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ABSTRACT

This monograph explores aspects of science and technology in contemporary society and suggests methods for teaching about social policy issues which have resulted from scientific and technological developments. Section one offers an argument for teaching about science and social policy; surveys the sociology, politics, and history of contemporary science and technology; and identifies methodological problems in teaching about science and social policy. Included is a discussion of six general learning objectives which should be met in a study of science and social policy. The objectives include understanding the (1) role of citizen participation in policymaking, (2) extent to which scientific and technological developments can change people's lives, (3) ways in which laymen depend upon experts' knowledge, and (4) importance of translating personal values into participative action. Section two presents social studies units on nuclear energy, electronic technology, and genetic engineering. Each unit includes expository reading material, learning activities, and reading lists. (AV)

TEACHING AND LEARNING ABOUT SCIENCE AND SOCIAL POLICY

by

Kenneth D. Benne and Max Birnbaum

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PREFACE

In early June of 1978, members of the Social Science Education Consortium gathered in Boulder for the annual conference and corporation meeting of the Consortium. The conference topic, "Science-Related Social Issues and Social Science Education," reflected the personal and professional concerns of many SSEC members who felt that the schools could and should do a better job of preparing citizens to participate intelligently in making important social policy decisions.

Before the conference, a background paper was prepared for participants by Kenneth D. Benne and Max Birnbaum, emeritus professors at Boston University and partners in Staff and Organization Consultation, Inc. Between them, Benne and Birnbaum have amassed close to a century of experience in teaching the disciplines of science and social science, both to students at all levels of schooling and outside the context of the school classroom. Benne subsequently served as a most eloquent synthesizer of the conference proceedings.

Building on their original working paper and on some of the ideas and needs expressed at the conference, Benne and Birnbaum went on to develop this practical resource for teaching about science-related social issues. We believe that it may help to fill a critical gap in today's social studies curricula, and we hope that both teachers and students will find it useful in developing some of the skills required for responsible citizenship in a world of ever-increasing technological--and thus moral--complexity.

Irving Morrissett
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GENERAL BACKGROUND AND PREPARATION

1. INTRODUCTION TO TEACHING ABOUT SCIENCE AND SOCIAL POLICY

Social issues and social problems have long been an accepted part of the curriculum of social studies in American secondary education. The reasons for focusing instruction on the exploration of unresolved social issues are convincing ones. Such issues represent the agenda of unfinished societal business into which citizens in a democracy are expected to invest their participation in social and public policymaking. And the study of social issues, under responsible educational auspices, should help to make citizen participation better informed, more thoughtful, and more responsible.

This argument is, of course, based on the premise that an important objective of social studies education is to deepen and extend literacy and effectiveness in citizen participation. The authors believe that this objective is still an accepted and acceptable part of the social studies curriculum in the 1970s. But many educators feel that the study of social issues is now in need of revision and refocusing. In 1975, the National Council for the Social Studies gave autonomous status to its Science and Society Committee with a mandate "to help teachers, students, and others deal effectively with science-related social issues." The preamble to this mandate deserves full quotation:

> The impact of science and technology on society, and of society on science and technology, are of increasing and vital importance. Scientific and technological developments often move so rapidly that social institutions are unable to respond effectively. This gives rise to unprecedented ethical questions and societal problems and creates demands on citizens and on society for new insights and understandings.

It has long been recognized by educators and others that science and technology are important and powerful elements in contemporary societal change. But only recent have the interrelationships between science, technology, and society become a focus for study in some colleges. And our survey of the literature indicates that these interrelationships have yet to become an important focus for study in high schools and intermediate schools.

No doubt there are many reasons for this educational lag, but two reasons seem particularly important for our purpose.

First, the study of science and society has fallen between stools in our departmentalized high school curricula. Does the study belong in the curriculum of social studies? Or does it belong in the science curriculum? Collaboration between social studies teachers and science teachers would most probably be desirable in presenting such material. However, the need to bring science-related social issues into the classroom is too important and urgent to wait for widespread development of such collaboration.

