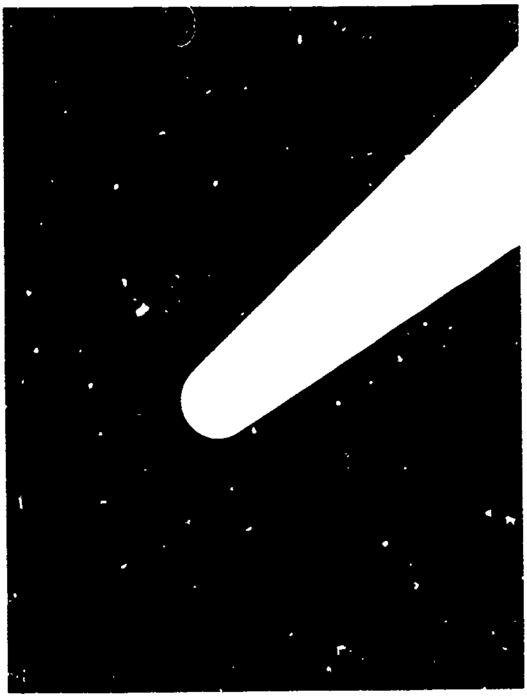
ED 309 058 SE 050 711

AUTHOR	Johnson, James R.
TITLE	Technology: Report of the Project 2061 Phase I Technology Panel.
INSTITUTION	American Association for the Advancement of Science, Washington, D.C.
SPONS AGENCY	Andrew W. Mellon Foundation, New York, N.Y.; Carnegie Corp. of New York, N.Y.
REPORT NO	AAAS-89-06S; ISBN-0-87168-347-4
PUB DATE	89
NOTE	44p.; For other Project 2061 panel reports, see SE 050 707-711; for overview and summary, see SE 050 712-713.
AVAILABLE FROM	AAAS Books, Dept. 2061, P.O. Box 753, Waldorf, MD 20604 (for price, contact AAAS offices; quantity prices available).
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS	Elementary School Science; Elementary Secondary Education; *Fundamental Concepts; Futures (of Society); Science Activities; *Science and Society; *Science Course Improvement Projects; Scientific and Technical Information; Secondary School Science; *Technological Literacy; *Technology
IDENTIFIERS	Project 2061 (AAAS); *Science Policy

ABSTRACT

This is one of five panel reports that have been prepared as part of the first phase of Project 2061, a long-term, multipurpose undertaking of the American Association for the Advancement of Science designed to help reform science, mathematics, and technology education in the United States. Major sections included are: (1) "Introduction" (describing the nature of technology); (2) "Technology and Education" (discussing a framework for technology, course of technology education, integrated programs, aspects of technology education, conceptual learning and experience, and interface of technology and society); and (3) "The Technologies" (covering fields such as materials, energy, manufacturing, agriculture and food, biotechnology and medical technology, the environment, communications, electronics, computer technology, transportation, and space). The members of the panel and consultants are listed. (YP)



TECHNOLOGY

REPORT OF THE PROJECT 2061 PHASE I TECHNOLOGY PANEL

by James R. Johnson

AMERICAN ASSOCIATION
FOR THE ADVANCEMENT OF SCIENCE

1989

Founded in 1848, the American Association for the Advancement of Science is the world's leading general scientific society, with more than 132,000 individual members and nearly 300 affiliated scientific and engineering societies and academies of science. The AAAS engages in a variety of activities to advance science and human progress. To help meet these goals, the AAAS has a diversified agenda of programs bearing on science and technology policy; the responsibilities and human rights of scientists, intergovernmental relations in science, the public's understanding of science, science education, international cooperation in science and engineering, and opportunities in science and engineering for women, minorities, and people with disabilities. The AAAS also publishes *Science*, a weekly journal for professionals, and *Science Books & Films*, a review magazine for schools and libraries.

ISBN 0-87163-347-4

AAAS Publication 89-06S

Library of Congress Catalog Card Number: 89-77

Printed in the United States of America

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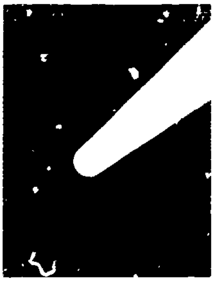

On behalf of the Board of Directors of the American Association for the Advancement of Science, I wish to acknowledge with gratitude the many useful contributions made by the members of the Phase I Technology Panel to the first stage of Project 2061.

The nine panel members were most generous with their time and efforts over a two-year period in developing their response—as presented in this report—to the complex question of what young people should know about technology by the time they complete their high school education The board is also very grateful to James R Johnson, who chaired the panel and wrote the panel's report.

During this essential first stage of Project 2061, the Technology Panel was one of five scientific panels charged by the AAAS with developing independent reports on five basic subject-matter areas. At the same time, the Project 2061 staff in conjunction with the National Council on Science and Technology Education was preparing a separate overview report—*Science for All Americans*—that was able to draw on the conclusions reached by the individual panels.

We also want to add our thanks to those of Jim Johnson to the many people who assisted the Technology Panel in the course of the panel's deliberations —the consultants, the national council members and other reviewers, and the Project 2061 staff.

Finally, it is appropriate to note that Project 2061 is indebted to the Carnegie Corporation of New York and the Andrew W. Mellon Foundation for their overall and ongoing support of our various Phase I efforts.

Sheila E. Widnall
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FOREWORD

This report is one of five prepared by scientific panels as part of Phase I of Project 2061. Each of the panel reports stands alone as an independent statement of learning goals in a particular domain. In addition, the reports contributed to *Science for All Americans*, a Phase I report that cuts across all of science, mathematics, and technology.

The work of the Technology Panel was to reflect on all aspects of technology—its nature, principles, history, future directions, social dimensions, and relation to science—and to produce a set of recommendations on what knowledge and skills are needed for technological literacy (as part of general scientific literacy). The other panels focused in a similar way on the biological and health sciences, mathematics, the physical and information sciences and engineering, and the social and behavioral sciences.

In considering this report, it is helpful to see it in the context of Project 2061 and to be aware of the manner in which it was generated.

The American Association for the Advancement of Science initiated Project 2061 in 1985, a year when Comet Halley happened to be in the earth's vicinity. That coincidence prompted the project's name, for it was realized that the children who would live to see the return of the comet in 2061 would soon be starting their school years. The project was motivated by a concern that many share for the inadequate education those young Americans will receive unless there are major reforms in science, mathematics, and technology education.

Scientific literacy—which embraces science, mathematics, and technology—has emerged as a central goal of education. Yet the fact is that general scientific literacy eludes us in the United States. A cascade of recent studies has made it abundantly clear that by national standards and world norms, U.S. education is failing too many students—and hence the nation. The nation has yet to act decisively enough in preparing young people—especially the minority children on whom the nation's future is coming to depend—for a world that continues to change radically in response to the rapid growth of scientific knowledge and technological power.

Believing that America has no more urgent priority than the reform of education in science, mathematics, and technology, the AAAS has committed itself, through Project 2061 and other activities, to helping the nation achieve significant and lasting educational change. Because the work of Project 2061 is expected to last a decade or longer, it has been organized into three phases.

Phase I of the project has established a conceptual base for reform by defining the knowledge, skills, and attitudes all students should acquire as a consequence of their total school experience from kindergarten through high school. That conceptual base consists of recommendations presented in *Science for All Americans* and the five panel reports.

In Phase II of Project 2061, now under way, teams of educators and scientists are transforming these reports into blueprints for action. The main purpose of the second phase of the project is to produce a variety of alternative curriculum models that school districts and states can use as they undertake to reform the teaching of science, mathematics, and technology. Phase II will also specify the characteristics of reforms needed in other areas to make it possible for the new curricula to work. teacher education, testing policies and practices, new materials and modern technologies, the organization of schooling, state and local policies, and research.

In Phase III, the project will collaborate with scientific societies, educational associations and institutions and other groups involved in the reform of science, mathematics, and technology education, in a nationwide effort to turn the Phase II blueprints into educational practice.

Each of the five panels was composed of 8 to 10 scientists, mathematicians, engineers, physicians, and others known to be accomplished in their fields and disciplines and to be fully conversant with the role of science, mathematics, and technology in the lives of people. The panelists were different from one another in many respects, including their areas of specialization, institutional affiliations, views of science and education, and personal characteristics. What made it possible to capitalize on the rich diversity among the panelists was what they had in common—open minds and a willingness to explore deeply the questions put to them.

The basic question put to the Technology Panel was: What is the technology component of scientific literacy? Answering this question—difficult enough in itself—was made more difficult by the conditions, or ground rules, set by Project 2061. Abbreviated here, these were:

- *Focus on technological significance* Identify only those concepts and skills that are of surpassing technological importance—those that can serve as a foundation for a lifetime of individual growth

- *Apply considerations of human significance* Of the knowledge and skills that meet the criterion of technological significance, select those that are most likely to prepare students to live interesting and responsible lives. Individual growth and satisfaction need to be considered, as well as the needs of a democratic society in a competitive world.

