving

Problem solving in the sciences and social studies involves formulation and testing of hypotheses about what is and why. In technology, problem solving refers to application of scientifically tested hypotheses (principles) to practical affairs, to achievement of goals such as constructing sound bridges and buildings or designing improved systems for administering complex social organizations. In STS, problem solving may include forecasting and predicting with reference to assessments of current conditions, of trends, and of relationships between options and their likely consequences.[3]

An important skill in problem solving--in science, social studies, and technology--is the ability to identify and frame a problem so that subsequent inquiry can be focused on it. This cognitive operation is triggered by experiences that stimulate awareness of a problem area. Then, a specific problem within this broad category, which can be investigated empirically, is stated clearly and exactly. Thus, the boundaries of inquiry are set: attention is directed toward certain kinds of objects, events, or phenomena and away from other objects, events, and phenomena.

Another problem-solving skill is formulation of alternative hypotheses, which can be tested empirically, in response to a specific problem. An aspect of this cognitive operation is clear and precise statements of hypotheses in terms that suggest procedures for testing the hypotheses.

The problem-solving process in various sciences involves skills in selecting, designing, and carrying out suitable means to test hypotheses. Which general method is most appropriate--experimental, sample survey, case study, or some other approach to finding solutions supporting one proposition over alternatives? How should particular procedures for testing hypotheses be modified to fit various conditions?

The problem-solving process in technology involves application of tested hypotheses--which constitute our fund of knowledge about the way our world works--to achievement of desired outcomes. Thus, for example, we use knowledge derived from chemistry and botany to make and use synthetic fertilizers and pesticides to solve problems related to achieving greater farm production. Problem-solving processes vary within and across academic disciplines and technologies, because of significant differences in types of phenomena and events. However, there are general similarities in these processes and skills in both the sciences and social studies. Educators in both fields share goals about developing problem-solving abilities that can be applied to the daily concerns of individuals in their various roles as citizens, consumers, workers, and parents. Thus, problem-solving processes and skills in using science and technology in society should be essential elements of the core curriculum in secondary schools.

Civic Decision Making

Decision making about issues in the use of science and technology in society is a logical extension of information processing and problem solving. The findings of scientific inquiry are relevant to everyday concerns, because they have a bearing on public policy decisions we make as citizens and as private individuals. For instance, knowledge based on scientific inquiry that cigarette smoking is associated with heart disease and lung cancer is relevant to personal decisions about whether or not to smoke and to public policy decisions about limitations on smoking in public places.

Decision making about science/technology-related social issues is an inescapable part of civic life. Consider three examples that are representative of topics covered regularly and elaborately in daily newspapers. How should citizens vote on a local referendum to approve construction of a trash-burning power plant for the city? Was the FDA's decision to ban laetrile as a cancer therapy another example of unwarranted government paternalism, or was it a necessary safeguard? What criteria should be used to judge proposals and practices in organ transplantation?

As citizens, we make personal choices that have social consequences; we also participate in collective decision making about public policies, whereby the civic communities to which we belong (local, state, and national) make authoritative and binding decisions about governance. These kinds of choices are referred to as civic decisions.[4] In contemporary society, civic decisions increasingly pertain to issues based on developments in science and technology.

Essential elements of civic decisions are: (1) awareness of an occasion for decision, (2) definition and clarification of an issue within an occasion for decision, (3) formulation and clarification of alternatives on an issue, (4) use of knowledge to predict (hypothesize) consequences that are more or less likely to result from selecting one or another of the alternatives, (5) assignment of positive and negative values to consequences connected to each alternative, (6) determination of more or less important goals and values associated with each set of alternatives and consequences (establishment of priorities), (7) selection of one alternative or choice as better than others in terms of priorities--the ranking of goals and values associated with the various options, and (8) acting on the decision.[5]

These essential elements of civic decision making are involved variously in different situations. In some instances, decision makers may readily identify alternatives, but have difficulty in clarifying values and ranking goals. In other situations, the heart of the decision-making process may be thinking creatively about alternatives for reaching a clear and long-standing goal. In other situations, alternatives and goals may be clearly known, but the real challenge is predicting accurately the consequences of alternatives. In short, civic decision making about complex social issues is not a linear or mechanical process to which one simply applies a formula. Rather, these essential elements, considered together, form a coherent frame of reference to guide decision makers--to remind them of interconnected cognitive operations involved in this process and to help them keep track of moves associated with each of these operations.

Civic decisions can be divided into three general types, depending on the amount and quality of the information or knowledge available to the decision maker: (1) decision making with certainty, (2) decision making with uncertainty, and (3) decision making with risk. Different decision-making strategies are implied by these three types of situations.[6]

In decision making with certainty, the evidence for consequences linked to each alternative is so complete and valid that there is virtually no risk in anticipating what will happen when one or another of the alternatives is selected. Under this condition, the decision maker needs only to choose the action associated with the highest valued outcome. The challenge is exclusively one of identifying and ranking goals and values to be applied to outcomes that are known in advance.

In decision making with uncertainty, little or nothing is known about the consequences that may occur when the various alternatives are chosen. Under this condition, decision makers are left only with hunches or intuition to guide their choices.

Decision making with risk is the most common condition associated with social issues. It involves choices made with more or less knowledge about outcomes. Decision makers have a reasonable sense of the probabilities connected with different sets of alternatives and consequences. Thus, the risks of choosing various options are more or less known. The full range of skills associated with essential elements of decision making (described above) are utilized to choose an alternative that seems most likely to yield a desired outcome or to avoid highly undesirable results. These socio-civic decisions often involve tough choices between desirable outcomes, such as maintaining high employment in a particular area and also curbing environmental abuses caused by the major employers in the region. In this type of occasion for decision, choosers usually try to resolve an issue through compromise--by selecting an option that gives each side something it wants, but which completely satisfies no side in the controversy.

Civic decision making requires scientific knowledge to define issues, clarify alternatives, and justify hypotheses about consequences that are more or less likely to result from one choice or another. However, civic decision making moves beyond scientific knowledge; judgments must be made about the relative desirability of consequences. Are the likely outcomes more or less negative or positive? Civic decision making requires assessment of likely outcomes according to priorities that represent personal and social values and goals. Thus, civic decision making involves use of knowledge produced by science to make informed judgments about what should be done to resolve public issues or policy debates.

Skill involved in the civic decision-making process can be acquired and improved upon through practice in secondary school courses in the social studies and sciences. Indeed, if these skills are not emphasized in school, through formal education, they are not likely to be learned by most people.

Guidelines for Education on Cognitive Process Skills in STS

The aim of developing cognitive process skills in STS is *not* to educate experts in academic specialities, although students preparing for careers in science, engineering, and public administration will certainly benefit from these kinds of learning experiences. Rather, the goal is general education for effective citizenship in a democracy. With this end in mind, the following guidelines are presented to curriculum developers and teachers of secondary school courses that include the science/technology/society theme. These guidelines, of course, reflect the basic place of cognitive process skills in the framework for STS curriculum reform (see Figure 1 in Chapter 1).

1. Emphasize development of cognitive process skills involved in scientific/technological inquiry--including information processing and problem solving--as ways of producing and applying knowledge about nature and society.

2. Emphasize development of cognitive process skills involved in civic decision making as a rational means of assessing, judging, and selecting from among options to resolve issues about the uses of science and technology in society.

3. Provide continual practice, across disciplines and sequentially, to direct students' use of cognitive process skills, to correct mistakes immediately and constructively, to reinforce desirable performance, and to enhance learning.

4. Use direct or didactic teaching as a useful means to introduce skills; however, students must also be stimulated and guided to think about their resolution of problems, take stands on issues, and judge propositions about knowledge.

5. Emphasize practice of skills with recognition of how they are part of a process, such as civic decision making or problem solving in scientific inquiry; avoid teaching skills discretely, which is a weak means to the development of higher level cognitive capacities.

6. Incorporate learning activities on cognitive process skills in the core curriculum--school subjects required of all students; cognitive process skills in science/technology/society should be developed systematically and extensively in all social studies and science courses, in a manner consistent with the intellectual development and prior learning experiences of students.

Notes

1. Rodger W. Bybee, "The Sisyphean Question in Science Education: What Should the Scientifically and Technologically Literate Person Know, Value, and Do--As a Citizen?" in Rodger W. Bybee, editor, *Science/Technology/Society* (Washington, DC: National Science Teachers Association, 1985), pp. 79-93; Committee on Science, Engineering, and Public Policy of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine, *Scientific Futures: Selected Areas of Opportunity* (Washington, DC: National Academy Press, 1986), pp. 17-36.

2. Ronald N. Giere, *Understanding Scientific Reasoning* (New York: Holt, Rinehart, and Winston, 1979).

3. *Ibid.*, pp. 209-279.

4. Howard Raiffa, *Decision Analysis* (Reading, MA: Addison-Wesley, 1968).

5. *Ibid.*

6. Ronald N. Giere, *op. cit.*, pp. 305-342.

4. VALUES AND ATTITUDES IN EDUCATION ON STS

Values and attitudes are associated with practices and products of science and technology. Our standards (values) and dispositions (attitudes) about what is good or bad, better or worse, desirable or undesirable cannot be separated from human actions, which are influenced by the social climate and culture in which one acts. Science and technology in Western civilization, for example, were shaped by the 18th century European Enlightenment,[1] which promoted values of freedom, rationality, and objectivity. America, the child of Western Europe, has been nurtured by values of the Enlightenment, including beliefs undergirding the processes of science and democracy. According to Max Lerner, in *America as a Civilization*, "American science had a few crucial things in its favor. It had the whole body of Europe's science to use as an unlimited drawing account; yet it had also the advantage of distance--the extra margin of freedom from the grooves of conventional thinking which often hemmed in the European scientists."[2]

Values and attitudes associated with science and democracy are essential elements of the American heritage and contemporary society. Therefore, these values and attitudes should be emphasized in both science and social studies courses, especially in lessons on science/technology/society. The overriding purpose, of course, is educating for citizenship in a free society.

Three kinds of values and attitudes about science/technology and democracy can be stressed in both social studies and science courses: (1) values, attitudes, and assumptions about ways of knowing and knowledge, (2) values, attitudes, and assumptions about persons who engage in science, and (3) values, attitudes, and assumptions about citizenship that pertain to uses of science/technology in a democratic society. The items that fit these three categories are listed and discussed briefly as elements of the STS curriculum framework.

Values, Attitudes, and Assumptions About Knowledge

Methods of inquiry in science are embedded in a network of values, attitudes, and assumptions (statements accepted as true without proof) about knowledge--what it is and how it is produced. Understanding these values, attitudes, and assumptions is likely to foster appreciation of what science is and is not and to stimulate reflection, which transcends the boundaries of scientific inquiry, about the social uses of science--about the central question of philosophers and responsible citizens: "To what end?"[3]

Following is a list of statements that should be addressed by designers of STS courses and units of study:

1. Knowledge is never complete and humans should engage in the quest for it. The forms and sources of human knowledge have limits. There are always more questions than answers, and the body of knowledge on any topic is never adequate. Furthermore, seeking and producing knowledge are worthy human endeavors.

2. Knowledge changes over time, as does the structure of knowledge. This distinction is as subtle as it is significant. Obviously, the information we possess on a topic changes as more is learned. But it is also true that the way that information is processed, organized, and evaluated changes. Facts thought unimportant at one time may prove central to the scientific enterprise at some other time. One need only recall the rediscovery of Mendel's forgotten principles of heredity and their place in the life sciences today to see this point. Care must be exercised to see this process as never-ending. Mendel's laws are now used less and less to explain modern genetic research. So the structure of knowledge in genetics is continuing to change and will continue to change in the future. Scientists and citizens should learn to appreciate and cope with change in both knowledge and in the structure of knowledge.

3. The physical world can and should be known through the processes of scientific inquiry. Scientists believe that there are no invisible or supernatural barriers between their minds and the physical world. They believe that the physical world exists independently of human perceptions, that it can be known through objective, empirical investigation, and that acquiring this knowledge is worthwhile.

4. The physical world operates under a set of laws that are constant, thereby permitting prediction. Scientists assume that the laws governing objects and phenomena are the same across time and space. Thus, one can form a theory

about cells or gravitation and predict with great accuracy how a variety of cells and falling objects will behave under varying conditions. There are exceptions to this belief. For example, some scientists now contend that during the billionths of a second that followed the Big Bang, physical laws as we know them did not exist.

5. Phenomena should be described and explained in mechanistic terms without using supernatural interventions. Scientists seek to describe and explain phenomena. Whether supernatural forces may be at work is unknown and unknowable to the scientist. The scientist looks not for purpose or deliberate design, but for the character and function of objects or phenomena as they exist now or as they have existed in the past.