Part of the hesitation of social studies teachers to assume leadership in this neglected area of instruction may well stem from the fear that they are not prepared to provide science instruction. Yet it is not technical education that is being called for; such content is properly in the domain of science and engineering instruction. The teacher of science-related social issues requires only an intelligent lay person's understanding of the scientific and related technological developments which have precipitated urgent and unsolved social problems in our society. The focus of study should not be the technical character of these developments but rather their actual and potential effects on people's lives. We need to examine the sociology, politics, and history of scientific and technological developments in order to understand the ethical and moral implications of proposed alternative ways of managing the powers which scientific and technological discoveries have placed into human hands.

The second reason for the neglect of science-impacted social issues in high school instruction is methodological in nature. In its mandate to the Science and Society Committee, the NCSS noted that contemporary science and technology have confronted citizens and societies with "unprecedented ethical questions." The resolution of ethical questions always involves people in practical judgments about what should be done. And practical judgments inescapably involve value judgments--choices between competing and conflicting interests and value orientations.

Questions of social and individual ethics are inherently controversial. Educators have, not infrequently, sought to avoid controversy in teaching-learning situations. There is no doubt that harmonious classroom and school-community relations may be endangered by focusing school instruction on controversial, value-laden issues. And teaching may well be more difficult--it certainly more challenging--when the subject matter deals with controversial issues.

Part of the difficulty arises from the false assumption by some teachers and parents that school instruction will and should lead to the "right" answers to all questions raised and considered in the classroom. A social issue that is genuinely unsettled has no one "right" solution, so long as society is struggling toward workable agreements about acceptable trade-offs and resolutions. Teachers should expect that different students, during and after study of a social issue, will choose different positions with respect to that issue, since we live--and will continue to live--in a pluralistic society (Birnbaum 1964). But teachers can reasonably expect that any position chosen by a student will be informed and reasoned and that students will be aware of and understand alternative positions in the controversy.

Another part of the difficulty arises from the fact that teachers often hold to a model of problem solving better suited to making theoretical judgments than to making practical judgments. In making practical judgments, the reconciliation of competing interests and conflicting value orientations is an inherent part of the process. In theoretical judgments, choices between alternative hypotheses are based, ideally and primarily, upon the weight of factual evidence. The judgments that students should be expected to learn to make through the study of social issues are practical, policy judgments in which relevant facts are only one component. The discipline which students ideally acquire in such studies is that of participating responsibly and effectively in the making of policy choices and judgments.

The argument that the basic discipline to be cultivated in civic education is related to practical judgment and policy choice is not new in the literature of educational theory. This argument is based on the recognition that while scientific and technological expertise is an indispensible component in public policymaking, the ability to appreciate and adjudicate conflicting interests and value orientations is equally indispensable if technological expertise is to be used in the service of humanly defensible and acceptable ends (Raup, Benne, Smith, and Axtelle 1943 and 1963).

In this monograph, we will first discuss some aspects of the sociology, politics, and history of science and technology in contemporary society. We will then try to suggest a desirable balance between scientific, social, political, and ethical considerations as we discuss what and how to teach about some of the policy issues which have grown out of a few important scientific and technological developments. Our hope is that this monograph will help teachers find and use appropriate models of discussion and deliberation as they introduce students to the study of science-impacted social issues.

2. THE SOCIOLOGY, POLITICS, AND HISTORY OF CONTEMPORARY SCIENCE AND TECHNOLOGY

Those who are entrusted with responsibilty for guiding human conduct into the future seldom have in themselves the knowledge and information needed in order to make long-range plans which are valid and workable. The policymakers must seek advice from persons who claim expert knowledge about the activities which the policy or plan is designed to order and control.

However, expertise is only one requirement for making valid and workable policies. Other factors--legality, morality, economics, and the often-conflicting attitudes, needs, and values of people affected by the policy--must also be considered. The fact that expert knowledge is a necessary component of policy decisions does not mean that we should leave policymaking to the unchecked judgment of experts, even in issues that are complicated by highly technical considerations.