- *Begin with a clean slate* Justify all recommendations without regard to the content of today's curricula, textbooks, state and school district requirements, achievement tests, or college entrance examinations

- *Ignore the limitations of present-day education* Assume that it will be possible to do whatever it may take—design new curricula and learning materials, prepare teachers, reorganize the schools, set policies, or locate resources—to achieve desired learning outcomes.

- *Identify only a small core of essential knowledge and skills* Do not call on the schools to cover more and more material, but instead recommend a set of learning goals that will allow them to concentrate on teaching less and on doing it better

- *Keep in mind the target population—all students* Propose a common core of learning in technology that can serve as part of the educational foundation of all students, regardless of sex, race, academic talent, or life goals.

Taking these ground rules into account, the members of the Technology Panel met frequently over a period of nearly two years to present and debate ideas and to consider the suggestions of consultants. The panel members prepared working papers and revised them in response to the criticisms of reviewers. This process—which also included meetings with the chairs of other panels—led to the preparation of this report.

The task ahead for the United States is to build a new system of education that will ensure that all of our young people become literate in science, mathematics, and technology The job will not be achieved easily or quickly, and no report or set of reports can alter that. I believe, however, that this report on technology literacy, along with the other panel reports and *Science for All Americans*, can help clarify the goals of elementary and secondary education and in that way contribute significantly to the reform movement

F. James Rutherford
Project Director, Project 2061

PREFACE

The Technology Panel is responsible for suggesting appropriate concepts for programs from kindergarten through high school that will help students develop an understanding of technology and its relationship to the world around them.

For this report, technology is viewed as the workings and works of humankind, from flint tools to moon landers—activities more often known by their embodiments Subject to the governing principles of the sciences—physical, economic, and social—and patterned after the designs of engineering, technology in the end is used by society for its benefit or peril.

The panel members were chosen for their expertise in certain fields of technology and for their ability to find consultants who could help the panel examine those fields Further, they were selected because they were known to have an interest in education and considerable sensitivity to human needs and values. Each panel member was responsible for a one-day meeting in which his or her field was presented and then discussed by the panelists in depth.

While we, the panel members, cannot pretend to have covered all of technology in this manner, we hope we have examined enough of it to help us find the content elements we seek for Project 2061

We have found the process of examining specific fields helpful in identifying common themes. Further, we have accumulated considerable specific material about the fields of technology chosen that may be useful to the participants in the next phases of Project 2061.

The suggestions in this report are meant to go beyond adding bits of technology to the present school curriculum Rather, they are the basis for a major revision of U.S. education, reflecting throughout the learning process the pervasiveness of technology in our lives, and using a wide range of methods ranging from simple laboratory experiences to studying socioeconomic effects.

The report was written by the undersigned on the basis of the discussions and findings of the Technology Panel, and it was subsequently reviewed by the individual panel members, the consultants to the Technology Panel, and other reviewers (see Appendix), and by the Project 2061 staff.

The Technology Panel wishes to express its appreciation to the many people who took time to review and criticize this document The richness and diversity of their comments have added immeasurably to the finished work. We are indebted to Patricia Powell of the Wisconsin Academy of Sciences for her early editorial review. Our work was made easier by the guidance and assistance received from Project Manager Patricia Warren and from Janice Merz, Gwen McCutcheon and Carol Holmes on the Project 2061 staff.

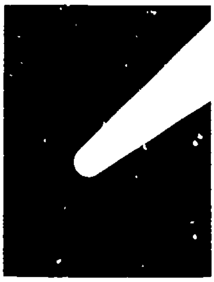
Finally, we acknowledge with great appreciation the seminal ideas for Project 2061 that we first heard from Project Director F.

James Rutherford and Associate Project Director A. A. Ahlgren and that were the basis for our charge.

James R. Johnson
Chair, Technology Panel

SECTION 1

INTRODUCTION



Throughout the history of civilization, the social fabric of humans and their enterprises has been interwoven with the thread of technology. Accordingly, young adults need to be familiar with technology and its dynamics, pervasiveness, and relationship to the society in which they will live and work.

Technology is the application of knowledge, tools, and skills to solve practical problems and extend human capabilities. Technology is best described as process, but it is more commonly known by its products and their effects on society. It is enhanced by the discoveries of science and shaped by the designs of engineering. It is conceived by inventors and planners, raised to fruition by the work of entrepreneurs, and implemented and used by society. Sometimes, though, it enters the social system imperceptibly and brings about many changes, often in unforeseen ways.

Technology is in part a social process. Technology is supported to serve the society that generates and controls it through society's private and public institutions and people. Society affects and is affected by its technology. Thus, people need to understand the interactions of technology and its various fields with human social systems and the values that society may apply The results and dynamics of these interactions are key to the ways in which technology affects people's lives.

Technology is also a technical process. It is different from science, whose role is understanding. Technology's role is doing, making, and implementing things. The principles of science, whether discovered or not, underlie technology The results and actions of technology are subject to the laws of nature, even though technology has often preceded or even spawned the discovery of the science on which it is based. Most modern technology, particularly that embodied in systems, is fabricated through the technical designs of engineering, and it enters society according to the perceived needs of the socioeconomic system. Therefore, young adults should know some of the underlying basic science, mathematics, and engineering concepts and their relationship to technology. They should be familiar with the use of the basic tools involved, from applied mathematics to design, to computers, to hardware. They should understand that technology does not stand apart from the society it serves.

Technology can be illustrated by general concepts such as work, flow, design, innovation, and risk/benefit. It may be regarded as benevolent, making modern life possible It may also be seen as evil or as not always to be trusted. Technology's embodiments and processes are often described as wonders—such as the wonder of antibiotics and the wonder of transmitting pictures of distant planets from space probes. Or technology may be a source of public concern and consternation—for example, there is the problem of what to do with radioactive wastes.

Through technology, the public is drenched in information, much of it technical itself Radio, television, and newspapers all spew out undigested and sometimes conflicting information Young adults must have a framework from which to respond This framework should include a clear understanding that technology is inherently neither good nor evil. It is the use made of technology, relative to a culture s social customs and beliefs, that determines whether that technology is ultimately to be viewed as good or evil

Technology is chiefly responsible for the ever-increasing rate of change in the world Such changes are vital to growth, and perhaps they are inevitable, since the world must support a burgeoning population. Modern production demands an advancing yield of technology and change Young adults should not believe they must passively accept or cope with whatever technology brings, rather, they should be part of its evolution.

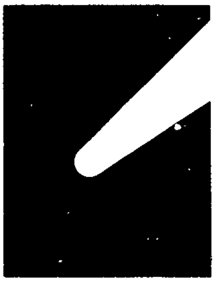
Technology is revealed by its contributions to humankind, both current and historical, and by technical advances foreseen for the near future And yet, its uncertainty and ambiguity, and the always possible unexpected consequences for good or evil, cannot be neglected or minimized Technological solutions to human problems are not unique There are no right answers, and choices must be made. It is vital that these choices be informed and value-based.

General education should describe technology in a holistic way, showing it as part and parcel of our history, our everyday existence, and our future It should provide opportunities to experience technology as well as learn about it in the abstract. It should connect the technics with the ethics. By the time they finish high school, young adults should be fully aware that they will encounter technology on an ever-changing basis throughout their lives But it is not enough that they accumulate knowledge along the way, they should also know what it means and how it is and can be applied. Ultimately, each such person will become to some extent a technologist, prepared to participate in a highly technical world

A major question about this technical world is, "Who will develop and control the technologies so that they can best serve all citizens?" In the broadest sense, the answer has to be—for a democratic society—a technically literate citizenry. This report (following the introduction) consists of two major sections. The first, Section 2, describes some general themes and suggests a framework for the consideration of technology in the context of society, including ways in which the framework might be learned. The second, Section 3, describes a number of technology fields and suggests the kinds of things that young adults should know about them. The specific technologies embraced by these fields will be swept away by the onrushing future, and updating must be continuous. What must remain is a lifelong interest in learning about this changing scene Carefully integrated conceptual and experiential learning is key to providing the necessary framework for young adults to understand and benefit from rapidly changing technology.

SECTION 2

TECHNOLOGY AND EDUCATION



Although the primary charge to the Technology Panel was to consider content in future curricula, the panel concluded early in its deliberations that technology, unlike science and mathematics, currently has little or no place in elementary and secondary school programs Thus, the panel believed it should start by suggesting how technology should be integrated into future elementary and secondary school programs It does so, however, without making any pretense of expertise in curriculum design or theories of education

Technology education should reveal the process of technology as it evolves from ideas to fruition This can best be learned using laboratory experiences to augment classroom instruction. Likewise, such education should show how technology affects individuals and society.

Technology education should be appropriate to the students' age and experience. It should begin with descriptive material and then involve principles and concepts, incorporating direct experience at all levels.