6. Every cause has at least one effect and every effect has at least one cause. The aim of science is to develop necessary and sufficient explanations for natural phenomena; while this goal is not achieved, it nevertheless serves as an ideal. The action-reaction model from physics exemplifies the aim of scientific explanation. Single cause and single effect are directly and equally related: simple, constant, and predictable. In the life sciences, multiple interacting causes are linked with multiple interacting effects within ranges of statistical error. Researchers attempt to sort the range of causes and to assign relative weights to specific variables within a large set. Though more complicated in expression, the fundamental principle of cause and effect is still at work.

7. Data do not necessarily speak for themselves. A single body of data may logically support more than one conclusion, just as different bodies of data may support a single interpretation. Inferences from data are made by humans and are, therefore, fallible constructions. Conclusions must be viewed as tentative and subject to refutation. Thus, responsible skepticism and criticism are continuing activities within the natural and social sciences.

8. If observations are valid, they are replicable. Single-source, one-time reports are insufficient evidence. Replication is an essential activity in both the natural and social sciences.

9. Scientific explanations have an aesthetic quality. This is the "elegance" of experiments, hypotheses, and theories. When the parts of an intellectual puzzle fall neatly into place, the result has beauty.

10. Knowledge is more likely to approach the ideal of truth when obtained objectively. Data obtained from controlled experimentation have greater validity than opinion, conjecture, and even judgment based on experience. Thus, objectivity is valued in the pursuit and production of knowledge.

Values, Attitudes, and Assumptions About Persons Engaged in Scientific Inquiry

Characteristics of persons engaged in scientific inquiry are linked to values, attitudes, and assumptions involved in the heuristics of science, which are listed above. The following statements, therefore, can guide curriculum developers and teachers in development of students' values and attitudes through studies of science/technology/society:

1. There is value in diversity of ideas and a commitment to remaining open-minded in confronting competing ideas. Science requires its practitioners to sift through alternative hypotheses, all of which must be assumed plausible until empirically refuted. Science grows through the testing and accepting or rejecting of competing ideas. Therefore, the scientist values diversity of thought in the scientific setting.

2. Knowledge is good. Science--by definition a search for answers to questions--rejects the maxim that ignorance is a satisfactory state of affairs. The scientifically-minded prefer empirical knowledge as explanations for objects, events, and phenomena in the physical and human environment.

3. Curiosity is essential to scientific progress. Science is the enterprise of the curious. We assume that science continues with a vigor roughly proportionate to the curiosity of its practitioners.

4. Prudence resides in the tendency to defer judgment until the facts are available and can be assessed rationally. Like other people, natural and social scientists must make decisions in the face of incomplete data, but the scientifically-minded person is prone to seek out relevant facts, consider options, and postpone judgment until data are analyzed.

5. Logic is an essential attribute. The resolution of problems through logical approaches is central to the methods of science. This is not to ignore the often-critical place of intuition and creativity in arriving at new procedures or answers. The test of new knowledge lies,

however, in the appeal to data and logic in the construction of new theories.

6. Patience and perseverance are important qualities for scientific research. Some problems in science require lifetimes for their resolution. The scientifically-minded believe that there is value in sticking with a task, even when conventional wisdom might suggest a gallant retreat. Perseverance also means dedication to an idea or an ideal and a high level of tolerance for the monotony and frustration of continued long-term investigation.

7. Error may be honorable in the honest search for knowledge and applications. Criticisms from other scientists and refutation of assertions are part of the process of science. Of course, scientists are human beings like everyone else, and they are subject to personal involvement and defense of their ideas, projects, and papers. Sometimes they defend their ideas beyond the reasonable canons of scientific inquiry, but the value of "honor in error" is a goal, even if one not too often achieved.

Values, Attitudes, and Assumptions About Citizenship in a Free Society

Values and attitudes in science are compatible with civic values in a free society. Progress in science depends upon open communication, free speech and press, freedom of assembly, and academic freedom, which are basic values of the American constitutional democracy. Specifically, they are guaranteed by the First Amendment of the Constitution. While scientific work may be encouraged in authoritarian societies, it often is seen primarily as a tool of the state, or the ruling powers, and is often hampered by state-sanctioned orthodoxies.[4]

Those who understand the value structure of science have a head start on tasks of good citizenship in a democracy. They have patience for a diversity of ideas and points of view. They are skeptical of short-term solutions. They also have confidence in the ability of thinking human beings to sort through their difficulties and achieve workable solutions to problems. The student who understands what it means to think scientifically is not only prepared as a citizen to ask pertinent questions about science and technology, but also to ask relevant social questions and to demand defensible answers. Finally, such a citizen can deal with a world changing at a faster pace than ever before. Understanding that knowledge changes and that decisions result from interactions of knowledge and attitudes. the student of STS is equipped to face the challenges of the 21st century.

Following are statements about civic values that should be stressed in education about science/technology/society. These civic values are compatible with values in the heuristics of science.

1. Civil liberties and rights of individuals are protected by law. The U.S. Constitution guarantees civil liberties of individuals and minority groups against the tyranny of ruling elites and the tyranny of majority rule. A basic value of a democracy is freedom to think and express ideas, even if they are unusual, unpopular, or critical of prevailing practices and beliefs. Freedom to think, examine, and express ideas is, of course, critically important to the vibrant exercise of scientific inquiry. In contrast, an authoritarian society never permits critical examination of prevailing and sanctioned ideas--not even by leaders of a scientific elite. Examples of the openness of our society are found in debates about heart transplants, the rights of infants, and death with dignity.

2. Social pluralism and diversity are accepted and encouraged within reasonable limits. A free society is open to variation in thinking and acting, so long as this does not undermine or threaten to destroy social unity or the common good. An open society--tolerant of diversity--encourages innovation and progress in science, because science depends upon open communication and free movement of people and ideas within and across cultures.

3. Citizens have freedom and responsibility to participate in policy decisions. In a democracy, policies reflect the popular will of the people. Experts, such as scientists, are called upon to inform citizens and policy makers, but the limits of scientific expertise are recognized. Policy decisions are made in terms of values, which are outside the boundaries of scientific expertise. As a participant in policy decision making, the scientist plays the role of citizen in concert with other citizens. Thus, in a democratic society, the power and limits of science are recognized in civic decision making and governance.

4. Equality of opportunity and rewards based on merit, not special privilege, are main characteristics of a free society. Individuals are en-

couraged and assisted in developing their talents to the fullest and are enabled to achieve rewards commensurate with contributions to the society. These values and attitudes about opportunity and rewards, if operational in a society, are likely to stimulate maximum development and use of talent in science and technology as well as other fields of work.

5. The dignity and worth of the individual, as a responsible member of society, is a fundamental premise of a modern democracy. In a democracy, the society is organized to reflect the popular will through majority rule. In a modern constitutional democracy, however, the rights of individuals and minority groups must always be respected within a framework of concern for the common good, as expressed by majorities. The social uses of science/technology in a democratic society must therefore reflect majority rule with protection of minority rights and the dignity and worth of individuals. Civic decision making about science/technology-related social issues should combine concern for individuals and their communities. The decision makers should always ask: How will my choice affect both me and others with whom I live? What will the consequences be for individuals and their society? How can the needs of the individual be combined with the needs of the society? The best civic decisions balance concerns for the individual and the common good. While the will of the majority should prevail, that will, to be rightful and moral, should never abuse the dignity and worth of individuals.

Guidelines for Education on Values and Attitudes in STS

Following are guidelines for curriculum developers and teachers of courses or units of study on STS. These guidelines reflect the fundamental importance of values and attitudes about science and democracy in the framework for curriculum reform.

1. Foster appreciation of science/technology as worthwhile human endeavors.

2. Develop understanding of and intelligent commitment to values, attitudes, and assumptions associated with products, processes, and persons of science--the knowledge produced by scientists, the methods used by scientists, and the individuals engaged in scientific inquiry.

3. Develop understanding of and intelligent commitment to values, attitudes, and assumptions of a democratic or free society, which are compatible with the premises and precepts undergirding scientific inquiry.

4. Emphasize the critical importance of ethical questions about the limits and possibilities of science/technology in society.

5. Develop commitment to rational consideration--in terms of democratic values--of issues about applications of science and technology in society. Teachers should not lose sight of the perennial question: "To what end?"

6. Teach values and attitudes of science and democracy in combination with knowledge and cognitive process skills that are central to studies of science/technology/society; these connections are likely to contribute significantly to students' comprehension of core values and their ability to apply them to analyses and appraisals of ideas.

Notes

1. See the following sources for a discussion of scientific ideas, particularly from the Age of Enlightenment, and their influence on American society: Garry Wills, *Inventing America: Jefferson's Declaration of Independence* (New York: Vintage, 1978); Henry Steele Commager, *The Empire of Reason* (New York: Oxford, 1977).

2. Max Lerner, *America as a Civilization* (New York: Simon and Schuster, 1957), p. 209.

3. Many of the values of science pertain to its limitations. Science deals only with objects and phenomena subject to observation, whether by direct (human senses) or indirect (tools, instruments, measuring devices, calculation, etc.) means. Therefore, values typically associated with spirituality (faith, belief, awe, and so on) and with human relationships (love, compassion, courtesy, and so on) must by definition lie outside the realm of science. See the following sources for discussion of the values and limitations of science: Carl G. Hempel, *Philosophy of Natural Science* (Englewood Cliffs, NJ: Prentice-Hall, 1966); John G. Kemeny, *A Philosopher Looks at Science* (Princeton, NJ: D. Van Nostrand, 1959).

4. See the following sources for discussion of civic values in a democracy: Donald W. Oliver and James P. Shaver, *Teaching Public Issues in the High School* (Boston: Houghton Mifflin, 1966); R. Freeman Butts, *The Revival of Civic Learning* (Bloomington, IN: Phi Delta Kappa, 1980).

5. ALTERNATIVES FOR THE DESIGN OF STS CURRICULA

Previous chapters have argued the importance of education about STS for young people soon to achieve the status of adult voters in a complex society, where many issues of public policy arise from science and technology. Educators who are convinced that such instruction is needed will, nevertheless, find themselves faced with the task of turning philosophy into practice. Support for the goals of STS will not suffice. What lies beyond general support are specific questions of learning objectives, subject matter, staff development, student assessment, program evaluation, dissemination, and implementation of a K-12 curriculum.

Identifying the Options

Like a homeowner pondering a comfortable but aging house, teachers and curriculum designers face decisions involving estimated investments and projected returns. Consider the parallels. The householder owns a building that has some value, but that value can increase dramatically with wise improvements. Teachers and curriculum specialists possess a sequence of course work and content that--while supported through many years of practice and firmly implanted by tradition--may fall short in meeting the needs of today's students and of the time and society in which students live now and will live in the future. Here, too, investments must be made and risks taken, and variable returns on different investments and risks may be expected.

Homeowners and educators have at least three options. The homeowner may choose redecoration. A fresh coat of paint, colorful curtains, parquet flooring--these and other amenities may enhance the appearance of a house in profitable ways. When redecorating, no modifications of structure are necessary. Instead, the visible aspects of the home are brightened. The parallel option for educators is the option often described as infusion. That is, the structure, goals, and content of an existing course remain intact. Infusion involves introducing concerns about technology and society whenever related topics arise in the sequence of "regular" course content. For example, AIDS may be mentioned when the students study viruses, or nuclear power may be discussed when the text treats energy use at various stages of industrial development. The advantages and disadvantages of this option are evident. Changes can be made at low cost and with marginal risk, providing moderate advances. Conversely, there is the problem of making minor changes when major ones are needed; prolonging the inevitable major change can subsequently have costly consequences.

The second alternative for the homeowner may be termed refurbishing, in which some structural work is undertaken or added but the basic design of the building remains unchanged. The refurbishing homeowner may build a new porch, add a bedroom, or convert a garage into a family room. The house increases in value because it performs functions that it could not before: it may be bigger, enclosing more space used productively. The danger is that the add-on may be incompatible in style or function with the primary structure. Educators encounter a similar option when they adopt, adapt, or create units or modules for incorporation into an existing course. Something must be removed in order to free time for the module, but once again the structure of the course--while expanded--remains essentially unchanged. Modules or units typically treat one issue of science, technology, and society, such as air quality or energy shortages. Upon completing the unit, students return to the traditional course of study. One must ask about the long-term plan for change in the house or curriculum. Is there a long-term strategy for change? If not, one should be developed. If there is a plan, how is it compatible with the school, students, and fiscal limitations?

The third choice is the most drastic, expensive, risky, and time-consuming, both for the homeowner and for the curriculum designer. It also provides the possibility for greatest gain. This is the option of rebuilding. The old house may be torn down and some of its component materials used to build a new house--designed to meet the owner's needs and wishes for both form and function. The analog of rebuilding for the curriculum planner is creating a totally new course designed specifically to attain unique objectives, while boasting the best content from both the old and the new. Perhaps established courses are abandoned, as content from all the natural sciences is woven together with knowledge from the social sciences and the humanities to create a truly integrated learning experience. Alternatively, such old standbys as biology, chemistry, physics, history, and government can be left as is for those who want them, while a new STS course is offered either as a requirement or an elective. Of course, this curriculum option carries the risks associated with building a new house with an innovative design. One can expect difficulties in achieving a satisfactory design, cost overruns, construction delays, and other problems.