Most unsettled areas of social policy which plague people in America today bristle with technical questions which nonexpert "lay persons" are unable to answer for themselves. For example, how much can and should we depend on nuclear energy as an alternative to our dwindling supplies of petroleum and natural gas? Laymen are dependent on the knowledge and know-how of experts in answering such a question. We must depend on the knowledge and research of geologists in assessing the extent of untapped supplies of fossil fuels in the earth and on the know-how and research of petroleum engineers in assessing the accessibility of these supplies and the cost of extracting them. We must depend on nuclear physicists for knowledge about the radiation effects of various fissionable materials and on nuclear engineers for information about the feasibility and cost of building nuclear reactors. And they in turn are dependent on medical scientists and biologists for estimates of the effects of various radiation levels on land and sea life and on construction engineers for assessments of the feasibility and cost of building structures for safely housing reactors and sequestering nuclear wastes.

The situation is similar with other kinds of unsettled policy questions.

How can and should we control cancer-producing chemicals in food, air, and water? Here the expertise of chemists, chemical engineers, medical scientists, and sanitary engineers comes into play. How can and should we rebuild and maintain damaged life-support systems for endangered animal species, including man? Here the advice of ecologists and environmental engineers is required. How can and should we protect individuals from the invasion of their privacy by the intrusions--dangerously implicit and to some extent now explicit--of computers and other forms of electronic science and technology? Here the resources of solid-state physicists and electronics engineers and technicians become important.

Two significant points about contemporary policymaking emerge from these observations. The first point is that policymakers are now inescapably dependent upon two classes of experts: scientists and technologists, or engineers. Although this condition has existed since the Industrial Revolution, the extent and quality of this dependence changed in the United States and other developed nations during and after World War II. The revolutionary character of this change can be illustrated by pointing to what has happened in recent years to the so-called natural sciences--physics, chemistry, and biology. The adjective "natural," when applied to science, once connoted the study of and accumulation of knowledge about the forms of energy, matter, and life that existed and functioned naturally on and around our planet Earth. The technological application of scientific knowledge was focused on improving and refining the utilization of natural energies, materials, and life forms.

However, recent advances in the "natural" sciences have produced energies and materials not previously found in terrestrial nature. Nuclear physicists have converted matter into energy, created new chemical elements, and produced concentrations of radiant and heat energy not previously occurring on Earth. And nuclear engineers have developed these findings into artifacts that introduce unprecedented conditions into our habitat. Chemists have produced thousands of compounds with no counterparts in nature, and chemical engineers have impregnated our environment with these artifactual substances in the form of insecticides, herbicides, drugs, synthetic fibers, and plastics. We are told by physicians that more than

90 percent of the drugs they now prescribe did not exist prior to World War II. Biologists have recently begun to produce forms and species of life that transcend those developed in the long course of organic evolution. And before long bioengineers may be employed to support industrial entrepreneurs in offering new, self-perpetuating species for sale and utilization, just as chemical engineers have helped produce new commercial compounds and nuclear engineers have been employed to develop new elememts and energies.

The poet e.e. cummings once noted wistfully that "a world of made is not a world of born." We have moved dramatically into a "world of made" as our lives have been increasingly shaped and influenced by man-made features in our environment. In many cases, traditional wisdom is no longer helpful in guiding our lives. Herbert Simon has termed this aspect of the "new" science and technology the "science of the artificial." It is this science, with its cognate technologies, which has emerged only recently to complement and in some cases to supplant the traditional "natural" sciences and their related technologies (Simon 1968).

The second point concerning science, technology, and policymaking today is illustrated by the form in which the policy dilemmas cited earlier were stated. The question is not simply "How can we control cancer-producing chemicals in food, air, and water?" but rather "How can *and should* we do so?" Our policy dilemmas present us not only with "can" questions of fact and possibility but also with "should" questions of ethics and morality.

Our traditional social moralities took form within the parameters of a slowly evolving natural environment and were communicated from old to new generations as axioms of folk wisdom and common sense, often with little or no conscious assessment of their adequacy in guiding the conduct and management of contemporary human life. Today, as we seek to shape social policies toward humane ends in an environment that has been transformed through the agencies of science and technology, neither the content nor the method of transmission of traditional moral precepts can be assumed to be adequate. The consequences of various proposals for utilizing new knowledge and managing novel technologies must be critically assessed, and "new" ethical and moral foundations for social policy must be forged and tested. This charge suggests a second condition of civic literacy for men and women today: They must accept responsibility for helping to forge a morality which can bring the awesome powers released by modern science under humane direction and control.