Technology education that includes social impacts as well as the technics provides the opportunity to integrate the two in newly formulated curricula, possibly making increased use of team teaching.

The sciences and mathematics are important to the understanding of the processes and meaning of technology. Their integration with the technology education curricula is vital

A FRAMEWORK FOR TECHNOLOGY

The people who generate new technology or control its use often do so by first considering a framework of interconnected questions designed to lead to a full understanding of the likely effects and implications of the technology These questions—as presented below—should also be familiar to the technologically literate citizen:

- What is the goal? What is to be done, to be made?
- What can be conceived or invented to achieve the goal? Born of need, how does technology evolve through ideas, designs, or plans to practice?
- What knowledge and know-how are needed?
- What materials will be used to construct the artifacts of the technology?
- What tools or machines can be used to help do it or make it?
- What energy source will drive it, form it?

- Does it function alone or should it be incorporated into a system or network?
- How is its manufacture or use to be operated, controlled, and managed for optimum efficiency and quality?
- Does the technology serve the original goal or purpose?
- Does it compete in the local and global economic systems?
- What are the mechanisms by which the technology enters social systems?
- Is it safe according to accepted risk/benefit standards?
- Does the technology put at risk the users, or other people who are not beneficiaries?
- What are the technology's effects on the environment and human well-being?
- As it becomes obsolete or worn out, how is its manufacture or use terminated? What is done to safely dispose of its used materials?
- Will the technology have long-range effects on the course of human history?

The technologically literate citizen should not only understand the questions but also be familiar with the ways in which answers are developed. There are no simple or easy answers. Rather, the responses to the questions in the framework are likely to come from thought processes ranging from intuition to systematic analysis Furthermore, these responses may be shaped by any of a range of human values, traditions, emotions, and societal norms, which tend to vary considerably from society to society and from one era to another. Ultimately, though, all such answers lead—or should lead—to something that is essential to the well-being of the world sound human responses to technology

THE COURSE OF TECHNOLOGY EDUCATION

The introduction of technology should begin with description, accompanied by experimentation and experience, all at increasing depth and involvement as students proceed from kindergarten through the twelfth grade. Embodiments of technology known to the students at the kindergarten level may include houses made of brick or the household telephone. At the twelfth-grade level, the telephone system, its networks, switching, and other features can be learned. Similarly, at the kindergarten level, use can be made of simple experiments such as forming plastic clay into shapes, which reveal plasticity and hardening by drying. At the twelfth-grade level, the extraordinary compressive strength of clay bricks can be measured with instruments. For students at all levels, field trips coupled with laboratory work can provide stimulating experiences with technology

As learning progresses, concepts associated with technology should be introduced These may be technical, economic, or social ideas that elucidate what is going on—how the technology process functions At the fourth-grade level, for example, the idea of storage in various ways or forms can be learned on the basis of, say, the commonality of nuts stored by a squirrel, water stored behind a dam, and electricity stored in a battery. At the tenth-grade level, the chemistry of the process can be added to what students learn about the storage of electricity in a battery

Principles govern the processes of technology These principles, which are derived from the physical sciences, biological sciences, social sciences, and humanities, provide students with a basis for understanding the science associated with the technology The principles may include scientific laws, principles of economics, and the human values to be considered, and they should be introduced at all levels.

As learning progresses, use of the tools of technology should be introduced. Such tools include the library, laboratory, shop, equipment, computers, and the use of mathematics, and they should be made part of the learning process at all levels.

Concluding the process should be the analysis of results, which includes observing the physical responses or the effects of the actions taken and the consequences for people of implementing the technology. At the kindergarten level, focusing the sun's rays to warm an object may be an appropriate example. At the twelfth-grade level, an experimental solar collector and a discussion of "sun rights" as a human issue could serve that purpose.

INTEGRATED TECHNOLOGY PROGRAMS

Traditionally, technology has been taught in diverse ways at various levels—primarily in the curricula of industrial arts, vocational education, and manual training, and in some science courses. Students learn how to draft and design, use tools, type, cook, sew, and make minor repairs to electrical or plumbing equipment. Advanced versions of technology education also include the use of calculators and computers, the design of elementary communications systems, and the building of robots. Technological and social issues are often included in these courses. Although many of the specific skills learned may be outmoded by advancing technology, the process of learning skills remains a valuable asset to students. A common theme of these activities is "hands-on/minds-on" education—the purposeful, intelligent honing of knowledge, talents, and skills. The Technology Panel continually emphasized the importance of this experiential learning process, and nearly every consultant advocated the need for more. A key question is how to expand the technique to serve a much broader pedagogical role.

Expanded technology education can be integrated with history, social science, and many other subjects For example, a major event in history was the telegraph, which was not just a new technology but the root of modern long-distance communications technology. Students can learn about the advent and importance of telegraphy in the traditional lecture/text way, and at the same time they can design and build a simple telegraph system—in the laboratory or shop—in a sense re-creating the invention. Coordinating these activities provides an additional and very interactive role for faculty engaged in technology education.

NEW TECHNOLOGY INVITES NEW USES IN EDUCATION

The use of technology in new ways through application of tape, disk, and interactive computer programs can augment this experiential learning, not only as a means of imparting facts but also as a way to link the classroom experimental activities with the world outside the classroom. This can provide a means for offsetting some current education system constraints, such as lack of teachers and equipment. The combination of these teaching and learning mechanisms makes it possible for teachers to tailor their activities to individual needs, including those of rapid learners and slow learners, and to have more time for laboratory and problem-solving activities.

THE IMPORTANCE OF THE USE OF SCIENCE AND MATHEMATICS IN TECHNOLOGY EDUCATION

Modern technology and its artifacts embrace virtually the whole of science and are indebted to the powerful ideas and tools of mathematics. In turn, science and mathematics depend heavily on advances in technology such as electron microscopy and electronic computing. These close relationships should be made explicit in the examples chosen in the classroom and the laboratory Some typical examples below illustrate this theme.

Modern biotechnology is a direct outgrowth of mid-twentieth-century discoveries of bioscience—the structure of the DNA molecule, the mechanisms of protein synthesis, and the elucidations of microbiology, among others Bioscience is the basis for the technologies involved in genetic engineering—recombinant DNA, the deliberate modification and synthesis of proteins through intelligent manipulation of segments of DNA Students can study the history of this science and technology, acquire their concepts, and link them by means of insights, translations, and derived processes so as to understand the connections between them.

The calculation and projection of the paths of space vehicles have made possible the remarkable flybys of the outer planets. At the ninth- through twelfth grade levels, students could develop the concept of escape velocity and proceed to calculate a geosynchronous orbit, in which a satellite rotates so it is always above the same spot on the earth and its velocity is just sufficient to keep it from either falling or rising (escaping). This can then lead students to the planning of a space communications network, illustrating the use of mathematics, science, engineering, and imagination in the development of a technology.

Logic derived from the three basic ideas of "and," "or," and "not" is the basis for computer operation An analysis of this logic speaks to the possibility or impossibility of machines being able to "think" as humans do. Students can follow the reasoning of this logic and match it with the proposals of those who believe they can move around the constraints of the logic to develop artificial intelligence.

Thus, a sound base in mathematics and the biological, physical, and social sciences is vital to an understanding of modern technology. They should be part of technology education curricula, just as technology should serve to bring additional meaning to the curricula of the sciences

SOME ASPECTS OF TECHNOLOGY EDUCATION

Technology education should emphasize problem solving The posing and solving of problems, increasingly complex as students move from kindergarten through the twelfth grade, will enable students to develop techniques that are vital to living in a technical world of diverse cultures and technical status. The problems and their solutions may be technical, experimental, mathematical, technical-social, or value-laden. Designing alternatives to circumvent problems and learning to deal with options are also important techniques.

Observation, measurement, and analysis are universal tools of technology They are key to research and development, to processes ongoing in industrial production, and to the impacts of technology on society. These techniques should be used throughout elementary and secondary education in both technical and social contexts

Intelligent observation is crucial to invention The elements of creative thinking and work and what to do about them are important for young adults to know. This process should include not only creative activities and implementation but also knowledge of the social system that encourages innovators to develop new enterprises that provide jobs—for example, the patent and copyright system, public and private research laboratories, and various institutions that foster entrepreneurial activities.

Imagination is a powerful human trait that needs early and continuing stimulation. Connections to technology can be made—as, for example, by envisioning times when the telephone, lights, plow, wheel, etc., did not exist as well as times in the future when cancer will have been conquered or planets will have been settled. These considerations should prompt questions about what such connections meant or will mean in terms of life, values, and expectations.

Still another important technique is learning to question basic assumptions, purported facts issues, results, and the like while seeking solutions to problems

Learning to visualize the whole but at the same time also to see the components of systems and organisms and how they interact should be developed at various levels of understanding For most students, it will suffice if they can grasp the idea of an organized entity made up of interacting parts designed to fit and work for the benefit of the entity (living) or of the user (machine or network). Other students may want to know how such entities work and to explore their symbiosis They may recognize that in some cases the whole is greater than the sum of its parts and that often synergy plays a large role in the effectiveness of processes.