In theory and in practice, these options are not mutually exclusive. A little redecorating along with some refurbishing may offer promise of a higher rate of return than either option alone. Or, it may be prudent to refurbish this year with an eye toward a major rebuilding project later. In any case, the decision must rest upon a thoughtful assessment of the cost of the investment, the risks, and the expected return.

Assessing the Options

For the curriculum planner, investment costs favor infusion, with add-ons constituting a moderate investment and a new course costing the most in both human and material terms. Infusion is likely to require the least time, risk, money, and human resources. Human resources include the time, knowledge, and hard work of teachers and, to a lesser degree, administrators. Resources for implementation include such factors as staff development of teachers, duplication or purchase of learning materials, and hiring consultants for training and assessment tasks.

Obviously, more resources are required for the implementation of an entirely new course than for either adding a unit/module or infusing some new material into an established course. The same holds true for the resources needed to evaluate both the efficacy of the program and the performance of the students. Most difficult also for developing a new course is the effort in translating theory into practice. Even teachers who eagerly embrace the philosophy and goals of STS instruction may find themselves using habitual modes of operation when they attempt to design units or teach new lessons.

When developers, curriculum writers, administrators, teachers, and parents have diverse opinion about a new interdisciplinary course, achieving consensus may be difficult. The potential for conflict is directly proportional to the magnitude of the change. The greater the deviation from the status quo, the higher the probability of objections, criticisms, and resistance. Infusion is the least likely to engender conflict, while a new interdisciplinary course is very likely to cause dissension.

Finally, while it may be relatively easy for teachers to agree upon promising topics for infusion into courses, it is more difficult to reach consensus on goals, content, and pedagogy of a totally new course. Teachers who would create an interdisciplinary STS course face complex and unresolved conceptual problems. Hazel Hertzberg has documented the troubled efforts of social studies educators to create interdisciplinary courses based on social issues. She concluded: "The conceptual problem of combining subjects within the social studies had always been a formidable one that remained largely unresolved . . . When to the usual problems of fusing the social studies were added subjects not so obviously related (sciences), the difficulties became even more formidable."[1]

Hertzberg and others have observed that there is no theory of knowledge that incorporates the sciences and the social studies.[2] There is no accepted framework for a comprehensive curriculum that incorporates the sciences, social sciences, and humanities. Given these conceptual limitations, curriculum reformers should proceed cautiously--with respect for the challenges and risks--in their attempts to integrate the sciences and social studies in new STS courses. We suggest one way to approach the development of a new curriculum that avoids the disciplinary issue: begin the development by centering on such problems as hazardous substances, water resources, air quality, or population growth. Regardless of who identifies the problems (i.e., students, teachers, curriculum developers), the problems usually integrate disciplines in the search for understanding and solutions.

What are the relative returns on investments and risks of options in curriculum reform? Great returns might be achieved from a successfully designed interdisciplinary course on STS. However, the risks and efforts associated with this approach to curriculum reform are large. In addition to the conceptual challenges discussed above, there are difficulties in achieving immediate and highly visible results or sustaining impact over time. Difficulties in achieving immediate and visible results are a function of the considerable amount of time (perhaps one to five years) required to prepare a new course for even pilot testing in the classroom. Difficulties in sustaining positive achievements result from the educational system, as evidenced by the tendency of educators to gradually revert to traditional patterns after trying new approaches--even when those new approaches were highly successful. A well-known example is the steady decline in the number of schools using the NSF-supported curricular programs of the 1960s, despite the impressive weight of research evidence showing dramatic and substantial increases in students' mastery of subject matter, competency in problem solving, and positive attitudes toward science.

What about new goals for science education proposed by current curriculum reforms? Statements of goals for science education, summarized by the Project Synthesis teams,[3] suggested that four goals are possible for science programs: (1) academic knowledge--the transmission of selected facts, concepts, and principles from the major scientific subdisciplines such as biology or earth science; (2) personal goals--the encouragement of knowledge, skills, and attitudes that students may use to achieve ends of importance to the individual, such as promoting good health; (3) social goals--the fostering of knowledge, insights, and competencies that individuals need to participate fully in the resolution of societal problems (e.g., toxic waste dumping, nuclear arms control, or ethical dilemmas associated with the *in utero* diagnosis of genetic disorders); and (4) career goals--the promotion of knowledge, attitudes, and skills needed to explore various career options (including leisure time activities) and to function well in an appropriate and satisfying work role. The goals outlined by Project Synthesis do not include developing facility with the processes of science, one of the long-standing goals of science education, which should be included in any STS program. Project Synthesis did complete a separate report on inquiry.

The Project Synthesis report criticized science instruction in the United States for emphasizing the first goal--academic knowledge--to the exclusion of the other three--the personal, social, and career goals that make science meaningful to young people. A similar criticism of the social studies curriculum was made by Project SPAN.[4] Specially designed STS courses are more likely than either infusion or add-on efforts to address personal, social, and career goals. That assertion assumes the course is designed purposely and explicitly to achieve those ends. If it is not--if, as too often happens, it becomes nothing more than a collection of facts about STS topics rather than a delving into STS issues--then the STS course, like its predecessors in biology, chemistry, earth science, physics, history, or government, can rate low on relevance and high on the transmission of knowledge. The infusion option retains a strong orientation toward communication of factual knowledge because, presumably, the course into which new material is being inserted is directed toward the goal of academic knowledge.

Critics of STS warn that new interdisciplinary STS courses will remove rigor and substance from the science and social studies student's experience. This criticism poses a challenge to advocates of interdisciplinary courses to demonstrate that students will neither learn less science nor less social studies. Proponents of interdisciplinary courses contend that facts are as plentiful as they are in the typical text-dominated course in biology or chemistry, history or government. The difference, they argue, is simply one of context. Students learn facts, concepts, and principles within the framework of a real-world, contemporary, multifaceted problem, situation, or issue.[5]

Finally, new courses in STS are consistent with the development of STS interactions discussed in Chapter 2. The interdisciplinary STS course can be systematically designed to achieve those precise purposes. There are no competing priorities left from an existing course with its established norms.

Thus, the choice of how to approach new STS programs in a school, a district, or a state is similar to any other business decision. The homeowner, a rational investor, knows that large, risky investments--while dangerous and difficult--nevertheless offer the highest rate of return, if new problems in design and implementation are overcome. For the cautious, low profits are an acceptable compromise, given the relative ease and safety of low-cost, low-risk investing. From this vantage point, it is easy to see why many educators opt for infusion of STS content and learning activities into standard secondary school courses in the sciences and social studies. The investment of time, money, and human capital required to create, establish, and sustain a new course may seem too high a price. Furthermore, low-risk gains or losses seem preferable to the risk of complete failure.

Which option is best? It is impossible to say which of these options is best for individual teachers, school districts, or states. All three approaches have merit. It is even possible that some sensitive blending of all three can accomplish more in the long run than any single approach undertaken alone, no matter how well implemented. For example, infusion may represent a more feasible and desirable alternative for elementary students and teachers, while new courses may better satisfy concerns at the secondary level. Another alternative is to infuse STS content and learning activities into standard secondary school courses in the sciences and social studies. In addition, a separate, interdisciplinary course on STS may be offered as an elective. The key to strategic planning for curricular improvement over a three- to five-year period is to determine acceptable and reasonable levels of investment balanced against risks and probable rates of return.

Notes

1. Hazel Whitman Hertzberg, *Social Studies Reform: 1880-1980* (Boulder, CO: Social Science Education Consortium, 1981), p. 80.

2. *Ibid*; see also Lawrence A. Cremin, *Transformation of the School* (New York: Random House, 1964); Diane Ravitch, *The Troubled Crusade: American Education, 1945-1980* (New York: Basic Books, 1983).

3. Norris Harms and Robert Yager, editors, *What Research Says to the Science Teacher* (Washington, DC: National Science Teachers Association, 1981).

4. Project SPAN Staff and Consultants, *The Future of Social Studies* (Boulder, CO: SSEC, 1982).

5. Rodger Bybee, editor, *Science-Technology-Society: 1986 NSTA Yearbook* (Washington, DC: National Science Teachers Association, 1986).

6. STS IN SECONDARY SCHOOL SCIENCE

Incorporating STS topics and themes into an existing course is the method of choice for many schools and school districts. As detailed in Chapter 5, "redecorating" or "refurbishing" courses offers a number of advantages, not the least of which is ease of development and implementation. Teachers and administrators alike are more comfortable with shifting the emphasis in an existing course than with creating a new course. Obviously, these options are not mutually exclusive and both actions may be pursued simultaneously.

Despite the relative ease of the redecorating and refurbishing options, difficult questions still need to be answered. Perhaps the most frequently asked question is: "What do I leave out?" Teachers often feel pressure to cover a lengthy textbook, which, presumably, represents at least one author's judgment of what is important to know in one of the science disciplines. Teachers who perceive the curriculum as already overcrowded may hesitate at incorporating still more new material into a desperately short semester or school year.

Unfortunately, there is no easy answer to this common question. While it is true that time is a limiting factor, it may also be true that a change in emphasis does not necessarily doom students from the mastery of content. In truth, they may master more ideas, because STS provides a relevant perspective that gives facts pattern, meaning, and purpose. Every teacher knows that facts taught in isolation from students' life experience are quickly forgotten. The STS perspective is drawn from life and--if carefully tailored to the experiences and needs of learners--can do a great deal to make subject matter meaningful and memorable. Thus, while some material may of necessity be left out, students may learn more about the topics they do consider in their course work and may even learn more on a wider variety of topics, since STS problems and issues are broadly applicable.

Guidelines for Infusing STS into Secondary Science Courses

Some content or activities must be omitted to allow time for developing STS ideas and themes. How much, and what, will be left out must be determined by teachers and curriculum developers working cooperatively to create a course description that teachers find acceptable, students find engaging, and parents find productive. By answering the following questions, decision makers should develop a defensible strategy for incorporating STS topics into science courses:

1. Is the material directly applicable to the lives of our learners now (not just in the future and not just in other classes they may take someday)? This is a hard criterion to meet. Too often, teachers answer students who ask "Why do I have to learn this?" with "You'll thank me someday," or "Wait until you get to college." Such responses are insufficient. Students should gain knowledge that they can use in the process of living, apart from the process of schooling. Vague responses such as "It is fun to know" or "It might interest them in a hobby" lack sufficient justification for curriculum decision making.

2. Is the material consistent with the cognitive development and social maturity of the students? Introducing the structure of DNA in the seventh grade is probably inappropriate for most 12- to 13-year-olds, whose patterns of reasoning Piaget called concrete operational. Students of this age are still growing cognitively; they need hands-on experience with objects and phenomena that they can see, hear, taste, touch, and smell. Abstractions such as molecules, electrons, and double helices mean little to an adolescent, who may be savvy enough to parrot the words but lack the intellectual schema needed to give them substance. Even in high school, the majority of students are best served by linking abstract, theoretical material with concrete experience. Thus, the curriculum can be trimmed in areas where experience is inaccessible and concepts too abstract for young learners.

Social maturity is an equally important consideration. The controversy over Surgeon General Koop's advice to teach third-graders about AIDS is a case in point. Young children may be able to link information about AIDS to their emerging conception of disease in general, but it is unlikely that they are ready to understand the concept of risk factors associated with intravenous drug use and homosexuality.

3. Is the topic important in the world today and is it likely to remain important for a significant portion of the students' adult lifetimes? Some topics deserve detailed consideration because they are issues important to humankind as

the 20th century draws to a close. Radiation biology is a good example. Students who will grow up to deal with such issues as nuclear arms limitation, underground weapons testing, the disposal of nuclear wastes, and SDI (Star Wars), need some knowledge of the effects of radiation on plant and animal life in order to evaluate political options realistically. Furthermore, some knowledge of how plants grow, how food is produced, and how food webs operate is fundamental to citizens' assessment of the "nuclear winter" scenario.

4. Can students apply the knowledge in contexts other than science? This criterion fits the skills dimension of science instruction. Students can learn to ask researchable questions, formulate hypotheses, design and carry out experiments to obtain reliable answers. They can learn the fundamentals of observation and accurate measurement. They can sharpen their logic by learning to draw defensible inferences from data. They can become analysts of rhetoric by learning to differentiate fact from opinion. All these skills will serve students well--whether they are attending a political rally, repairing a car, or choosing a breakfast cereal.

5. Is it a topic for which students show an interest and enthusiasm? This is a practical criterion: it is hard to teach boring material. Motivation is the first step toward learning, and students express unprompted interest in many areas associated with STS. The curriculum should use those interests to build an understanding of fundamental concepts, processes, and skills in science.