A Brief Historical Digression

Even though our contemporary situation is in many respects novel, we should not neglect the history of past attempts to use the expert resources of knowledgeable men and women in formulating, evaluating, and justifying social policies. Many--perhaps most--"educated" persons in Western societies have grown accustomed to thinking of scientists and technologists as the only legitimate repositories of expertise. The utilization of alternative, "nonscientific" resources in forming, legitimizing, and evaluating social policies may be seen as "superstitious" and thus without relevance in a "nonsuperstitious" age.

Without some historical perspective on the emergence of modern science as the principal arbiter of factual knowledge, it is easy to forget that the claims of science have been challenged repeatedly and insistently by other claimants to knowledge about the meaning and workings of nature, of history, and of mankind. Sometimes these challenges have come from priests and leaders of traditional religions, at other times from prophets--religious or secular--possessed by compelling visions of human destiny. Students of the arts and humanities have at times claimed knowledge "higher" than that provided by science and technology. Faith healers, soothsayers, and astrologers are others who have never surrendered completely to the forward march of science.

And--lest we think that challenges to the authority of science and its claims to superior knowledge occurred only in the dim past--the turbulent decade of the 1960s should be recalled. Widespread disillusionment with the bitter fruits of militarized science and technology, widespread anxiety about technological threats to the natural environment, widespread despair about the failure of established ways of policymaking to achieve just and humane ends--all these led to the widespread embracing of alternative ways of living and knowing. Indeed, the reaction of many, especially among the idealistic young, was to rebel against all established authority--and, to many of these young rebels, science and technology were seen as synonomous with "the establishment." The alternative sources of knowledge to which these rebels turned were diverse--astrological, religious, pharmacological, magical. Leading scientists and scholars were sufficiently concerned about these challenges to devote two entire issues of *Daedalus*, the journal of the American Academy of Arts and Sciences, to a reassessment of the hold and authority of science in the public consciousness (*Daedalus* 1974 and 1978).

In the first of these issues devoted to an assessment of public acceptance of the "authority" of science, many of the articles reflected a sense of bafflement and some defensiveness in response to challenges to the autonomy of scientists to determine valid directions for scientific investigations. One author, Rozak--himself an exponent of the counterculture and an advocate of human dependence on nonscientific knowledge--contributed an essay which supported a polarized definition of the situation as "science *versus* non-science" (*Daedalus 1974*). In the second assessment, four years later, most authors accepted the rationality and necessity of placing some limits upon scientific inquiry, and some authors explored the possibility that citizens might participate, along with scientists, in making decisions about the direction, tempo, and conditions of scientific investigation (*Daedalus* 1978).

Sociologists of knowledge have reminded us that, throughout the history of human societies, policymakers have always sought the advice of men and women with claims to special knowledge (Znaniecki 1940). Rulers in ancient Greece consulted the Delphic oracle and her attendant priests and priestesses before undertaking important public ventures. Egyptian pharaohs sought the advice of the priests of Ammon-Ra concerning questions of statecraft. Saul, king of the ancient Hebrews, turned for insight into the future to the witch of Endor. Roman rulers depended on soothsayers and their examinations of the entrails of sacrificial animals for omens predicting the success or failure of imperial projects. Chinese emperors sought and listened to the counsel of Confucian sages, whom they supported as part of their courts, in forming and executing public policies.

In our contemporary period, with its unprecedented dependence on science and technology, policymakers still sometimes depend on the functional equivalents of oracles, sages, and soothsayers in making and justifying public policies, though these modern counterparts are likely to wear the laboratory coats of scientists and talk the language of engineers. One might also draw an analogy between opinion polling and market research and the auguries of Roman soothsayers. Or the mantle of sage may rest upon the shoulders of James Reston, Eric Sevareid, or some other influential journalist. However, as has already been noted, accurate and valid information is only one--albeit indispensable--component of wise policymaking. To thrust the role of soothsayer, sage, or oracle upon the scientist or engineer, as anxious leaders and citizens are sometimes prone to do, is to fail to wisely use the limited, though indispensable, contribution such an expert can make to policymaking.