Students should learn to differentiate between possibilities (whereby something can happen) and probabilities (whereby something is either likely or unlikely to happen). They also need to know that many technological decisions must be made without complete information, or sometimes with wrong information.

Developing the ability to collaborate or cooperate is important and can be part of tech activities throughout the school years. Although invention is usually traced to a single mind, it is more often many people working together who develop an idea to fruition More important, the sharing of talents, skills, and knowledge is vital training for the interactive roles most citizens will play in their lives

It is important to know how to obtain and organize reliable information by way of the literature, human interactions, and observation Communication skills are vital in a technical world. They range from knowing how to use the tools of communication—from languages to the telephone and computers—to learning how to derive true understanding from what is communicated.

It is important to develop a strategy for learning, to be able to discern what is and what is not relevant. For example, in trying to learn to speak a new language quickly, it is relevant to know some nouns and a few verbs, but less crucial to learn all about sentence structure.

Students need to master at least a few skills for learning on their own to build confidence. Further, each student should have one capability or more in which he or she has developed excellence or has mastered some task.

CONCEPTUAL LEARNING AND EXPERIENCE

General concepts are essential to the learning process in that they underlie the ultimate understanding that enables people to adapt and apply their knowledge in diverse situations. Laboratory or other experiential activities are vital to this learning process, for they serve to bring about and preserve understanding.

The general concepts of technology may be technical or social in nature, with some concepts being both. One social expression of a law of thermodynamics is "There is no free lunch "

Many general concepts are appropriate to technology, with ideas ranging from technical to social in nature (such as flow, conversion, storage, and risk/benefit). For example, the word "flow" is conceived in many ways relating to the movement of things in time—the flow of water, electricity, sunlight, traffic, ideas, etc In a technical sense, flow is a process common to moving water, moving air (wind), and radiation. The student may learn about the windmill, the water wheel, and solar cells as energy producers at different levels in elementary and secondary school, but the concept of flow is common to all of them. Simple laboratory experiments can reveal what is occurring in each case, helping to speed the desired "Aha!" or concept building. The student learns that flow is a general concept useful in many technologies. The science underlying each kind of flow can be more easily comprehended as the connections are developed The mathematical equations describing the phenomena may have different symbols, but their form and fundamental meanings have much in common

Generating concepts in the mind should start very early in the learning process, and they should be related where possible to familiar experiences. Experience is the application of understanding. It builds familiarity and helps fix what has been learned so that it can be applied in future, perhaps unfamiliar situations. It is the indispensable servant of technology education.

THE INTERFACE: TECHNOLOGY AND SOCIETY

One of the most important purposes of technology education is to equip children and young adults to understand and be able to participate in and cope with the world in which they live. Modern technology is a crucial aspect of the world, from household appliances to the machines of the workplace to the complex technical systems of communication, transportation, and manufacturing. An understanding of the technology of the day has probably been important since the dawn of civilization, but there is a special urgency today The fast pace of technological change can cause some people to feel loss of control. Many can expect to have several occupations, and all will find that technological change will affect both the marketability of their skills and their social relationships.

The relationship between technologies and the social order should be taught as an integral part of history and the other social sciences and—in some cases—as part of literature and art There are many examples of how this can be done. for instance, the printing press as it affected the expansion of learning in Renaissance Europe, and the impact of mass-production technology on social organization

Two principles must be developed, articulated, and illustrated: (1) technology affects society, and (2) society affects technology The first is relatively easy to illustrate. The first cities emerged only with the development of technologies for bringing in food, water, and raw materials and sending out finished products and waste. (Cities today are still involved in such activities.) The technique of large-scale water control was crucial to the form of government and administration of what has been called the hydraulic civilization of China and parts of the Middle East New technologies for weapons and manufacturing were essential in the transformation of medieval society. The kind of society we live in in twentieth-century America is, to a significant degree, a product of our modern technologies, also derived from human needs, and military or defense requirements, and occasionally born of pure imagination.

The general principle must be developed in social studies from the early years, both at a personal level and in social context The particular examples will probably be determined by the concerns of social studies and other curricula, but no period in history should be taught without explicit attention to the prevalent technologies of the time and place

It may be more difficult to demonstrate the influence society has on the course of technological development, and yet there are compelling relationships among epochs cultural conditions, and the emergence of new technologies In recent times, for example, one multibillion-dollar nuclear power plant was abandoned just prior to its opening ceremonies

Another example is that society generates the need "Necessity is the mother of invention" (but not every need generates a technological response). The technologies for using coal in ferrous metal refining followed the depletion of forests and rapidly increasing costs of charcoal production. The moldboard plow, the harvester, the mechanical planter, and eventually the tractor came to Western agricultural nations where growth was constrained by limited labor resources, whereas in Japan new varieties of rice and techniques of fertilizer use and pest control were invented to increase production when labor was plentiful but land was limited.

If society influences technology, then people should be able to influence or control the course and direction of innovation Historical examples of this control and elucidation of the mechanisms of induced innovation should help give students some sense of mastery and reduce their feelings of helplessness before a seemingly mindless technological juggernaut But it should be made clear to them that not every problem will yield to a technical solution—and further, that even when a new technology is effective and appropriate for coping with a problem, it may take decades or even generations for its impact to be significant The U S approach to the energy issue furnishes an excellent example Thus, the pace of technological change, which appears to be so rapid from one point of view, can seem frustratingly slow when directed at alleviating a problem that arises as a result of a large-scale sociotechnical system, for example, the development of coal-conversion plants to produce synthetic oil and gas.

Of great importance is the idea of the sociotechnical system, which should be introduced in the early grades when specific technology is presented. This concept can later be used to help illuminate the relationships between technology and society. The development of the automobile and its social impact cannot be understood by simply looking at the automobile alone as a technological innovation. The automobile needed highways, but highways could be built only when a means of financing them was invented The surtax on gasoline dedicated to highway construction created a positive feedback loop The more gasoline sold, the more money for highways, the more money for highways, the more demand for cars, the more cars, the more gasoline, and the more money for highways Other social innovations, such as installment payments and the assembly line, all fit together in a system in which technology affects society and society affects technology.

The specific example is not what is significant, though. All transportation, communication, and manufacturing are best understood as a social-technical system, and features such as the pace of change can be understood at least partially by viewing the relationship between technology and society in terms of systems The reasons for the rapid pace of technological change in the twentieth century should be elaborated, as should the conditions under which the pace could decline or decelerate in the twenty-first century

Complexity is one of the dimensions in which sociotechnical systems should be compared and assessed. Contemporary sociotechnical systems tend to be more complex than their predecessors. They have more components and there are more relationships among components. The greater the number of components and their connections, the more pertinent the issue of reliability, because a breakdown in one component can ramify throughout a system. The breakdown of an electric power station, for example, can shut down a large city, and the failure of an air traffic controller's station in Chicago can affect transportation nationwide.

Technology can serve as a great multiplier of social change, sometimes in new or unexpected ways. The development of the office copier, for instance, did not just replace the use of carbon paper but eventually revolutionized the modern office and was a pioneer event in the information age. But there are also negative examples. Terrorists, for instance, have been with us for centuries, but worldwide television has increased their potential impact dramatically.

One significant aspect of a high-technology world is that the great benefits brought about by modern sociotechnical systems also carry risks. An early pioneer in nuclear energy suggested that it might be a Faustian bargain. The industrial age of the last century not only transformed society, it choked some of its citizens to death in smoke. It led to both machine tools and the machine gun. One great hope for a technologically literate society is that it can consider at least some of the outcomes and develop ways to increase the benefits and reduce the risks of new technologies as they are introduced. Regulation and control might then be based more on knowledge than on emotion or political expediency. Studying the risks versus the benefits of technology in history courses can provide the context for considering important contemporary issues. Current examples include nuclear energy and genetic engineering. Between now and the year 2061, there will undoubtedly be many others.

Control of technology extends beyond its regulation. Commercial success or failure will depend on whether or not people will buy the products. Control at the point of origin may depend on political or corporate decisions about sponsorship of technology.

The economic relations between technology and society deserve particular attention. New technologies create employment, make some jobs obsolete, affect work conditions, and give some firms a competitive edge. Increasingly, it is becoming important to view these issues in a global perspective. Currently the microelectronics industry provides an example, from the invention of integrated circuits to the development of multibillion-dollar domestic business to the movement of enterprises overseas, all in less than two decades. The market for microelectronics evolved from needs and inventions in electronic equipment (military, commercial, and consumer). The advantage lay first with the innovators, but it later moved to those whose products cost the least for given value.