Application of Guidelines to Secondary Science Courses

If the five criteria listed in the previous section are stringently applied, teachers and curriculum planners may find many of the "sacred cows" of science courses toppling. If topics cannot remain simply because they are favorites, or because they are "basic" to a discipline, or because that's the way things have always been done, then we suddenly find more room in the curriculum than imagined.

Suppose we do not teach mitosis and meiosis as ends in themselves, but subsume a general discussion of the phenomena within our studies of reproduction and genetics? Suppose we do not spend several weeks learning to balance chemical equations, but instead examine only a few equations to see what they tell us about air or water pollution? What we have done, in those cases, is shift the emphasis of a traditional biology or chemistry course away from the discipline for its own sake toward the elements of the discipline that can be used in the lives of learners. A tall order, perhaps, but undeniably worthwhile.

The first step, then, is to apply the criteria to decide what to retain and what to omit. The next step is to determine how each of the three perspectives--science, technology, and society--can be developed within the topics selected.

The science part of the triad is best developed by considering how the knowledge is (or was) constructed. Strangely, this is the dimension most often absent from science textbooks. The books tell us scientific knowledge, but too seldom do the books tell how and why scientists came to know what they know. What is the evidence? How complete is it? What kinds of experiments were done in the past or are being done today? What are the best alternative hypotheses? What evidence has led to the rejection of some of these alternatives?

Those who wish to bring an STS perspective to their science courses need to develop ways to deepen students' understanding of the processes of scientific inquiry. We know that knowledge will change in the future and that the change will be dramatic. Truths generally accepted today will be discarded tomorrow in the light of new data. A body of knowledge mastered now will probably prove obsolete in a few years, but a mastery of the process of science as inquiry will serve students well throughout their lifetimes.

Next, the dimension of technology can be developed within each topic. This is done rather simply by asking how the knowledge generated by science can be or is used and applied in practical matters of everyday life. Students need not learn in detail how refrigerators and television sets work. But they should gain enough knowledge of these devices to see how basic principles of chemistry and physics can be turned to practical ends. In fact, some courses may be enriched and enlivened by considering the practical applications to technology first and then examining the underlying principles of science.

Finally, concepts relative to society can be developed by considering why the knowledge of science and the applications of technology are important to people We have knowledge and we use it, but what difference does that make to people? This dimension of STS courses demands some exploration of political science, psychology, economics, sociology, and probably history. Science teachers may seek help with these matters from their colleagues in the social studies.

Once topics have been selected and ways of developing the dimensions of science, technology, and society have been identified, the final decision has to do with preferred instructional methods. Perhaps the simplest solution is to present more information in the lecture-discussion mode. This approach has the advantage of being quick, controllable, and easily tested, but may not be consistent with the STS perspective. Planning ways of providing students with direct experience with a topic (e.g., a field trip to a water treatment plant or a laboratory exercise on eutrophication) is preferable. Even more appealing may be situations that require students to use their investigative skills to collect data and then to apply their interpretive skills to problems of personal and/or societal decision-making. The last category includes such learning strategies as debates, independent projects, small-group discussions, simulations, surveys, interviews, class presentations, and written reports. In any event, a mix of instructional strategies throughout the school year minimizes boredom and keeps the pace lively.

This, then, is the three-step process: select content, develop the STS dimensions, and identify instructional strategies. Some educators will note that no mention has been made of objectives. Isn't that, after all, the place to begin? Yes and no. First, the general objectives of the course are implicit in the five criteria for selection of content. Our goal is to create a science course that is applicable to the students' present lives, important to society's future, and attractive to students' own interests. Specific objectives will be derived from the content selected to meet these criteria. Finally, objectives are embedded in methodologies. If we want our students to become good decision makers, we are likely to give them opportunities to develop and practice their decision-making skills.

Many of the objectives typically associated with units of study in traditional science courses meet these tests and may actually be developed more fully within an STS perspective. The examples described in the following sections may illustrate this point.

STS in Earth Science

Study of the oceans and seawater is likely to survive the scrutiny demanded by our five criteria. Students who live near the ocean have an opportunity to apply their knowledge of seawater in both work and recreation. Land-bound learners may have experienced the ocean only on vacations, if then--so their opportunities for immediate application of knowledge may be less. Whether this limitation is too severe to include this topic depends on circumstances and judgments of teachers and curriculum planners. Nevertheless, the topic holds up well according to our other criteria. It is a topic that students should be able to understand in high school. It is quite important to the world today and likely to remain so in the future. Learning about scientific inquiries into the topic should provide students with skills they can apply in other contexts. Finally, many students seem interested in the ocean--especially in its plant and animal life and in possibilities for future technologies, such as farming the oceans.

The text *Modern Earth Science*[1] has five objectives in a chapter on sea-water:

- Describe the physical properties of seawater.
- Describe several conditions that change these properties.
- Describe the chemical properties of seawater.
- Explain how the salt content and dissolved gases in seawater affect sea life.
- Explain how the sea can be a valuable resource.

These objectives fail to do justice to a chapter that is rich in potential for development of STS themes. In fact, the chapter introduces the technology and society dimensions, although it does not fully develop them. For example, the chapter describes technological means of obtaining freshwater, minerals, and food from the sea. Methods of mining nodules from the sea are described and illustrated graphically. Desalinization is described as too expensive to be feasible unless cheaper ways of using solar or nuclear energy are developed. Some intriguing possibilities for aquaculture are explained, and an aquatic farm where trout are raised for food is pictured. This material can easily provide the core of the technology dimension of the study of seawater. Teachers could introduce contemporary readings on these topics or invite students to research these options and present their findings to other students. Videotapes, slide sets, and filmstrips available on these topics can do much to take students to places they cannot visit. Finally, students might be engaged in a debate over some hypothetical policy issue--for example, a bill before the U.S. Congress to invest 100 billion dollars in research and development of various schemes for farming the oceans.

The chapter from *Modern Earth Science* has also done a creditable job of addressing the question of why the oceans are important to society (i.e., the societal dimension). The chapter looks at why some materials (e.g., DDT, lead, radioactivity) are present in seawater as a result of human activities. Until recently, people were able to safely use the oceans as a dump. Wastes could be made harmless by being diluted or destroyed in seawater, but growth of population and increase in industry have seriously changed the situation. The ability of the oceans to absorb wastes is far less than the ever-increasing amounts that are discharged all over the world. Coastal waters are particularly in danger, but pollutants can be found everywhere in the sea.

A great profit in learning could be returned from only a small investment of class time on these topics Students could be engaged in discussion of the significance of these topics. Why is it important that lead and DDT have been found in the oceans? How is it that materials not directly dumped into the oceans end up there anyway? Is the problem technology, population growth, or both? What might be done to clean the oceans? Is it even important to do so at this time?

Answers to these questions rest in some fundamental considerations of the science involved--curiously, the dimension this chapter treats least well. Teachers and students must examine pertinent research studies to find how investigations of the ocean's properties are undertaken, what data are derived, and the difficulties of interpreting such data for local or worldwide decision making. This chapter abounds with the conclusions derived from scientific investigation: that chloride ions are 55.04 percent of the total dissolved solids by weight in seawater; that surface temperatures around 30° C are not unusual in tropical waters; that various colors of the visible spectrum are absorbed at different depths in the ocean. The chapter even tells that the total amount of solar heat falling on the surface of the sea is much greater at the equator than at the poles. In no instance, however, does the chapter provide any insight into how scientists have come to believe these things to be true. Obviously, high school earth science students need not be burdened day after day with the technicalities of sophisticated methodologies, but they should, if they are to understand science as a human endeavor, be confronted with the important scientific question: "How do I (we) (they) know?" Delving into methods and evidence can help students master some investigative skills they can apply in other areas of learning and living. It is probably not necessary that students examine the primary data of original research reports for every topic they study, but it is imperative that they do so at some time during the school year.

Some laboratory activities suggested with the text chapter might be skipped in other courses, but acquire new significance from an STS perspective. It would, therefore, be important to allow time for students to measure and compare temperatures in equal volumes of fresh- and seawater exposed to light, to construct a temperature profile of a room from door to ceiling and compare it with the profile of the open ocean, and to use a homemade hydrometer to investigate differences in the density of various solutions.

STS in Life Science

Topics of respiration and waste regulation are typically addressed in life science courses, and they are likely to find a place in a course taught from an STS perspective as well. Respiration and waste regulation meet the five criteria for content selection quite well. The topics are important to young people, especially in terms of health and physical fitness. The topics can be readily understood by most students of middle or high school age. They are important to society as new advances in biomedicine raise issues of the ethics of artificial organs, organ transplants, life-prolonging respirators, and so on. Obviously, students can apply their knowledge of these topics to personal decisions about exercise, nutrition, and use of the health care system. Finally, the topic stands a chance of being reasonably interesting to students, as most prefer human studies to studies of other organisms.

Holt Life Science divides its chapter titled "Respiration and Waste Regulation" into three sections: one on gas exchange, a second on the excretory system, and a third on the liver. The objectives are:

Section One:

- Identify the human respiratory organs and give their functions.
- Explain the process of breathing in humans.
- Measure your breathing capacity.

Section Two:

- Identify some metabolic wastes and explain the importance of excretion.
- Explain the structure and functions of the human urinary system.
- List the functions of the skin and explain how wastes are excreted by the skin.
- Examine the skin and its excretory functions.

Section Three:

- List the many functions of the liver.
- Explain why urea formation is an important function of the liver.
- Describe how the liver regulates the blood sugar level.
- Outline how the blood sugar level is regulated.

This modest list of objectives misrepresents a unit of instruction rich in possibilities for development from the STS perspective. The question "What is the evidence?" is no better developed in this chapter than it was in the earth science selection, but the opportunities are there to explore scientific research close to the cutting edge of contemporary biomedicine. For example, the chapter mentions emphysema as a "common disease among smokers and people who breathe 'dirty' air." But it makes no mention of the many years of epidemiological studies that linked smoking not only to emphysema but also to lung cancer and heart disease. Even middle school students are capable of appreciating the limitations of scientific investigations in cases where single-factor, controlled experiments cannot be conducted. (Ultimate answers might be obtained by randomly dividing persons into two groups at birth and controlling all aspects of their environment through old age--one group forced to be smokers, the other group forced to abstain. The absurdity of this kind of science should be obvious.) More subtle are the ways scientists use to discern subtle trends among multivariate populations, seeking causality by possible association (correlation) alone.

Other opportunities to expand the science dimension of this chapter are inherent in the suggested laboratory activities. By measuring their vital capacity, students can improve their skills of measurement and calculation. By noting the evaporation rates of water and alcohol rubbed on human skin, students can relate a simple physical phenomenon to the more complex function of cooling the body.

The chapter makes some mention of technology; given the rapidity of change in this field, it is likely that reports from current newspapers and magazines can be used to enrich the instruction. The chapter discusses kidney machines and kidney transplants and makes passing reference to diabetes and low blood sugar. Students have likely heard discussions of these topics at home or elsewhere and may be eager to delve into these topics more fully.

From these beginnings, it is an easy next step to consideration of the societal dimension. Small-group work, library research, debates, and brainstorming sessions may be used to move beyond these specific technologies to analysis of the social, ethical, and legal aspects of other "extraordinary" medical technologies.

STS in Physical Science

Holt's *Modern Physical Science* devotes an entire chapter to engines. This is unusual, as most physical science texts only have brief mention of engines embedded in a theoretical discussion of the laws of mass, energy, and motion. The existence of this chapter implies the authors' possible intent to use a technological topic as a means of conveying not only important physical laws, but their practical importance as well. The objectives of the chapter hint at this purpose:

Describe the effects of engines on the world.

- Distinguish between rotary and reciprocal engines.
- Distinguish between internal and external combustion engines.
- Compare the four-stroke engine with the diesel.
- Describe how jet and rocket engines work.

The subject of engines nicely meets the five criteria for selection of content. There are many direct, immediate, and everyday applications of a knowledge of engines. Teenage fascination with cars suggests that the topic is of some interest. The topic is currently very important to the world of manufacturing, transportation, and commerce; it is certain to remain so into the future. Middle and high school students are certainly capable of understanding what engines are and how they work. Students can, from their study of engines, gain important skills of problem-solving that they can apply outside their formal science courses.

This chapter is written almost entirely from the technological perspective. The questions of "What is it?" and "How does it work?" are encountered throughout the chapter. For example, the text discusses why turbines are more efficient than reciprocating engines, why diesels are more efficient than gasoline engines, and how solid fuels are used to power rockets. The chapter even concludes with an essay on careers, titled "Jobs in Mechanics and Repair," an option that may appeal to many students.