Another lesson to be drawn from the history of the interactions between policymakers and persons with specialized knowledge is that tension always exists between people who are interested in action and those who are primarily interested in seeking and extending knowledge (Kelly 1963). "Action" leaders are interested in maintaining and extending their power in social control; knowledge is sought and used insofar as it is instrumental to this purpose. For the knowledge builder, knowledge is both a valuable end in itself and a prerequisite for the finding and testing of more knowledge. Action leaders want guarantees that success and "payoffs" will result from the knowledge they employ. For the knowledge builder, the failure (disconfirmation) of a knowledge claim may be just as significant as or even more significant than the success (confirmation) of a hypothesis. Action leaders value knowledge which is applicable in the short run. Knowledge builders have a different time perspective on knowledge; to them, the most important kinds of knowledge may take a long time to acquire and confirm or disconfirm. Thus, the interests of scientists and those of policymakers and policy executors are not always compatible.

It is true that new knowledge-based roles have developed in our science-shaped society which are intermediate between those of basic scientists and action leaders, or organizational executives--the roles of the applied scientists, the engineers, and the technicians. These roles will be explored later. However, the tensions between scientists and policy-makers remain even as their interdependence has increased.

Science vs. Technology

So far, we have made no distinction between science and technology, nor have we differentiated the functional role of the scientist from that of the engineer or technologist. There is, of course, a defensible (though not always clear) distinction between the two roles. Put simply, the scientist's function is to find out how things work and how to do things. The engineer's role is to plan and design ways of getting things done. The aim of the scientist is to produce tested knowledge. The aim of the engineer or technologist is to transform knowledge into techniques and artifacts for which there is a human demand. Scientists operate within the domain of knowledge. Engineers and technologists operate within the domain of practice.

There was a time when the roles and domains of the scientist and those of the skilled artisan or craftsman were more clearly separated than they are today. Skilled artisans possessed lore and skills which had accumulated through a long history of human experience. These skills were transmitted through an extended working association between master and apprentice--not uncommonly, between father and son. This was true of the practical arts used in the making of artifacts: metalworking by refiners, blacksmiths, silversmiths, and toolmakers; woodworking by carpenters and cabinetmakers. It was also true of the practical arts used in doing things, often with the aid of artifacts: farming, navigating, making war, keeping the peace.

Science on the other hand, flourished--where it did flourish--apart from places of industry, commerce, and agriculture: in monasteries, in royal courts, in private laboratories, in associations of gentleman scientists (for example, the Royal Society in England), and, increasingly, in universities and institutions of learning. The findings of scientists were transmitted primarily by written documents and treatises, in contrast to the greater dependence on oral transmission exhibited by artisans and craftsmen. As a result, didactic instruction was more important in the education of scientists than in the training of artisans. The associations between scientists and craftsmen were further inhibited by social class divisions, with the higher social status usually ascribed to persons who "worked with their minds."

Only when the economic and other advantages of production based on scientific knowledge were discovered by men of action in warfare, industry, and commerce did scientifically educated engineers and technologists begin to displace skilled artisans and craftsmen in armies and navies, in factories, in marketplaces, and eventually on farms. This displacement was hastened by the adoption of mass-production methods in the 19th and early 20th centuries. Unskilled and semiskilled workers began to replace skilled workers in processes of production designed and controlled by engineers--processes that often used "artificial" materials discovered and developed by scientists and engineers. The hegemony of scientists and engineers in industry, commerce, and agriculture has been further strengthened in the 20th century by the trend toward automatized production, a trend made possible by developments in electronic and cybernetic science and engineering.

These revolutionary developments were facilitated by the subsidization of scientific research by industries and governments toward the end of the 19th century and, much more heavily, in the 20th century. As J.J. Thomson, the British physicist, once remarked, "Research in applied science leads to reforms; research in pure science leads to revolution." To this the authors would add that the linkages between basic science, applied science, and engineering--linkages supported and subsidized by governments and industries--have created a continuing revolution in the conditions of our lives.