The well-being of the nation depends upon its ability to compete and the inventiveness, creativity, motivation, and pride in ac complishment that come with success in competitive markets. Competition can serve to raise the quality and performance of the competing technologies and their products, thereby benefiting society There is also a cooperative aspect Management and labor must work together The contracts between labor and management in the United States, the Soviet Union, Western Europe, and Japan provide interesting comparative and contrasting patterns At a time when labor/management relations in the United States are changing so rapidly, it is important to provide some cross-cultural perspective. Firms cooperate as well as compete (the patent agreement among U.S. automobile producers in the 1920s is a good example of cooperation involving technological innovation) Even nations can cooperate in sharing technologies, particularly those that affect the protection of the environment worldwide and the safety of humans. It would, for example, be in everyone's interest to disseminate as rapidly as possible any technology to improve safety in the management of wastes from nuclear reactors.

To live a fruitful and rewarding life in the twentieth-first century will require a knowledge of technology and society learned from historical examples, contemporary illustrations, and informed prognostication. It will be necessary to understand some of the basic precepts of the social sciences and their application to what occurs at the interface of technology and society.

SECTION 3

THE TECHNOLOGIES

Technology includes many fields. Learning about technology should include the history of these fields and something of their current state. Since the fields are advancing rapidly, what is taught about them must be frequently updated. Nevertheless, as suggested in Section 2, an examination of these fields as they now are provides a rich source of common themes and concepts that students should learn.

The following brief essays on selected technology fields are based on the deliberations of the panel and its consultants. They present some of the ideas the technology panel believed to be important for the graduating high school senior to know. Each essay is intended to illustrate one or more general technical or social concepts, as well as to provide examples of experiential learning. Different concepts have been selected for each of the various fields so as to maximize the number of concepts covered in this brief report. Accordingly, this limited survey of some current technologies and appropriate concepts should be viewed only as a guide to future technology education; in the development of a full curriculum, this process would have to be greatly extended.

MATERIALS

The material world is dependent on resources, both raw materials and the energy to convert them into products. A convenient way to represent this process is as a materials cycle. The earth is the source of raw materials in the form of ores, organic materials or biomaterials, air, and water. This is the cycle for a typical metal: Iron ore is made into metal and then upgraded to intermediate working fabricable materials—say, steel I-beams. The beams are then used in products, such as buildings and bridges. After use and eventual degradation, the products are returned to the earth as waste or are recycled. Descriptions of how various materials move through such cycles are a rich source of information about technologies of processes and products, and those descriptions can be elaborated to include the economics and politics of production of raw and converted materials, since these often critically affect decisions about the availability and use of resources.

Materials Technology

The use and processing of materials are very dynamic and are intimately tied to technology. Changes are rapid and greatly affect the economic system. There is evidence, for example, that the use of traditional materials such as steel, aluminum, cement, and paper is declining in the United States (as measured per capita and per dollar of gross national product). In some cases, other materials have been substituted, such as plastic for steel in automobiles As the overall national output of products becomes increasingly advanced technologically, fewer traditional materials are used, for example, little steel is now used in making television sets Further, production of basic materials from the early stages of processing is moving overseas, while U S. materials producers are moving more toward the manufacture of specialty goods and the production of new advanced materials (for instance, some producers of bulk chemicals are now turning to the manufacture of advanced ceramics). Materials conversion processes and further upgrading to value-added products are closely tied to the markets for these products and the competitive position of the industries producing them.

Materials respond according to how they are used, and each one can be thought of as having a "personality" with characteristics in part intrinsic and in part deriving from how it is made. Knowledge of materials processing is therefore important to understanding both the properties and uses of materials.

The properties of materials are fundamental to their uses. Properties are related to the elements and compounds that make up the materials, to their physical structures (atomic, micro, macro), and to how the materials are made and used. For everyday life as well as for scientific application, it is important that people have knowledge of certain properties of materials and the concepts associated with them Examples include ductility, brittleness, transparency, degradation caused by corrosion or by mechanical fatigue, and conduction of and insulation against heat and electricity.

In the future, materials will be lighter, stronger, and more durable, resulting from control of composition and microstructure, and from the invention of composites made of several materials Special demands on properties may include "smart surfaces" (electronically or biologically active), survival in extreme conditions (for instance, in space stations), and use in the human body (biomaterials for organ replacement).

Suggested Experiences for Students

Traditional industrial arts programs are named after materials (such as wood or metals) or their processing (such as foundry or welding) Students should have some ongoing experience with making artifacts of wood and metal during their school years, as well as with other traditional hands-on activities such as typing (currently, keyboarding or data entry), cooking, and sewing. But hands-on practice with regard to materials should be extended to include some of the advanced materials used in electronics, composite materials, and biomaterials. A central focus for these experiences should be determining properties, first qualitatively (in the fifth grade, for example, making structures of soda straws or toothpicks to show compressive or tensile strength) and later quantitatively (in high school, for example, using testing equipment to make numerical measurements of the strength of various materials).

ENERGY

A simple but profound truism is that "the energy available to people limits what they can do and influences what they will do." The growth of human enterprises and their associated technologies is closely tied to the amount and kind of energy available. The industrial age required the opening and exploitation of enormous coal resources. The modern motor vehicle transportation system is dependent on the availability of liquid fuel that has a very high energy-to-volume ratio, hence the need for oil. The information age is possible not only because of advanced electronics but also because of a reliable supply of electric current.

The student's awareness of energy as being fundamental to life and work is basic to technology education. The need for food—be it that of a microbe, a plant, or a person—is the need for the energy to act—which is no less than a working diesel engine's need for fuel oil or a computer chip's need for flowing electrons.

Energy Sources

For the world's people, the major source of energy at present is a finite resource of economically recoverable fossil fuels that effectively will be depleted in the foreseeable future. Differences of opinion exist as to the appropriate and ethical uses of this resource, but the actual uses are governed by the need to fuel our modern technological world.

The development and use of alternative energy sources pose problems. Nuclear power has unresolved waste-disposal difficulties, public fear of anything radioactive, and still uncertain technology and economics. Solar energy has a fundamental problem of low net energy yield, which is a consequence of the relatively weak energy flux of available sunlight. Such problems as these need to be understood by all citizens so that reasonable approaches can be taken toward managing the long-term energy situation. For example, the so-called energy crisis of the early 1970s was substantially moderated by the application of conservation measures. Nevertheless, more efficient use of energy produced in existing systems and the search for alternatives remain as major sociotechnical problems.

Suggested Experiences for Students

The principles of energy and its use should be taught in science courses, but their application must be thoroughly experienced or demonstrated in technology activities in elementary and secondary school. Concepts of work, kinetic and potential energy, storage of energy, and thermodynamics and entropy, among others, should be accompanied by purposeful experiences. For example, in the early grades, water wheels, windmills, and simple solar heaters can be built or demonstrated. Conservation of heat can be shown with insulation experiments (resistance to heat flow) and with reduction of convection (use of barriers or a vacuum). Combustion of fossil fuels can be studied in chemistry courses, and—with the aid of video and computer simulations—the use of such fuels to produce electric power or heat can be demonstrated.

MANUFACTURING

Technology is viewed not only as the enabling ingredient of manufacturing but as a catalyst or promoter of change in the production of goods and services. The life spans of products, jobs, and even industries are shortened by the rapid evolution of technology, requiring continuing education or training of both workers and consumers. This puts a premium on human flexibility—that is, on people who can quickly learn new skills, adapt to new programs, and interact with new coworkers. Similarly, businesses must be able to respond to rapidly changing markets.

The Role of Technology

Manufacturing is a primary wealth-generating activity. Nations need a balanced overall production of goods and services, coupled with trade across regional and national boundaries. Manufacturing is a field in great ferment. Technology is vital to the United States' being able to remain competitive both intra- and internationally. Much business and many jobs are moving overseas. The nature of work is changing. Thus, it is essential that a framework as described in Section 1 be used to guide manufacturing strategy as a subset of industrial strategies and national actions. There are many limits to those actions including the inertia and the long time horizons that must be considered in the making of changes in large systems.

Advanced manufacturing can be expected to incorporate sophisticated electronic and computer technologies. Technologies now under development include robotics, automation, sensing with feedback and feedforward for process control, and—ultimately—full computer-integrated manufacturing. Although the technologists must know the details of these advances to maintain U.S. industry in the mainstream of the advanced world of tomorrow, all citizens should have a general understanding of the process so that they can provide the necessary societal support for the nation's industrial base.

In most cases, direct labor in advanced manufacturing will be reduced as much as 50 to 90 percent as computer-integrated production is implemented. However, indirect manufacturing employment such as process engineering, general office work, information processing, quality control, and maintenance will increase in proportion to direct labor and will open up many new opportunities.

The service sector of the economy is growing at a faster rate than manufacturing. Here, too, there is increasing use of advanced technology in the form of electronic instruments, computers and other kinds of information-processing equipment, and communication networks. The skills required for such future jobs will have much in common with those in manufacturing.