This chapter provides the context for developing numerous physical principles. The law that every action has an equal and opposite reaction may seem abstract and technical in isolation, but is easily understood when we learn that "gases rush out of the jet at the rear of the engine, giving the engine its forward thrust." The difficulty that middle school students often express in attempting to understand mechanical advantage might be alleviated somewhat if this concept were presented while studying engines: "The transmission permits the driver to shift gears to get the best . . . mechanical advantage . . . In low gear, the drive shaft turns much more slowly than the engine. This supplies a large torque to the wheels for starting and for steep climbs." Most physics teachers could not resist the temptation at this point to launch into the definition of torque and a few equations--equations perhaps made relevant by this application to engines.

The societal dimension is equally easy to develop from this technological starting point. The chapter begins with a discussion of the uses of engines in modern agriculture. Appropriate, then, might be in-depth investigations of the contention that "modern agriculture is merely a method of turning fossil fuels into food." It is also possible to envision some research into appropriate and inappropriate technologies for developing nations and the barriers to technological innovation that exist in non-Western cultures. Here, as before, library work, outside readings, guest speakers, field trips, independent and small-group projects, and simulations are promising instructional strategies.

These examples should illustrate the potential that lies often untapped in even the most traditional of earth, physical, or life science courses. What is required to bring an STS perspective to such courses is careful selection of content, deliberate allocations of time to STS topics and themes, exploration beyond the bounds of the text for opportunities to develop these themes, and a variety of instructional methods and strategies. This is a great deal to require from busy teachers and a large challenge for curriculum writers, program planners, evaluators, and school administrators. Yet such modifications of science courses are certainly achievable and potentially rewarding for educators and students alike.

Notes

1. As a matter of convenience, three textbooks from Holt, Rinehart and Winston were selected as source material for use in developing these examples. The books are *Modern Physical Science* (1983), *Holt Life Science* (1982), and *Modern Earth Science* (1983). These books are representative of texts available in these fields and therefore function well to illustrate how traditional course content can be approached from an STS perspective. The selection of these books for case material is not intended as recommendation or a condemnation of these texts or this publishing company.

7. STS IN SECONDARY SCHOOL SOCIAL STUDIES

Education for citizenship in a free society is the long-standing goal of social studies teachers in the United States. From the early years of our republic until today, general education for citizenship has stressed rights and responsibilities of constitutional government, which include participation in decisions about public policy. More than two hundred years ago, Thomas Jefferson wrote: "Every government degenerates when trusted to the rulers of the people alone. The people themselves therefore are its only safe depositories. And to render even them safe, their minds must be improved to a certain degree. . . . The influence over government must be shared among all the people."[1] In this quotation Jefferson identified two fundamental issues: the role of the people in government, and the central place of education.

Thomas Jefferson had great faith in the power of schooling to educate citizens to think for themselves about issues, policies, and officials in government. Americans today tend to share Jefferson's faith, but we also recognize that society has changed significantly since the founding period of our nation's history. The public policy agenda of the 1980s has been filled with issues generated by advances in science and technology ranging in complexity from health hazards of fumes from internal combustion engines to depletion of the ozone layers. The challenges of citizenship today, and hence the tasks of citizenship education in schools, have become enormously complicated by rapid advances in science and technology and profound social changes emanating from them.

Citizenship and citizenship education are connected to developments in science and technology in numerous ways, including the following: citizen awareness of science and technology in society; the need for citizens to make judgments about the social consequences of science and technology; the generation of public policy issues based on science and technology; citizen participation in the resolution of STS issues; and the need for citizens to make personal choices related to the impact of science and technology on ways of living. According to a prominent scientist, "the human race has never had such bountiful technological benefits as today. But there has also never been a time when the technological risks were greater. It is impossible to weigh benefits against risks without knowledge, and in a democratic society, that means knowledge for everyone, not just the experts."[2]

The democratic tradition of majority rule is threatened by massive ignorance about public issues related to science and technology. The challenge this situation poses to citizenship educators in the social studies is how to disseminate widely among the American people knowledge and cognitive process skills needed to participate intelligently in decisions about social issues related to science and technology. Failure to meet this challenge will compromise severely, if not defeat, fulfillment of Jefferson's ideal of the people as the "only safe depositories" of government. How can social studies educators in secondary schools address the challenges of education for good citizenship in our contemporary age of science and technology?

Guidelines For Infusing STS into Secondary Social Studies Courses

Following are six guidelines for selection and/or development of STS content and learning activities for integration into standard secondary school courses in the social studies. These guidelines fit the framework presented in Chapter 1, involving acquisition of (1) knowledge related to science/technology/society, (2) utilization of cognitive processes and skill in information processing, problem solving, and decision making, and (3) development of attitudes and values about practices of science/technology in a democratic society. The guidelines may be addressed variously as to order and emphasis in the development of instructional units or courses, but all of the guidelines pertain fundamentally to the overarching goal of education for citizenship in a modern democracy.

1. Treat interrelationships of science and technology in a social context. These interrelationships are various and begin with knowledge of the symbiotic connections of science and technology. Students should learn how science is related to technological developments and how technology is liked to scientific advances. The science/technology interface, however, always exists in a social context, which is the major emphasis in social studies courses. These STS interrelationships involve governmental and economic institutions and processes associated with the practice and achievements of science and technology. Students should learn

how federal and state governments and private businesses, especially large corporations, foster developments in science and technology. Finally, this guideline involves public opinions and attitudes about the practice and uses of science/technology in a democracy. Students should learn how attitudes and values influence choices on using resources to seek certain ends and to avoid others. They also should compare practices and uses of science/technology in democratic and non-democratic societies.

2. Emphasize the uses, limits, possibilities, and variable social consequences of scientific and technological endeavors in the past and present, both nationally and globally. This guideline focuses on social continuities and changes associated with processes and products of science/technology. Students should learn about science/technology as part of the social history of their nation and the world. Furthermore, students should learn about social origins and effects of science/technology as part of current national and international events. The products and procedures of modern science/technology have forged links between Americans and other peoples of the world. The cross-cultural movements of scientific and technological knowledge and products are among the most important global forces of modern times. As world leaders in science and technology, Americans have traditionally enjoyed a central position in this global exchange. To understand adequately how Americans are connected to one another and to other nations, students must know about the centrality of science/technology in American society.

3. Stress that science/technology have been fundamental elements of Western civilization (including America). Values associated with practices and products of science/technology are major elements of Western civilization, as are values about constitutional government and a free society. Students should learn that Americans have been and are a people of preeminent achievement in science and technology and that values associated with these achievements typify the American heritage. In *America as a Civilization*, Max Lerner wrote, "America is a civilization founded on science and rooted in its achievements. Without science the whole ribbed frame of American technology, and with it American power, would have been impossible."[3] Indeed, Americans are heirs of scientific and technological revolutions originating in Europe from the 16th through the 18th centuries and brought to North America by European colonizers and settlers. By the middle of the 18th century, Americans were making their own important contributions to science/technology; from that time to the present, the values, practices, and products of science/technology have been basic elements of the American way of life. Thus, to know and appreciate adequately their American heritage, students must understand and value science/technology as primary contributors to development of the United States.

4. Examine past and present public issues, in national and global perspectives, associated with the human effects of scientific/technological practices and products. In one form or another, issues related to science/technology have been a perennial part of the American experience in domestic and international affairs. Knowledge of these issues, their origins, development, and impact on societies, is necessary for students to understand contemporary questions and issues about the uses of science and technology. Of course, students should experience balanced treatments of issues with multiple perspectives and viewpoints. Furthermore, students should have an opportunity to compare and contrast responses of different societies and cultures to similar issues. Finally, students need to know how some basic issues have become global in scope and significance and that all humans, in all places in the world, have a stake in the resolution of these issues.

5. Develop cognitive process skills in social sciences and history and in civic decision making as ways of knowing and evaluating phenomena and issues associated with science/technology/society. Inquiry in social sciences and history refers to cognitive process skills that help describe and explain phenomena about people and societies in the past and present. Civic decision making involves cognitive process skills that enable rational choice about public issues. Civic decision making requires knowledge provided by social science and history to clarify alternatives and justify hypotheses about consequences that are more or less likely to result from one choice or another. Civic decision making also involves judging consequences as more or less positive or negative. It requires assessing likely outcomes according to priorities that represent personal and societal values. Thus, civic decision makers use knowledge and values to make informed, rational choices about resolution of public issues.

Given the interrelationships of cognitive process skills in social scientific and historical inquiry and civic decision making, these complementary ways of thinking should be integral parts of every course in the secondary social studies curriculum. In particular, students should be required to practice cognitive process skills in social science and history and civic decision making in reaching and justifying choices about science/technology/society issues. Students who reflect upon values about science/technology and democracy through exercises in civic decision making are likely to develop warranted commitment to these basic parts of the American heritage.

6. Connect content and learning activities about science/technology/society to obvious entry points in standard social studies courses in the core curriculum of secondary schools. Content and learning activities on science/technology/society are more likely to be infused into the social studies curriculum if they fit particular themes, topics, and concepts of standard courses. If these connections are made, lessons on science/technology/society will appear to enhance the coherence and integrity of the curriculum that is currently in place in most schools. Secondary social studies courses with the largest enrollments nationally are American history, civics/government, world history, and geography. American history is offered in junior high/middle school (usually at 8th grade and sometimes at 7th grade) and is a universal requirement for high school graduation (offered usually at 11th grade). Civics is usually taught at grades 9 or 8. Government, a nearly universal requirement for high school graduation, is taken by most students in the 12th grade. World history and geography are staples of 7th and 8th grade. In addition, geography is offered in many schools at the 9th or 10th grade, as is world history. Each of the standard courses listed above offers ample openings for integration of content and learning activities on science/technology/society.

STS in World History

Using the six criteria discussed above, a strong case can be made for emphasizing STS in secondary world history courses. Current issues and policies related to science and technology have a past that must be understood if one is to be a capable decision maker about these matters. Furthermore, one can neither understand modern world history nor contemporary American society without knowledge of the history of science and technology in Western civilization. The scientific and technological revolutions that originated in Europe have spread to the rest of the world and are the foundation we have for building global links between the disparate peoples and traditions of our planet. The late British historian, Herbert Butterfield, eloquently made the case for science and technology as the most powerful international force in modern history: ". . . when we speak of Western civilization being carried to an oriental country like Japan in recent generations, we do not mean Graeco-Roman philosophy and humanist ideals, we do not mean the christianising of Japan, we mean the science, the modes of thought and all that apparatus of civilization which were beginning to change the face of the West in the latter half of the seventeenth century."[4]

The Scientific Revolution in Europe is an important entry point for lessons on STS in world history courses, as is the later Industrial Revolution. Lessons should be developed to enhance limited textbook treatments of these major turning points in world history; major textbook coverage of the Scientific Revolution is especially scanty.[5] Students should be stimulated to investigate the origins and effects of the Scientific Revolution on countries in Western Europe. They might be asked to compare social conditions in 16th century Western European countries and selected non-Western societies of the same period in order to identify social factors in Western Europe that contributed to development of modern science and technology.

Another opening for integration of STS content and learning activities is the uneven spread of Western science and technology to various parts of the world in the 18th, 19th, and 20th centuries. Students might learn why Western science and technology have taken root in some societies and not in others. Furthermore, lessons might be created to teach relationships between scientific/technological developments (or lack of them) and certain characteristics of various nations, such as living standards, productivity, national security, national wealth, and exercise of national power in world affairs. Students might examine the links between imperialism and scientific/technological advances.

Finally, challenging global issues that stem from practices and products of science/technology might be the focus of lessons on 20th century world history. For example, case studies might be developed about the comparative benefits and detriments of using pesticides and chemical fertilizers to increase agricultural production in developed and third world countries. Another example is examination of issues associated with the use of nuclear power in industrial enterprises or in national defense. A third example, among the many that could be identified, is controversy about exploitation of resources under the world's oceans.

STS in American History

The history of science and technology in America is part of the development of Western civilization in modern times. However, Americans have made special and significant contributions to science and technology in the 19th and 20th centuries; these contributions should be highlighted in secondary courses. Students should learn about major persons, events, and achievements of American science and technology in terms of the six criteria presented in the first part of this chapter. Developments in science and technology should be treated as an integral part of American social history; indeed, no other social forces have led to more significant and enduring changes in our way of life.

The first opening for study of science/technology in American history is the period of European exploration, colonization, and settlement of North America. Students might study the relationships between science/technology from Europe and "discovery" and transformation of the "new world." Information on Native American science and technology, which was closely related to ecology and embodied their sense of time, space, distance, and lifestyle, should be included.

A second place to infuse STS content in the U.S. history course is the start of significant industrial development in North America with the application of industrial technology from England to New England by Samuel Slater and others.

A third place for inclusion of STS subject matter pertains to the westward movement and settlement of the advancing frontier by American pioneers. Students should learn how developments in transportation and communication accelerated settlement of the west and binding of these new territories to other parts of the nation.