The segregation of knowledge from practice has broken down as the efforts of scientists, engineers, policymakers, and leaders in government and industry have become more closely coordinated. Although skilled artisans and craftsmen have not disappeared from society, they have moved closer to the "artists" in social function, and they now join the market in the production of luxury goods. On the other hand, the dependence of engineering upon the sciences is evident in the names given to many of the former's contemporary branches--chemical engineering, electrical engineering, electronic engineering, nuclear engineering. The sciences are, in turn, fed by the demands and requirements of engineering.

There is indeed a division of function between scientists and engineers. However, the major impact on society has come from their joint and interacting efforts, not from the independent efforts of one or the other. The problems that have been generated from this combined impact are the focus of this monograph. In his four-volume work *Science in History,* J.D. Bernal made a statement that furnishes an apt conclusion to this section:

> Steady and cumulative improvement of technique can be expected from engineering; but notable transformations only when science takes a hand. . . . At the same time engineering successes, and even more engineering difficulties, furnish a continually renewed field of opportunity and problems for science. The complementary roles of science and engineering mean that they both need to be studied to understand the full social effects of either. (Bernal 1965, vol. 1, p. 42)

The Role of Governments and Corporations

Science and technology are both precipitators of problems related to social policy and sources of solutions to those problems. The life blood of science and technology is continuing research. It is the knowledge that has emerged from such research projects that has extended man's power to build and destroy. Social policies designed to channel this power toward constructive and humane ends must order and direct the utilization not only of the knowledge and techniques now available but also of those yet to be produced through continuing research.

Scientific and technological research is now linked to policymakers and policy executors in three principal ways. First, scientists and engineers have become dependent upon governments and industrial corporations for the funding of their research programs. Second, governments and industries have become primary employers of the talents of scientific and technological researchers. Third, both industries and governments have developed new patterns of social organization in order to facilitate the utilization of the findings of basic scientific research in applied research and technological development and in turn to facilitate the utilization of developed technologies in practice and production. In this section we will explore how each of these interrelationships is related to currently unsettled issues in the social utilization of science and technology.

Big Money for "Big Science". A.M. Weinberg has used the term "Big Science" to emphasize the exorbitant costs of research in many areas of science since World War II. The Manhattan Project during that war, which led to the development of the atomic bomb, required the production and use of costly equipment and the employment and coordination of a small army of scientists, engineers, and technicians. Only an affluent government could have mounted and supported such a vast program. The effort of the National Aeronautics and Space Administration (NASA) to put men on the moon required billions of dollars of public money both for the necessary instrumentation and apparatus and for the employment, coordination, and training of the scientists, engineers, and technicians who were involved.

These are two extreme examples of the heavy financial outlay now required for scientific experimentation and technical advances in many fields--among them high-energy physics, astrophysics, clinical health investigations into cancer and heart disease, energy research, and weapons development. Much of the expense is related to designing and building the elaborate apparatus and instrumentation required. However, the personnel costs of "team" and "project" research are also high.

Because only governments and large industrial corporations can afford to support research in today's "Big Science" and "Big Technology," the romantic image of the solitary scientific investigator, laboring and pondering in his private laboratory, has become obsolete in most fields of experimental investigation. Even though the functions of independent theorist and laboratory experimenter have become differentiated in some branches of physics and astronomy, and to a lesser extent in chemistry and biology, even the deliberations and calculations of the independent theorist are likely to be computer assisted. Moreover, theorists depend ultimately upon experimenters to put their theories to an empirical test. Thus it is probably accurate to say that "team" investigations and governmental and industrial subventions of scientific and technological research have become the rule rather than the exception in today's world.

This trend in research funding is seen as a mixed blessing by many basic scientists. The tensions between the scientific mentality and the action mentality have already been noted. Some basic scientists fear that increasing dependence on governmental and industrial funding will divert research away from questions arising out of the gaps and inconsistencies in the theoretical frameworks of the scientific disciplines, thus reducing the likelihood of achieving continuing breakthroughs in basic science. These scientists fear that the interests which control the purse strings will direct research more and more to applied problems, where the likelihood of immediate payoffs in practical results seems highest, to the detriment of basic scientific research.