In both the manufacturing and service sectors, technology is a lever that can increase the economic value of people and maintain the viability of their continued employment. Because products and services will evolve rapidly, people will be expected to have the positive attitude, interest, and flexibility necessary to learn skills for many new jobs over a lifetime.

A general understanding of how reliability relates to complexity is important as the working details of systems develop beyond the comprehension of a single mind. Nowhere is this fact more significant than in the manufacturing and distribution of goods Whether this situation obtains for a single workstation or for an entire plant, people with a holistic understanding of the process are essential in such activities.

Suggested Experiences for Students

Education has a unique opportunity to develop a variety of experiences for students in this field, ranging from the use of simple tools to building and programming robots to developing manufacturing systems that make simple products. Elementary study of manufacturing furnishes students with the opportunity to learn the basic concepts of processing, systems, and industrial organization.

AGRICULTURE AND FOOD

Agriculture, food production, and food distribution are fundamental to human life in that food is the principal biological source of energy for the human species. Before the impact of modern technology began to be felt in the nineteenth century, more than 75 percent of the U.S. labor force was engaged in farming or farm-related jobs. Now, less than 3 percent of the labor force feeds the nation, and even that percentage is decreasing. Formerly, increases in agricultural production resulted from opening up new lands; now, increased production derives from technology in the form of improved machines, chemicals, and biotechnology.

Technology, Agriculture, and Economics

Agriculture provides an excellent historical example of the link between economics and technology. In the labor-short United States that existed between 1880 and 1980, tractors and machines represented the dominant agricultural technology—whereas in land-short Japan, crop yields were increased by means of biological and chemical technologies and new crop varieties Agriculture is sensitive to market demand and conditioned by politics. The use of new technology is thus subject to social constraints. Government supports or restrictions have had a major influence on the use of technology in agriculture.

Continuing improvements in agriculture will come with larger, more efficient machinery, safer herbicides and insecticides (control), and fertilizers. The development of new strains and hybrids of plants has revolutionized agriculture, but genetic engineering adds a new dimension. It may become possible to accelerate the development of new strains of improved plants and animals or to develop plants that produce their own nitrogen for self-fertilization or develop their own protection against insects.

Likewise, aquiculture and commercial fishing have felt the impact of modern technologies. Biotechnology, radar, satellite imaging, and modern fishing vessels, for example, have all increased the production of food from the sea.

Food production and distribution in forms suitable for consumers involve still other technologies Purity, cleanliness, and safety are of paramount importance. Additives, for example, keep foods fresh and make them more attractive. Many processing techniques are used to make foods in different forms (for example, corn slurry is toasted to make cornflakes), and many different foods are canned or frozen.

Packaging has been a rapidly growing technology of great importance to the food industry. Although packages serve to keep food free of damage and safe to use, they also provide convenient and attractive containers. The package must not contaminate the food with chemicals that may be in the plastic films, metals, or paper of which it is made; nor should the package present a disposal problem.

Nutrition also has technology components. For example, at one time the processing of food to preserve it destroyed or reduced some of the food's vitamin content, as well as other qualities and the food's visual appeal Technology has since been developed to maintain the nutritional value of foods through appropriate cooking, processing, packaging, and use of additives.

The consumption of food from local sources has decreased as the development of transportation, refrigeration, and chemical preservation technologies has led to national and international distribution.

The use of chemicals in the production, packaging, and distribution of food has considerable benefit, but it may also present some risk. Traces of elements or compounds in food, for example, increase in significance as biomedical evidence accumulates on the risk that such substances will cause illnesses such as cancer. It becomes important to develop instruments and techniques for finding and measuring minute quantities of these substances and their effects. Usually, to draw reasonable and useful conclusions, many experiments must be run and statistical analysis must be used to find or develop the desired information from large amounts of data.

Suggested Experiences for Students

Curricula should emphasize the techniques of agricultural technology, including advanced biotechnology as it becomes available at the elementary and secondary school level. Students should be involved in experiments with plants, animals, insects, fungi, molds, and other life forms They should also have direct experience with the effects of fertilizers, animal nutrition, plant physiology, and ecology The implications of the laboratory results should be discussed in concurrent social studies classes to continue the learning process Many schools have laboratory facilities for food preparation. Those activities should be encouraged, and extended to include experiments related to nutrition and to home, industrial, and commercial food processing and packaging.

BIOTECHNOLOGY AND MEDICAL TECHNOLOGY

Biotechnology is one of the oldest technologies practiced by humans. For example, the fermentation of fruits and grains to make alcoholic beverages and the use of natural enzymes for making cheese are believed to be of prehistoric origin. Modern biotechnology has its roots in the work of nineteenth-century scientists, including Darwin and Mendel, and is growing out of the remarkable advances of bioscience in this century. The evolution of medicine has followed a similar path over the same periods of time. Knowledge of medicinal plants and their use, an ancient art, is still common in most contemporary societies, but modern health care includes the use of so-called miracle drugs and complex diagnostic machines.

Modern medical technology developed alongside discoveries in physics and chemistry, especially from the time of Leonardo da Vinci and Vesalius in 1543. Vaccination was invented by Edward Jenner in 1795. Life processes came to be understood as chemical processes with the synthesis of urea in 1828 It was with such findings that molecular biology was born. Starting in 1859, Charles Darwin outlined the main mechanisms of biological change. Modern genetics is rooted in the rediscovery, in 1900, of Gregor Mendel's laws of segregation. Molecular biology made a major stride forward with the discovery that heredity is coded in the DNA molecule, and with the breaking of that code in the early 1960s. The ability to splice genes came in the early 1970s With such very recent techniques, enormous advances in medicine and biotechnology lie ahead. Developments in public health and agriculture had already started to have profound effects on human population growth by the nineteenth century, and subsequent progress has continued to alter the face of the planet, human life-styles, and geopolitics

In addition to knowing this background, the high school graduate should have at least a conceptual knowledge of the molecules of life and how the proteins of which living matter is made are constructed of amino acids according to a transferable code preserved on molecules of DNA. Such knowledge is needed to understand the modern technologies used to build products and processes based on molecular biology.

One of these technologies, that of recombinant DNA, was developed by using means for tampering with the code. By the insertion of a specific gene into the DNA of certain bacteria, the bacteria can be made to produce enzymes or drugs of commercial value (such as insulin) Another technology is the cloning of antibodies useful in making vaccines (monoclonal antibodies) by using living cells (certain cancer cells) to cause their production. An initial step has already been taken to alter genes in human somatic cells, potentially a treatment for those who have certain genetic disorders. New and safer vaccines are being developed, and a synthetic growth hormone is under test. These developments extend beyond such immediate biological or medical applications, for example, uses of biotechnology are now occurring in agriculture, the production of chemicals, the synthesizing of fuels, mining, food processing, and pollution control. The list of applications is already long, and some of them are controversial. And yet the possibilities loom more exciting than the problems.

New materials can be used in making durable replacements for body parts and durable implanted devices for cardiac control and for physiological monitoring and control. New equipment and procedures are opening frontiers in research diagnostics and treatment. Such advances may extend human life, make it possible for parents to choose their baby's sex (thereby possibly skewing sex ratios in the population), detect genetic diseases and malformation in utero, and improve the general quality of life.

New technologies often raise ethical and economic issues. Advances involving organ replacements and other costly treatments, for example, have led to the need to make difficult and sometimes controversial choices about who should be selected to benefit and who should pay. There is also ongoing public debate over such issues as the use of drugs to perform abortion and the use of various advanced medical techniques to keep brain-dead people alive. Further, there are many questions that at this time have no certain answers, not even controversial ones; these include the consequences of tampering with the human gene line or the release of genetically engineered organisms into the environment to benefit agriculture.

Biotechnology has a direct and personal impact on human life and health. It is particularly important that young adults be aware of the activities in this field, which is now more than ever alive with new works and discoveries and is very likely poised to revolutionize their lives.

Suggested Experiences for Students

Experiential learning should be associated with biology programs, including experiments with plants and animals and even with mutating genes. After learning simple concepts, a student can now actually do these kinds of experiments. Mutating a gene in a high school laboratory serves to demystify the process. In addition, building and working with biological molecular models (physical and on the computer) can help students develop a sound understanding of the concepts of molecular templates, bonding, and energy transfer, which are essential aspects of biochemistry and technology. In addition, taking students on visits to health care facilities, as well as bringing outside experts into the classroom, can help familiarize students with equipment and techniques and with the latest technologies and the related social issues

ENVIRONMENT (ATMOSPHERE)

The atmosphere of the planet is vital to life It is in chemical equilibrium with the lithosphere and the biosphere, depending on oceans, winds, rocks, and plants but modified by the activities of humans. The oxygen in the atmosphere is required for combustion of hydrocarbon fuels. The atmosphere is a sink for the combusted fuels, dumped as smoke and emissions. Control of the emissions involves technologies and includes the use of both social and technical fixes.