Following is a list of additional topics in American history that can serve as openings for integration of STS content and learning activities:

- Urban development and the growth of modern metropolitan regions.
- Weapons and tactics in the Civil War, which has been called the first modern war.
- Growth of businesses and industries following the Civil War, which made the United States the leading industrial power in the world by the turn of the 20th century.
- Development of mass production and mass marketing in the first half of the 20th century.
- Weapons and tactics in World Wars I and II.
- National security in our nuclear age.
- Development of our post-industrial era, based on continuing "high-tech" innovations.

Science/technology-related social issues of the past and present should be emphasized in treatments of these various topics in U S. history Students should be challenged to reflect upon the advantages and disadvantages of various developments in science/technology in different periods of American history and how these developments and controversies reflect continuities and changes in American society Through study of these issues, students should learn how science and technology have been continuingly potent forces in American society that have led to profound and sweeping social changes and that will continue to do so in unpredictable ways. Finally, investigation of STS issues should teach students the relationships between science and democracy--the compatibility of the values of a free society and scientific innovation.[6]

STS in Civics/Government

Secondary school courses in civics and government treat the democratic values and political-economic institutions of a free society Scientific/technological processes and products are conducted within a social nexus consisting of various public and private institutions--state and national governments, corporate enterprises, special interest groups, and the values that undergird these institutions. Thus, courses in civics and government provide significant openings for learning experiences on science/technology/society.

The first opportunity to treat STS in civics or government courses is provided by studies of the meaning and functions of government and comparative government; such studies appear in the opening sections of most textbooks. Students should learn the relationships of government to stimulation and regulation of scientific/technological practices and products. They also should be taught about the similarities and differences of public linkages to science/technology in different systems of government. For example, they should compare and contrast the roles of government in science/technology in the United States and other political systems, such as the USSR, Japan, and France. The relationships between values of democracy and science should be examined in these learning activities.

Following are additional connections between standard topics in secondary school civics/government courses and STS content and learning activities:

- The relationship of the Constitution to science/technology as indicated by Article I powers of Congress to authorize and regulate a system of patents and copyrights, by Article I powers of Congress to regulate commercial uses of products of science and technology, and by Amendment I protections of free exchange of ideas.
- The relationship of scientific and technological work to the federal bureaucracy as exemplified by various regulatory agencies (EPA, FAA, FCA), executive departments (Defense, Transportation, Agriculture, Commerce, Education, Health and Human Services), and agencies (NSF, DOE) that have been created especially to promote education and research in science.
- Congressional support for and regulation of science/technology through the legislative process.
- Presidential influence on uses of science/technology through the Chief Executive's roles as setter of the national policy agenda, foreign policy leader, and commander-in-chief.
- Judicial influence on uses or regulation of science/technology through decisions in court cases.
- Influence of citizens, through participation in special interest groups, on national and state policies about the uses of science/technology.
- Influence of citizens, through participation in state elections on initiatives and referendums, on national and state policies about the uses of science/technology.

Science/technology-related social issues, which pertain to topics in the preceding list, should be highlighted through case studies about civic decision making. During a course in civics or government, the foci of these decision-making cases should vary across different levels of government (national, state, and local), branches of government (executive, legislative, and judicial), and policy concerns of the public (environmental, national security, economic development, consumer protection, and so forth).[7]

STS in Geography

Basic themes and concepts in geography provide openings for integration of subject matter about science/technology/society. For instance, a fundamental theme of geography is interactions of humans with their natural environment. People modify and adapt to natural settings in ways that reveal cultural values and capabilities, including values and capabilities having to do with science and technology. Students should learn how relationships develop between humans and their environment, how science and technology are involved in these relationships, and how these relationships affect both people and their environment. STS topics subsumed by this theme are: various means of using or conserving land and other natural resources, opportunities and problems associated with urban growth and development, and opportunities and problems associated with industrial development and controls on this type of growth.

Another basic theme of geography, which can be connected to topics in science/technology/society, is interaction of various groups of humans in different places on the Earth. Human beings, unevenly distributed throughout the world, interact through travel, trade, and communication. These interactions have been profoundly affected by developments in science/technology, which have connected people and places around the world in modern times. Today, complex communications and transportation networks link every part of the world; most people, directly or indirectly, interact with other peoples and places regularly. These interactions will continue to change with new developments in science/technology. Students need to learn about these changes and to examine their consequences for people and their social and natural environments. STS topics subsumed by this geographic theme are: relationships between science/technology and population growth, population distribution, and population density; local, national, and international transportation and communication linkages and their effects on people and societies; specialization and interdependence in using human and natural resources to meet human needs.

A third major theme of geography, which has implications for the study of science/technology/society, is the formation and change of regions. A region is any area that displays unity in terms of selected criteria, such as characteristics that define a culture and distinguish it from other cultures. Cultures vary in their use of science and technology to meet human needs and fulfill human aspirations. Students should learn how to compare and contrast the values and uses of science/technology in different cultures around the world.

Case Studies of Civic Decision Making About STS Issues

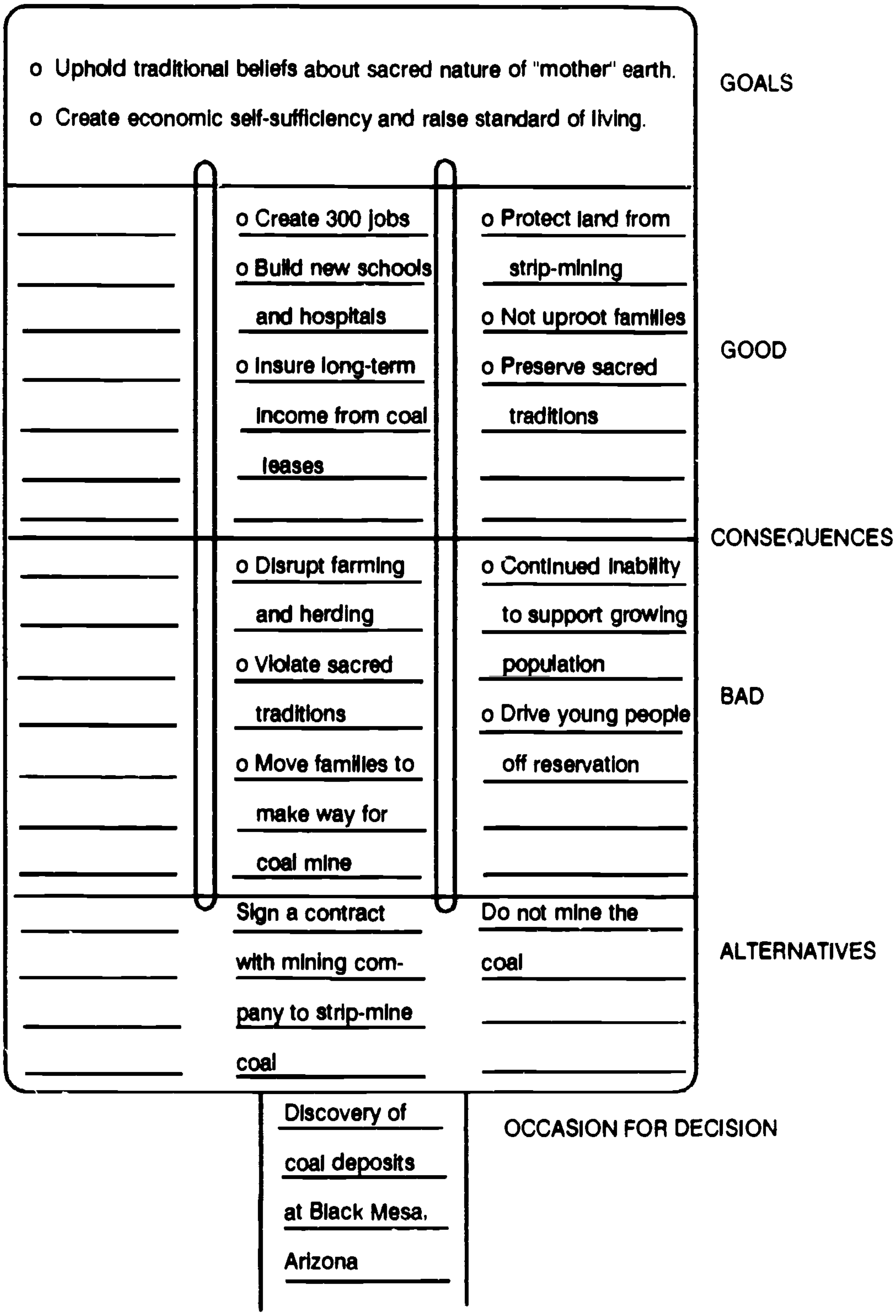
A fundamental part of all treatments of STS issues in social st[illegible] courses should be case studies of decisio[illegible] about science/technology-related socia[illegible]. In a free society or democracy, citizens [illegible]e the right and responsibility to participate, directly or indirectly, in choices about public policies. In modern times, no social issues and policy choices have been more significant than those having to do with processes and products of science/technology.

One effective means for helping students practice cognitive process skills in civic decision making is the decision tree strategy.[8] This device is an adaptation for secondary school students of a more complex process used widely in teaching and research in policy science, management science, and engineering.[9] For secondary school students, the decision tree strategy can be represented by a chart (Figure 6) that portrays essential elements of civic decision making: (1) an occasion for decision (science/technology-related social issue), (2) values and goals that pertain to the occasion for decision, (3) alternative responses to the occasion for decision, and (4) likely consequences--positive and negative--of the alternatives. These four elements are a slightly abbreviated version (for ease of presentation in a chart) of the essential elements of civic decision making discussed in Chapter 3 of this work. These elements involve interlacing of knowledge based on the sciences and social studies with the arts of critical thinking and value judgment.

The decision tree in Figure 6 has been filled in for a case study involving a recent science/technology-related social issue on the Navajo reservation in Arizona.[10] Before using the decision tree shown in Figure 6, students read a case study about the social issue on the Navajo reservation. The first move in response to the decision tree chart is to identify and clarify the occasion for decision--in this instance, the discovery of a huge, shallow vein of low-sulfur coal on the Navajo reservation. Students next identify and clarify the alternatives and then move to consideration of the likely consequences (see Figure 6). When considering these consequences, they make factual judgments about the outcomes that are more or less likely to result from selection of each alternative. Students also consider what is good or bad about these consequences in terms of values and goals they have applied to this issue. Finally, they choose one alternative as better than the others in terms of the analysis and judgment represented in Figure 6. Of course, students should not be expected to use the decision tree strategy in a lock-step or linear fashion. Rather, decision makers use the categories in the chart variously from one occasion to another. However, the standard categories in the chart help students keep track of cognitive moves that are--in one way or another--part of any civic decision. (See the discussion of this point in Chapter 3)

Students in social studies courses may use decision trees individually or in large or small groups to analyze and judge the decisions of others or to make their own decisions in response to an open-ended case study or computer simulation. Use of case studies in teaching is a long-standing practice in leading schools of business and law and in social science departments of major universities and colleges. Cases of science/technology-related social issues and policy choices can provide the slices of reality to which learners apply skills in civic decision making. These case studies can take various forms, such as court cases, policy cases, and referenda. Sources for creating the case studies include newspapers, magazines, novels, govern-

FIGURE 6
THE DECISION TREE



- Uphold traditional beliefs about sacred nature of "mother" earth.
- Create economic self-sufficiency and raise standard of living.

	Sign a contract with mining company to strip-mine coal	Do not mine the coal
GOOD	o Create 300 jobs o Build new schools and hospitals o Insure long-term income from coal leases	o Protect land from strip-mining o Not uproot families o Preserve sacred traditions
BAD	o Disrupt farming and herding o Violate sacred traditions o Move families to make way for coal mine	o Continued inability to support growing population o Drive young people off reservation

Discovery of coal deposits at Black Mesa, Arizona ment reports, legal briefs, and judicial decisions. Furthermore, cases might be presented in print, film, video or audio cassettes, computer software, or combinations of these media.

Providing students with learning activities based on case studies and civic decision making responds directly to the primary goal of secondary school social studies, which is education for informed citizenship in a democracy. Modern times often require citizens, as non-specialists, to participate in decisions with high stakes for themselves and their community. Paul DeHart Hurd, an eminent science educator, explains the central place of decision making in citizenship education: "In our civic and personal affairs, the cognitive processes that we most frequently use are those of decision making. . . . The educational goal, then, is to teach students how to marshal, organize and analyze information leading to a choice of action and to recognize the probable consequences."[11]

Notes

1. Thomas Jefferson, *Notes on the State of Virginia* (Brooklyn, NY: Historical Printing Club, 1894), p. 188. (First published in 1782.)

2. Malcolm Browne, "The Untutored Public," *New York Times* (22 April 1979), p. 14.

3. Max Lerner, *America as a Civilization* (New York: Simon and Schuster, 1957), p. 209.

4. Herbert Butterfield, *The Origins of Modern Science* (New York: The Free Press, 1957), p. 191.

5. John J. Patrick, "Science and Society in the Education of Citizens," *BSCS Journal* 3 (December 1980). pp. 2-6.

6. The following book is especially helpful in gaining insight into science and technology in American history: Robert V. Bruce, *The Launching of Modern American Science, 1846-1876* (New York: Alfred A. Knopf, 1987).

7. David Dicksons, *The New Politics of Science* (New York: Pantheon Books, 1984) is highly recommended as a book showing the relationship of science to universities, industry, the military, foreign policy, and public participation.

8. This device has been used in works of Richard Remy and John Patrick, such as *Civics for Americans* (Glenview, IL: Scott, Foresman, 1987) and *Lessons on the Constitution* (Washington, DC: Project '87 and Boulder, CO: Social Science Education Consortium, 1985).

9. The scholarly literature on decision making is voluminous. Following are representative items in this body of literature: Percy H. Hill et al., *Making Decisions: A Multidisciplinary Introduction* (Reading, MA: Addison-Wesley, 1979); Howard Raiffa, *Decision Analysis: Introductory Lectures on Choices Under Uncertainty* (Reading, MA: Addison-Wesley, 1970); Robert Bell and John Coplans, *Decisions, Decisions: Game Theory and You* (New York: W.W. Norton, 1979).

10. Paul DeHart Hurd, *Reforming Science Education: The Search for a New Vision* (Washington, DC: Council for Basic Education, 1984), p. 13.

11. *Ibid.*

8. AN INTERDISCIPLINARY APPROACH TO STS

A recent paper in the *Phi Delta Kappan* described the art of good teaching as the sharing of enthusiasm for one aspect of the culture[1] The simplicity of this description is a paradox. While one can be enthusiastic in ignorance, only through considerable knowledge can one communicate that enthusiasm to others in any persuasive and persistent way. Furthermore, the favored aspect of culture cannot be fully appreciated without attention to its links with all the other parts of the culture. Enthusiasm may be limited when the walls of a discipline confine it; enthusiasm flourishes when the whole culture is seen as greater than the sum of its parts.

In previous chapters, we have considered the options of "remodeling" and "refurbishing" existing science and social studies courses. These options allow retention of the traditional disciplines, with all that implies about goals, processes, and subject matter. The final option of rebuilding suggests that we can, if we desire, step outside our time-honored assumptions about what to teach, why to teach it, and how to teach it. From this new vantage point, we can create a course that approaches the theme of science, technology, and society in two ways: with enthusiasm for the scientific and technologic aspects of culture and with sensitivity toward how these aspects relate to the rest of the human experience--past, present, and future

The importance of the human perspective projected forward in time cannot be overemphasized. Isabel S. Abrams has noted:

> Today, more than at any other time, science and technology shape our world. Through science we have the knowledge and the methods to control many natural processes and, therefore, the potential to improve the quality of life. Technology enables us to apply scientific principles to the use of natural resources for economic development and for the production of goods and services. However, science and technology also can provide weapons for war and destroy the biosphere, the living world in which human beings are intimately linked with land, atmosphere and oceans, as well as plants, animals, and microorganisms. The way we direct our scientific research and the way we apply technology will determine whether we can sustain our society and its life-support system, the natural environment[2]

An interdisciplinary course in STS is built on the interrelationships that Abrams describes. Such a course has many educational advantages, not the least of which is the students' personal, firsthand participation with STS issues Hurd argues that during the study of real-world events, students develop skills in "processing information, formulating options, and making personal judgments . . . Thus, students develop an awareness of their own purposes, beliefs, and ideals, and are exposed to those of others. The resolution of STS problems goes beyond technical knowledge to human experience, purposes, and values, and to social, economic, political, and humanistic factors."[3] Such a course enhances motivation because students perceive their studies as relevant to the world outside of school. They may also be able to see links between their studies in science and other academic subjects--for example, as mathematics and civics are used in the analysis and resolution of an STS issue.

Hurd argues further that "knowledge, whether of facts or methods, gains meaning from the context in which it is used. Strictly discipline-based courses are too constrained to convey the full meaning of much that is taught. Facts are learned, but many are largely inert and have little effect on daily life . . . The STS theme is designed to make the study of science productive for more students by encouraging students to think about the social and personal implications of what they are learning."[4] Building a new STS course allows this goal to be sought daily, not just on occasions when the opportunity arises in some existing course.

For those who find these arguments convincing, the next step is the often-difficult transition from theory into practice. In order to design an STS course, one must make some difficult decisions about what to teach and how to teach it. Curriculum design groups often begin with the question of what is important to know. This exercise usually ends in one of two ways: either everyone agrees on lists of content and objectives that are no different from what is in the standard textbooks and what they have been teaching for years, or all involved become disgruntled with their obstinate colleagues who persist in their arguments for the supremacy of one body of knowledge over another. These outcomes are not the result of perverse intentions or inadequate intellect. They are, instead, the inevitable consequence of giving the right answer to the wrong question. The question is unanswerable. *Everything* is important to know in some way, at some time, for some purpose. Furthermore, something we all agree is unimportant may turn out to be very important as new insights change science, technology, society.

So, if we cannot determine what is important to know, what can we do? We can ask a different question: "Given a limited amount of instructional time (perhaps 150 hours in a typical school year), what *big ideas about life and living* should our students carry away from their STS course *for use throughout the rest of their lives?*" Note the four premises of this question. First, time is limited; therefore, we cannot teach everything, even though everything may be important to learn. Second, we are looking for big ideas about life; we are not looking for big ideas in science, nor are we looking for life's trivialities. We are concerned with those broad and generalizable truths that are likely to be encountered in many of life's unpredictable situations. Third is the concept of use. These big ideas should be applicable and applied, not bantered about as intellectual exercises. Fourth, the use should continue throughout the student's lifetime. For today's students, that means an adulthood spent making complex decisions in an increasingly precarious political climate. We can state this issue in a slightly different way--What does the student need to know that will contribute to (1) personal and social preservation and (2) personal and social development? This question and response are similar to those Herbert Spencer raised and answered in the mid-1800s.

Those who plan STS courses must formulate their own answers to this multidimensional question. The efforts of those who have attempted to do just that serve to illustrate the intent of the question and the richness of its four built-in criteria

Figure 7 elaborates the concepts listed in Chapter 2 of this work. Figure 8 reviews some of the important cognitive process skills. Once agreement can be achieved on the "big ideas" and essential skills, the next step entails the selection of content to carry these themes. Content may be selected for its currency, relevance, or student interest. Also important is the availability of materials and sources of data. Furthermore, opportunities for hands-on investigation in the laboratory or field need to be provided as the experiential base for the intellectual tasks of analyzing data, synthesizing information from many disciplines, and evaluating opinions, courses of action, and points of view. The topic is of less importance than the learning opportunities it provides. Students will work with the fundamental processes, principles, and concepts of several disciplines as they work through a real-world problem.

FIGURE 7
UNIFYING CONCEPTS FOR SCIENCE, TECHNOLOGY, AND SOCIETY

CONCEPTS	DEFINITIONS
SYSTEMS AND SUBSYSTEMS	A system is a group of related objects that form a whole or a collection of materials isolated for the purpose of study. Subsystems are systems contained entirely within another system.
ORGANIZATION AND IDENTITY	Systems have identifiable properties. There are boundaries, components, flow of resources, feedback, and open and closed aspects of systems organization. Changes in properties may cause a change in the system's identity

CONCEPTS	DEFINITIONS
HIERARCHY AND DIVERSITY	Matter, whether nonliving or living, is organized in hierarchical patterns and systems. Hierarchical levels of organization range from subatomic to cosmic. There is increasing complexity of organization within physical, biological, and social systems. Diversity can increase the stability of systems.
INTERACTION AND CHANGE	Components within systems interact, and the systems interact with each other There is usually evidence of the interaction. Evidence of interaction provides opportunities for identification and analysis of causal relationships. All things change over time. The course of change may be influenced to modify the properties, organization, and identity of systems.
GROWTH AND CYCLES	Linear growth occurs by a constant amount over a time interval. Exponential growth occurs by an increasing rate (at a constant percentage) over a time interval. Some systems change in cycles.
PATTERNS AND PROCESSES	Interactions, change, growth, and cycles often occur in observable patterns and as a result of identifiable processes.
PROBABILITY AND PREDICTION	Some changes are more predictable than others. Statistical calculations provide some degree of accuracy (a probability) in the prediction of future events.
CONSERVATION AND DEGRADATION	Matter and energy are neither created nor destroyed. Both may be changed to different forms. This is the first law of thermodynamics. Considered as a whole, any system will tend toward increasing disorder. This is the second law of thermodynamics.
ADAPTATION AND LIMITATION	All systems respond to environmental or cultural challenges. There are limits to environmental, organismic, and social changes. Adaptations may be biological, physical, technological, social, political, or economic.
EQUILIBRIUM AND SUSTAINABILITY	Equilibrium occurs when components of a system interact in ways that maintain a balance. Due to adaptation, growth, and change, all systems exist on a continuum from balanced to unbalanced. The extent of the equilibrium or disequilibrium is a function of the system's capacity to carry the load created by factors operating in and on the system A social system is sustainable if its organization results in stability of its natural resources and environment.

FIGURE 8
COGNITIVE PROCESS SKILLS FOR SCIENCE, TECHNOLOGY, AND SOCIETY

SKILLS	DEFINITIONS
Processing Information	
QUESTIONING AND SEARCHING	Curiosity and questions about the world are basic to inquiry skills. Thus, locating or discovering information based on questions is essential. Informal inquiry--questioning and searching--are first steps toward scientific and technologic problem solving and personal and social decision making.
OBSERVING AND ORGANIZING	One or more senses are used to gather information about objects, events, or ideas. Once observed and gathered, information must be grouped in relation to space, time, and causal relationships.
MEASURING AND CLASSIFYING	Elements of these skills are counting objects or events, establishing one-to-one correspondence, and organizing objects according to numerical properties; quantifying descriptions (e.g., length, width, duration) of objects, systems, and events in space and time; forming meaningful groupings; putting objects or events in order by using a pattern or property to construct a series (seriation); classifying includes defining similarities and identifying subsystems based on a property and arranging subsystems and systems in a hierarchy.
COMPARING AND CONSERVING	Comparing involves identifying similarities, differences, and changes in objects and systems in space (local to global) and time (past, present, future). Conserving involves understanding that quantitative relationships between materials and systems remain the same even though they have undergone perceptual alterations.
ANALYZING AND SYNTHESIZING	Information is reduced to simpler elements for better understanding of the organization and dynamics of objects, systems, events, and ideas. Analysis includes describing components, clarifying relationships among systems or subsystems, and identifying organizational principles of systems. Where analysis stresses reduction and parts, synthesis stresses construction and the whole: bringing together information to form unique organizations, patterns, or systems. Understanding that the whole is greater than the sum of parts is part of synthesis.

SKILLS	DEFINITIONS
Problem Solving	
IDENTIFYING AND DESCRIBING	These skills extend those of gathering information to problem solving. Problem identification and description are first steps in formal inquiry. Included are identification of personal and/or social problems, gathering information, and describing what is known and unknown about a problem.
HYPOTHESIZING AND PREDICTING	When confronting a problem, one must make reasonable guesses or estimates based on information Included are making statements of conditionality--"If . then..."--concerning a problem and predicting possible conclusions. Inductive (specific to general) and deductive (general to specific) thinking as well as propositional thinking are included.
SEPARATING AND CONTROLLING	Applying logical patterns of reasoning--whether to the design of formal experiments, analysis of data, solution of problems, or evaluation of policies--is based on the skill of separating and controlling variables. Making clear how a condition or event is similar to or different from other conditions or events is part of this skill, as is identifying factors and all possible combinations of factors relative to a problem. Factors must be controlled and one variable changed to determine how it influences reactions. Hierarchical thinking is used in such tasks as building classification keys.
Decision Making	
EXPLORING AND EVALUATING	Describing the decision to be made, using skills developed earlier to identify and gather information, converting information to alternatives, and examining the consequences of different decisions are all part of the exploration of a decision. Evaluating consists of making value judgments based on the internal consistency of information and clearly defined external criteria such as costs, risks, and benefits of alternatives.
DECIDING AND ACTING	Deciding involves selecting from among alternatives to make an intelligent and responsible choice. Available information is used to justify the decision. Ways and means of taking responsible action are identified to reduce or eliminate problems.

These points may be illustrated by an example drawn from an STS course currently being used in some American schools in England and Germany. Developed by teachers from the Department of Defense Dependents Schools, this series of 12 instructional modules treats topics ranging from water quality to food, energy, and biomedical technology.[6] Teachers may select any of the modules they wish to create a year's course, since each module provides students with the experience of *doing* science while simultaneously relating the knowledge of science to the political, social, and economic realities of the late 20th century.