One example of a social fix is the limitation placed on the total noxious emissions allowable for a geographical area. This limitation may take the form of forbidding additional manufacturing plants to be built in that area. Another example of a social fix is the passing of laws to prevent the use of chlorofluorocarbons where they might subsequently contaminate the atmosphere. It is believed that in the stratosphere, these chemicals deplete the ozone that shields us from the sun's ultraviolet radiation.

An example of a technical fix is the use of catalytic converters on automobile exhaust systems to oxidize hydrocarbons and carbon monoxide and thereby minimize smog. Another is the use of scrubbers on coal-burning electric power plants to remove oxides of sulfur that are in the smoke and that may later produce acid rain in the atmosphere. For some atmosphere-related environmental problems, there may not be a technical solution, or even an interim fix. For instance, there is no such solution for the release of carbon dioxide from burning fossil fuels. Although this gas is not harmful (in fact, it is vital to life), the huge amounts released—from burning the bulk of the earth's fossil fuel stores over a few hundred years—may overwhelm the earth's longer-term processes to absorb it and the excess gas may prevent the radiation of heat from the earth into space. This, likened to a greenhouse effect, may adversely warm the earth.

Suggested Experiences for Students

Experiments with the use of paper and fiber filters to remove particulates from various kinds of smoke can demonstrate the physical removal of undesired emissions. Students can design and construct devices and systems to do this. The collected material can be characterized microscopically. Chemical means of removal can be demonstrated by using lime to react with sulfur oxide gases, again in student-made systems. Field trips to local incinerators or power plants can add much to such experiential learning.

COMMUNICATIONS

Communications involves the representation of information, a means of transmitting and receiving it, and some assurance of fidelity between what is sent and what is received. Innovations in communications technology have transformed almost all technical and social systems, and inevitably they have come under some social control.

The electron has been the basic workhorse of communications technology. Interestingly, in the 1990s, we will be commemorating the first century of the electron, discovered by Ernest Rutherford in 1897. Back then, the telegraph and the telephone, invented decades before the electron was known, were already pioneering an age of real-time long-distance communications with information sent over wires Since that time, communications has been revolutionized by the development of many kinds of equipment, systems, and networks. Continuous technological change is a special attribute of communications technology. Commercial radio, for example, evolved from the use of crystal diodes in the 1920s to vacuum tubes through the 1950s to transistors and then to integrated circuits in the 1960s and 1970s. During the same six decades, signals have been transmitted by wire, radio wave, microwave (surface and satellite), and now light waves (using fiber optics), with the capacity of the transmission systems for information flow (bandwidth) being increased more than a millionfold. Communications has been extended from local to global to the outer reaches of the solar system. It is the basis for the often-cited world move to an information economy.

Information flows on a carrier, and so communications—in another sense—can be thought of as transportation of information Like other flowing entities, it can be—among other conditioning actions—connected, switched, modulated, or processed. Information can be coded in either analog or digital form. Speech and writing involve continuously variable modulation of the medium. At first, both wired and wireless electric communication was only in on-and-off bursts, requiring a special (binary) code. It was the invention of electronics—devices to transform sound and light signals into electrical signals, and vice versa—and of devices to amplify electrical signals that made possible the transmission of analog signals that represented subtle variations in sound or light and the transcribing of those signals as continuous variations in disk grooves or magnetization of tape.

The ability to transcribe information microscopically and to transmit information at very high rates has made it possible to return to the reliability of on-and-off digital signals. Analog signals can now be sampled and represented as numbers, stored or transmitted in that form, and conveniently processed by computers. Telecommunications networks are moving toward use of the binary format, encoding and transmitting information in digital form for more expedient and precise use of communications technology. There is a converting step at both sending and receiving ends that makes it possible to have the information in human-comprehendible form

The market demand or need in telecommunications is rapidly changing from voice to data transmission, including hybrid voice/data transmissions. This shift is being accompanied by a change in the business definition of communications—from the current "information movement and management" to a mode that reflects the ongoing processes. For example, telecommunications signals from space probes are processed by computers for management and control by other computers. In addition, images of planets may be viewed directly, but "management" (enhancement) reveals much more information—and even more when still further processed in the brain of the beholder

Internal communication networks or systems may link only offices in private organizations In such office systems, the links may go to computers, facsimile (or "fax") machines, file stores, data banks, electronic mail units, and the usual telephones.

These units, of course, may also be linked to external networks or systems. A new field of expertise is developing around the flow and management of information, independent of the electronic technologies that enable them to work. New ideas have arisen as a result of people's looking at communications this way—for example, efficiency of flow and processing Ways to eliminate "telephone tag," such as electronic "store and forward" and portable communications equipment, make telephoning more efficient. Meanwhile, the unit cost of communicating one bit of information continues to drop.

The effects on society of the rapid changes in communications are likely to be profound. Certainly, there is already an increase in jobs related to handling information. In a negative sense, privacy problems will also arise, as will other problems associated with misuse Unfounded credibility or confidence may be given to machine-generated-and-transmitted information, just as undue value has been associated with anything that is printed. But there is a much more positive outcome. Telecommunications links among people around the world can lead to attitude changes and better understanding through personal and firsthand contacts. Education itself has an enormous opportunity to use the benefits of advanced communications. Networks can bring in the best of people and materials from across the nation and can link classrooms with all kinds of data banks, supercomputers, and information-gathering equipment

Communications media are often subject to government control. In the United States, only broadcast transmission media are licensed and supervised by government. Although there is virtually no limit to the number of printed newspapers, magazines, books, and pamphlets that people can use to communicate, there is a limit to the number of stations that can operate in one area without interfering with one another. For both of these reasons, radio and television transmission power, frequency, and direction are assigned by the federal government. There is much competition for use of the broadcast spectrum by public and commercial stations, emergency agencies, the military, and private companies and citizens.

To participate fully in the information age, young adults should understand—at least conceptually—the technologies that are behind modern communications Further, they should be aware of the ideas, risks, and benefits of information management that are made possible by advancing communications technology.

Suggested Experiences for Students

Students can make simple devices that are used in communications, from historical gadgets (such as a carbon microphone or a simple telegraph) to modern electronic circuits, and they can then use them in elementary networks of their own design. Students should be encouraged to undertake imaginative projects, such as inventing ways of communicating with people in remote lands or searching for information from outer space that might reveal life there

ELECTRONICS

The late nineteenth century was a fertile period for the use of the electron—as electricity. Electricity brought to society lights, motors and generators, the production of aluminum, and many other developments. Modern electronics, however, can do things that were not possible in those times. For instance electronics makes possible such equipment as television sets, high-fidelity phonographs, radar equipment, and computers.

Electronics Technology

The history of electronics began less than 100 years ago. The gas discharge tube, the first electronic device, was invented in the late nineteenth century. Experiments with the gas discharge tube led to the discovery of the vacuum tube for radios. Since that time, electronics has gone through three major stages of development. In the first stage, vacuum tubes ruled the world of electronics. The second stage, which began in the 1950s, saw the first commercial use of transistors and other solid-state drives, and by the 1960s solid-state devices had largely replaced vacuum tubes. Electronics had already entered its third stage in the early 1960s with the invention of integrated circuits. With the integrated circuit—commonly called a microchip or chip—came microelectronics, a set of new technologies that made it possible to produce even smaller active and passive circuit elements. Today, more and more electronic products use integrated circuits to perform various electronic functions.

An integrated circuit with a million functional elements on a chip is now projected, thus expanding still further the applications in information processing. The elements per chip and the speed of computation have increased by several orders of magnitude since chips were invented, but both now approach physical limits, thereby providing an incentive to develop new approaches

Design of microelectronic circuits has become extremely complex, requiring computers to lay out the most efficient use of circuit pathways or interconnections. As a result of this design technology, the power of these devices is multiplied manyfold over what had been thought possible using earlier circuitry technology.

Even so, complex microelectronic products will be produced at a lower cost. Many of the advanced new products will not be purely electronic Rather, they will involve diverse technologies from other fields—for example, functions will be served by the manipulation of light (photonics) or by biological units (called biochips). It is possible that the calculator will be the last "pure" electronic device we will see.

Suggested Experiences for Students

Students in the elementary grades should have an opportunity to build simple circuits that do something, such as controlling motion or amplifying sound. Later, students can learn more of the actual electronics, such as what the transistor does. Designing new circuits and learning how to process semiconductor devices are potential experiments for students at the senior high school levels. Such activities should be coordinated with learning about the physics and chemistry of electronic materials and about the logic, interface design, and systems that are a vital part of electronics.

COMPUTER TECHNOLOGY

The modern general-purpose computer system is one of the most versatile and complex creations of humankind Its versatility follows from its applicability to a very wide range of problems, limited only by human ability to give definite directions for solving a problem. In only a few hours, a modern large computer can do more data processing than was done previously by all humankind before the electronic age (that is, before the mid-1940s). It is little wonder that this tremendous amplification of human information-processing capability is precipitating a revolution in information handling.