The module on consumer affairs, *Your Money, Your Choice*,[7] illustrates how this synthetic approach is achieved. During this five-week unit, students learn to classify advertising according to its psychological intent. They calculate unit prices, read nutritional labels, and make consumer decisions based on empirical data. They perform consumer tests on antacids and detergents. They also take one testing situation "from scratch," as they are challenged to design and conduct a controlled, scientifically valid test for the comparison of different brands of paper towels. Students use cost/benefit analysis to decide which among an array of products is the "best buy" for a given purpose. They also evaluate the environment and economic cost impacts of various types of packaging. The unit concludes with debate over the pros and cons of new technologies in food distribution.

This unit exemplifies an interdisciplinary approach. Its base is science. Students spend much of their time in the laboratory, designing and carrying out controlled experiments on products. Mathematical skills are sharpened in practical situations involving calculation of such things as unit prices and percent error on volume labels. The unit brings psychology and sociology to the fore, as students learn to read between the lines in advertisements clipped from magazines. The intricacies of the political process are illuminated in a simulation that requires students to develop and defend positions on proposed legislation to impose a deposit on bottles and cans. Students encounter economics at two levels: personal and societal. In the former context, they learn about choosing products that provide the best value for the money. In the latter, they confront the complexities of policy-setting when, for example, they see that a ban on cigarette advertising imposed for positive health reasons exerts negative economic consequences on several sectors of the economy, including the federal treasury. Environmental awareness enters during the study of packaging and becomes central when students analyze data on the environmental impact of paper-versus-plastic grocery bags.

Library skills are taught when students research consumer information in periodicals such as *Consumer Reports*. Students improve their communication skills by designing advertisements for products of their own creation. Engineering skills are involved in the design and testing of a package that (it is hoped) will allow an egg to survive a drop from a third-story window. Throughout these exercises, the values and attitudes of science discussed in Chapter 4 are introduced, explored, and reiterated. The authors of the course have designed the module to teach students to find and check their facts, to withhold judgment until facts can be carefully assessed, and to consider alternative courses of action and consequences when attempting to make a decision.

The next step in the design of an STS course is to select or prepare materials of this kind Ever-increasing numbers of materials are available for use in STS courses; many merit attention during the materials review process. The main point to remember in the selection process is that content is not the sole concern. It is equally important that students encounter the fundamental processes of science within a framework of societal relevance. As with any course, planning a variety of ever-changing instructional strategies will probably be important to the success of the course. Consider field trips, simulation games, audiovisual materials, laboratory exercises, primary source readings, small-group discussions, and a host of other means to the all-important end of learning.

Evaluation needs to be planned early and carried out throughout the development of the course. Evaluating student achievement, one aspect of evaluation, can be achieved through critical assessment of students' laboratory and project work, as well as their performance on objective and essay tests. Of even greater significance is the evaluation of the course itself Means must be identified to determine whether the course is proceeding as intended and whether it is achieving its intended outcomes. Observations and brainstorming sessions among teachers working as colleagues can provide much insight, as can analysis of students' performance in various parts of the course. Student opinionnaires can also be helpful. Whatever form the evaluation takes, it should be both continuous and continual, as the course grows, changes, and is shaped by teachers and learners alike.

In the final analysis, the success of any STS course depends first and foremost on the teacher Good teachers, as all students know, teach good courses--and STS is no exception Susan Speece suggests a formula for teaching in the years ahead that might well be the key to success with interdisciplinary STS:

> I would like to propose two components of teaching essential to encouraging young people to consider science careers and to producing generations of scientifically literate people. I propose that successful science teachers in the year 2000 will spend considerable time engaged in meaningful laboratory activities and will exude real enthusiasm for what they are doing. In defense of the anticipated cries of "too simplistic," I reply that these two components are indeed sufficient to make a difference.[8]

Working in the laboratory (and field) with enthusiasm is what *all* science teaching is about. If placed in the context of technology and society, it might also turn out to be what the *best* of science teaching is about.

Notes

1. M. Csikszentmihaly and J McCormick, "The Influence of Teaching," *Phi Delta Kappan* (February 1986), pp. 415-419.

2. Isabel S. Abrams, "The Sustainable Society," in Rodger W. Bybee, editor, *Science, Technology, Society* (Washington, DC: National Science Teachers Association, 1985), p. 46

3. Paul DeHart Hurd, "A Rationale For A Science, Technology, and Society Theme in Science Education," in Rodger W. Bybee, editor *Science, Technology, Society* (Washington, DC. National Science Teachers Association, 1985), p 98.

4 *Ibid* , pp. 99-100.

5. Rodger W. Bybee, "The Sisyphean Question in Science Education: What Should the Scientifically and Technologically Literate Person Know, Value, and Do--As A Citizen?" in Rodger W. Bybee, editor, *Science, Technology, Society* (Washington, DC: National Science Teachers Association, 1985), pp. 87-88.

6. The project is coordinated by Kent Rossler, Science Coordinator, Dodds-Germany, APO, NY 09633.

7. Pilot materials for limited distribution. Authored by Lloyd Brynle and Sandy Sapatka, Jim Szoka Revision Leader.

8. Susan Speece, "Teaching in the Year 2000," *The Science Teacher* (September 1986), pp 54-58.

9. SUMMARY OF GUIDELINES FOR CURRICULUM REFORM

Science and technology, powerful forces in contemporary American society and throughout the world, have generated exalted hopes, terrible fears, and critical public issues. To understand the workings of the modern world--to be a truly educated person in our times--requires an understanding of science and technology in a social context.

In modern democracies, such as the United States, educational goals extend beyond comprehension of the world to responsible citizenship in it. Citizenship in a free society entails rights and duties to participate responsibly in decisions about public policies, including complex choices stemming from developments in science/technology. Through their roles as voters, interest group members, workers, consumers, and office holders, citizens are increasingly challenged to make choices about the social uses of practices and products of science and technology. Thus, education for citizenship in a modern democracy must emphasize science/technology/society.

Educators have been recognizing the need to treat science/technology/society emphatically in the core curriculum of schools and in general education for citizenship. There is a trend among secondary school curriculum reformers in the United States, and several other nations, in favor of education on science/technology/society.[1] However, this trend among educational leaders has not been translated into widespread practice in secondary schools. There is a rather large gap between new goals on STS in national reports and the curriculum in operation in most schools. Clear thought and hard work in STS curriculum reform remain to be accomplished.

A basic step in curriculum reform is conceptualization, which involves construction of a framework to guide deliberation and decisions about design of new courses or significant modifications of old ones. A framework for curriculum reform consists of interrelated categories and criteria to guide selection and organization of content, cognitive processes, and affective processes to be taught and learned. A framework for curriculum reform establishes boundaries for a field of education, such as STS. Thus, users of the framework are able to identify content and learning activities that fit the proposed curriculum and to distinguish them from subject matter and pedagogy that do not belong.

Primary categories of the curriculum framework in this work are·

1 Acquisition of knowledge.

2. Utilization of cognitive process skills.

3 Development of values and attitudes

Each of these three categories is a guide to formulation or selection of educational goals, means of instruction, content, and learning activities.

Following are general guidelines for STS curriculum reform that fit the curriculum framework presented in Chapter 1 and elaborated upon in Chapters 2, 3, and 4 of this work. These guidelines represent common concerns of secondary school educators in the sciences and social studies. They are applicable to teaching and learning about science/technology/society in both areas of the curriculum--albeit in different ways suitable to variations in subject matter and methods of inquiry that distinguish subjects within and between the sciences and social studies.

Guidelines for Education on Knowledge in STS

1. Develop comprehension of three fundamental concepts--science, technology, society--and the various interrelationships among these three concepts, such as the symbiotic connection of science and technology occurring in a social context.

2. Emphasize knowledge of major concepts in science and technology that are associated with significant social changes and scientific issues; these concepts, anchored in the traditional academic disciplines of physical and natural science, should be applicable to social changes and scientific issues of continuing importance and relevance to citizenship in a free society.

3. Emphasize knowledge of major concepts and topics in history and the social sciences that are associated with significant social changes and scientific issues rooted in science/technology; these concepts and topics include institutions and human affairs connected with the practices, products, and effects of science/technol-

ogy in a social context. These concepts and topics should be treated in historical perspective and with futuristic vision.

4. Teach about STS issues in history and contemporary society which illuminate and enhance comprehension of STS interactions; these STS issues should be linked to core concepts and topics of standard secondary school subjects in the sciences and social studies.

5. Develop understanding of the uses, limits, abuses, and variable social consequences of scientific and technological endeavors; the ultimate goal is connecting education about science/technology/society to development of good citizenship in a free society.

Guidelines for Education on Cognitive Process Skills in STS

1. Emphasize development of cognitive process skills involved in scientific/technological inquiry--including information processing and problem solving--as ways of producing and applying knowledge about nature and society.

2. Emphasize development of cognitive process skills involved in civic decision making as a rational means of assessing, judging, and choosing options and resolving issues about the uses of science and technology in society.

3. Provide continual practice to direct students' use of cognitive process skills, to correct mistakes immediately and constructively, to reinforce desirable performance, and to enhance learning.

4. Use direct or didactic teaching as a useful means to introduce skills; however, students must also be stimulated and guided to think on their own, to resolve dilemmas, take stands on issues, and judge propositions about knowledge.

5. Emphasize practice of skills with recognition of how they fit together as part of a process, such as civic decision making or problem solving in scientific inquiry; avoid teaching skills discretely, which is a weak means to development of higher level cognitive capacities.

6. Incorporate learning activities on cognitive process skills in the core curriculum--school subjects required of all students; cognitive process skills in science/technology/society should be developed systematically and extensively in all social studies and science courses, in a manner consistent with the intellectual development and prior learning experiences of students.

Guidelines for Education on Values and Attitudes in STS

1. Foster appreciation of science/technology as worthwhile human endeavors.

2. Develop understanding of and intelligent commitment to values, attitudes, and assumptions associated with products, processes, and persons of science--the knowledge produced by scientists, the methods used by scientists, and the individuals engaged in scientific inquiry

3. Develop understanding of and intelligent commitment to values, attitudes, and assumptions of a democratic or free society, which are compatible with the premises and precepts undergirding scientific inquiry.

4. Emphasize the critical importance of ethical questions about the uses of science/technology in society.

5. Develop commitment to rational consideration--in terms of democratic values--of issues about applications of science and technology in society. Teachers should never lose sight of the perennial question: "To what end?"

6. Teach values and attitudes of science and democracy in combination with knowledge and cognitive process skills that are central to studies of science/technology/society; these connections are likely to contribute significantly to students' comprehension of core values and their ability to apply them to analyses and appraisals of ideas

* * * * * * * * * * * * * * * *

The preceding guidelines for STS curriculum reform can be applied to modification of standard secondary school courses in the sciences and social studies; this is the integration strategy of curriculum reform. The infusion or integration strategy may involve additions of STS content and learning activities to existing units of study in a course. Another approach to integration is to add a special STS unit to the end of a standard course in science or social studies

An alternative to the infusion or integration strategy is development of new, interdisciplinary courses in STS. Social issues rooted in science/technology would serve as the focal points for organization of relevant content drawn from various subjects of the sciences and social studies. The likely costs, risks, difficulties, and rewards of alternative approaches to curriculum reform are discussed in Chapter 5.

Applications of the preceding guidelines to secondary school courses in the sciences and social studies are discussed in Chapters 6 (sciences) and 7 (social studies). Chapter 8 treats the interdisciplinary approach to STS curriculum reform. Chapters 6 and 7 indicate the numerous openings for integration of STS content and learning activities into standard secondary school courses in the social studies (American history, world history, geography, and government) and sciences (earth science, life science, and physical science).

The social studies and the sciences have distinct and complementary contributions to make to education about science/technology/society. For example, the social studies contribute to an understanding of the social context, in historical perspective, of developments in science and technology. In addition, the social studies contribute uniquely to an understanding of the ethical and value components of social issues generated by science/technology. The moral-value judgment dimension of civic decision making, for example, is beyond the limits of scientific inquiry.

Science contributes basic knowledge about alternative courses of action and hypotheses about likely consequences of options in an occasion for decision about applications of science/technology in society. Knowledge produced by science, plus cognitive process skills in scientific inquiry, are essential to weighing the competing factual claims associated with complex STS issues

Widespread citizen comprehension and appreciation of the interrelated contributions of science and the social studies to knowledge about the modern world, and resolution of STS issues that threaten it, depend upon secondary school curriculum reform. Connections between the sciences and the social studies must be made in the secondary school curriculum in behalf of general education for responsible citizenship in a free society.

Notes

1. Rodger W Bybee and Teri Mais, "Science and Technology Related Global Problems: An International Survey of Science Educators," *Journal of Research in Science Teaching* 23, 7 (1986), pp. 599-618.