Working in the mid-nineteenth century, Charles Babbage was the first person to conceive of the essence of the general-purpose computer. He became convinced that error-free tables could be produced only by a machine that would accept a description of the computation by a human being, and that once set up, the machine would compute the tables and print them—all without human intervention.

The first third of the twentieth century saw the gradual development and use of many calculating devices. A highly significant contribution was made by the mathematician Alan Turing in 1937, when he published a clear and profound theory of the nature of a general-purpose computing scheme. The stimulus of World War II led to the development of many prototype computers in the 1940s, followed in 1951 by the UNIVAC I, the first of the mass-produced computers.

Five Generations of Computers

The term "first-generation equipment" is associated with the use of vacuum tubes as the major component of logic circuitry, but such equipment included a large variety of memory devices such as mercury delay lines, storage tubes, magnetic surface drums, and magnetic cores In second-generation equipment, transistors replaced vacuum tubes, making possible the widespread installation and use of general-purpose computers The third and fourth generations of computer technology (from about 1964 to 1970) saw increasing use of integrated fabrication techniques, from discrete components to highly integrated circuits. The 1980s ushered in the research for the fifth-generation computers designed to optimize artificial-intelligence processing that will appear in the 1990s. The advancement of computer technology has been achieved on two fronts. development of computers as tools to help humans do things, and development of computers as complex artifacts for humans to master and understand (a situation analogous to the dual development of applied and pure mathematics).

Modern computers are indeed powerful, and are growing explosively—with ever faster machines, advanced architecture, improved processing, and new languages and software. They can aid in designing molecules by using empirical quantum mechanical methods and chemical data, in analyzing complex patterns, in synthesizing moving graphics, and in doing other jobs requiring enormous calculating capability and memory.

Extensive use of computers as the "intelligence" in systems will require that users be able, at a minimum, to maintain and understand computing machines. Users will need to learn to externalize their knowledge and activities as algorithms, or pieces of knowledge that can be coded and represented in computer programs Mathematics and experimentation are vital components of this process.

Some degree of computer literacy thus will be required of all adults as computers become a part of daily life. At a minimum, this literacy will include the ability to use the computer for word processing and as a tool for problem solving. Additionally, adults should have the ability to write simple programs as a basis for organizing their thoughts in interacting and experimenting with computers. They should develop drawing skills—both freehand and on the computer—that will aid them in thinking in two and three dimensions. Such skills can add to people's ability to understand things through graphic displays and can expand their access to information through the use of interactive networks.

In many instances, solutions to problems will be so complex that problem solving will require people to work cooperatively and interactively in teams, and that such people also will have to have good verbal and written communication skills. In the decades to come, computers will be used by nearly everyone. It is possible that they could become one of the most powerful means of creative expression and communication ever known

Artificial Intelligence

Artificial intelligence (AI) is generally considered to be the ability of a computer system to perform tasks that simulate to some degree such human intelligence-based capabilities as reasoning, learning, and decision making.

Early in the evolution of artificial intelligence, the two most important forces were mathematical logic and new ideas about computation. Computers originally served the purpose of computation and data handling, but it soon became interesting to ask whether they might play chess, prove theorems, or translate languages—all of which they did, but not very well Learning about human thinking processes and intelligence is the focus of current efforts in this field

Applications of Artificial Intelligence

Nevertheless, there are already useful applications of artificial intelligence, such as for very specific medical diagnosis, in which so-called expert systems use branching questions to arrive at a diagnosis. Programs are written jointly by medical experts (who provide the content) and computer programmers. Thus computers can be made to appear to diagnose diseases. Artificial intelligence techniques have also been used in exploring for oil and minerals. Another application is simple speech recognition, and still another is the use of vision systems to recognize objects on a manufacturing line. All of these are elementary applications, which in no way should be represented as computers actually "thinking."

More complex programs are under development for speech recognition and image "understanding." Language translation assistance is already available. Beyond that, but far from achieved, are advanced learning, and planning and reasoning--but again, not "thinking" in the human sense.

In the future, adults who use artificial intelligence techniques will need to learn how to communicate so a computer can understand them, how to use a keyboard, how to construct grammatical sentences, how to ask questions, and how to interact efficiently with the computer

Suggested Experiences for Students

Practical experience with computers should begin very early in a student's school years. Students should use the computer for educational purposes and games, and as a means of visualizing problems and solutions. At a minimum, learning to write elementary programs would help the student to understand how the computer functions. The hardware and software in this field are advancing very rapidly. Students can expect to encounter remarkable changes during their school years, and educators themselves will have to make special efforts to keep their knowledge up to date.

TRANSPORTATION

The movement of goods or people from place to place is a major activity of humans. The medium for movement may be land, water, air, or outer space. Energy and usually vehicles are required for the activity. Various pathways—roadways, waterways, and airways—are used.

Earth Systems

Prehistoric humans moved themselves and their loads by walking along pathways, and probably by using streams to float rafts carrying goods, as elementary transportation methods. The invention of the wheel and the sail allowed significant advances to be made and created the need for more elaborate pathways and means of navigation. The movement of the stars in the heavens not only stirred the ideas of timekeeping but was important as a means of guiding early transport (just as it is today). A host of technologies subsequently led to modern transportation. These technologies included cartography, road building, and the use of strong but light materials and structures, the compass, and engines.

The concept of controlling and guiding vehicles is of great importance to safe and efficient transportation. Applications of this concept range from very simple mechanical devices such as guideways on a conveyor system to the very complex computer-assisted control of aircraft.

Energy use in transportation systems has grown increasingly important, and it has been related to the availability and costs of fuels. The efficiency of a vehicle is related to its speed (going faster costs energy) and to its weight/power ratio, its design, the kind of propulsion system, and other features—hence the development of modern technologies to make lightweight, streamlined vehicles with efficient engines.

Transportation, like communications, has transformed the world in the past century, thereby "bringing the world closer together." Foodstuffs moved in refrigerated vehicles release consumers from dependence on local supplies. Multinational business relies on the giant network of low-cost, intermodal rapid transportation.

Suggested Experiences for Students

Transportation technology allows students to design and test networks, including control systems. Students can do that by developing rail or road projects using toy or model vehicles. Limitations on speed, loads, and efficiency can all be revealed in simple experiments conducted as part of those projects.

SPACE

Few things have caught the imagination of the public, worldwide, as humankind's venture into space has. Based on a technology developed for missiles in World War II, space activities range from military uses to experimental manufacturing in the absence of gravity to exploration. Activities in space are expected to be a national priority for the United States for the indefinite future Long-range plans call for a space station next—a program far larger than the Apollo mission to explore the moon. Still further in the future are projects for colonizing the moon and Mars. Such expensive projects (in terms of both dollars and energy) will require unprecedented public support, since they will be competing with many other national goals. If they are chosen to be carried through, the public will have still other issues to resolve, such as deciding who the colonists will be.

Space technology involves strong but lightweight materials and designs that can accommodate extreme conditions of stress, vibration, heat and cold, corrosion, and—in space—erosion by ions and micrometeors. Activities in space require unique and reliable energy sources. Solar and nuclear energy are likely candidates New challenges face the space technologist, such as those involved in maintaining a human environment in a vacuum. Still largely unknown are the long-term health effects of zero gravity. Health care in space ships on long journeys may be impossible in some cases The risks will certainly be enormous, and the rewards remain unknowable for now.

Suggested Experiences for Students

Design of a space station with complete life-support functions makes an excellent learning project. It requires considerable imagination and forces students to search for advanced technologies in many fields. The analysis of space projects by students can lead them to consider social values or needs as compared with other needs that technology might serve, such as developing a cure for cancer.

APPENDIX

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NOTICE

This is one of five panel reports that have been prepared as part of the first phase of Project 2061, a long-term, multiphase undertaking of the American Association for the Advancement of Science designed to help reform science, mathematics, and technology education in the United States

The five panel reports are

- *Biological and Health Sciences Report of the Project 2061 Phase I Biological and Health Sciences Panel*, by Mary Clark
- *Mathematics: Report of the Project 2061 Phase I Mathematics Panel*, by David Blackwell and Leon Henkin
- *Physical and Information Sciences and Engineering Report of the Project 2061 Phase I Physical and Information Sciences and Engineering Panel*, by George Bugliarello
- *Social and Behavioral Sciences Report of the Project 2061 Phase I Social and Behavioral Sciences Panel*, by Mortimer Appley and Winifred B Maher
- *Technology Report of the Project 2061 Phase I Technology Panel*, by James R Johnson

In addition, there is an overview report, entitled *Science for All Americans*, which has been prepared by the AAAS Project 2061 staff in consultation with the National Council on Science and Technology Education.

For information on ordering all six reports, please contact Project 2061, the American Association for the Advancement of Science 1333 H Street NW, Washington, D C 20005