This concern was one factor that led to the establishment of the National Science Foundation in 1950. Government funds allocated to the NSF were to be used primarily to further basic scientific research. Harvey Brooks put this innovation in science policy into historical perspective:

> In the United States, government support of science evolved piecemeal in response to a succession of opportunities and needs arising in separate historical epochs. Only after World War II did the federal government begin to consider the support of science on its own terms a legitimate responsibility of government, and to contract to an appreciable extent for research to be performed outside government laboratories. A national commitment to the support of basic research was clearly institutionalized only in 1950 when the National Science Foundation was created. Even as late as 1972, however, the research budget of NSF accounted for only 2.5 percent of total [research and development] expenditures, or 5.2 percent of all non-military ones. The NSF supported less than 10 percent of basic research and less than 20 percent of all federally supported research in universities. All other [research and development] expenditures were budgeted and administered by the departments responsible for functions defined in social rather than scientific terms such as defense, health, agriculture, environmental services, housing, transportation, and social welfare. In this scheme the large expenditures of the space agency (NASA)

and the Atomic Energy Commission (AEC) are something of a hybrid, for neither space nor atomic energy is a social function in the normal sense. Rather, each represents a defined range of technology supporting a variety of social and political objectives. (Brooks 1978, p. 130).

Two sets of policy issues emerge from these observations about the trend in research funding. One set of issues has to do with the relative emphasis, in the allocation of grants and subsidies, on basic research as opposed to applied research. Another set of issues has to do with the allocation of research funds to activities related to various social functions--among them defense, health, environmental protection, agriculture, energy, education, and welfare.

Since government subvention of research is paid for by taxpayers' dollars, citizens have a stake and a legitimate voice in the extent and focus of research that is supported by government funds. Industrial research is, of course, also paid for by citizens in their role as consumers. The costs of research are built into the prices we pay for drugs, gasoline, cosmetics, desk calculators, and television sets. The influence of consumers on allocations for industrial research is perhaps more indirect and less well developed and exercised than their influence on allocations for governmentally funded research.

The Politicization of Science. Governments and industries not only pay much of the costs of scientific and technological research today, they are also the principal employers of scientists and even more so of engineers. Science and engineering have thus become politicized--perhaps more accurately, in Price's terms, science has itself become an establishment (Price 1965). The trustworthiness of scientific and technological expertise has traditionally depended on the "objectivity" and "factuality" it brought to deliberations about controversial issues of social and public policy. As scientists and engineers have been employed to serve the purposes of various special interests, both within and outside government, the "objectivity" and "factuality" of their expertise has been increasingly called into question. It is not that factuality and objectivity are no longer needed in policymaking but rather that policymakers are more and more called upon to judge the boundaries between "fact" and "interpretation" as they utilize scientific and technological expertise.

The lack of--and need for--policymaking processes that take into account the complex intertwining of scientific and technological expertise with governmental and industrial employment was aptly described by Brooks:

> Historically both science and technological innovation have received much of their impetus from war or from political competition between nation-states. In most industrialized countries the largest fraction of technological effort goes into projects for national defense, space, and nuclear energy and a large fraction also goes into supporting national competitiveness in international trade. Is is estimated that 25 percent of the world's scientists and engineers are engaged in military research and development, and the great majority of the rest are engaged in industrial research. In these areas a fairly comprehensive system of innovation has evolved, so that knowledge does move into action, and work in research and development is coupled to end products--though perhaps least successfully when governments have subsidized [research and development] directed at products and services for the private market which, outside the socialist countries, they have done most extensively in Europe and the United Kingdom.
>
> Today we are witnessing a broadly based world-wide movement, both within and outside the technical community, to utilize science and technology for less nationalistic purposes: for the alleviation of poverty on a global basis, for better management and protection of the world's resources with minimum detriment to economic development, for the achievement of greater social justice, for the more reasonable allocation of the resources of the biosphere toward sustaining a decent human life for all people. In these areas, however, we are faced with a massive deficiency of experience in coupling knowledge to action. We scarcely know how to translate what we know into tangible benefits or wise social restraints, and conventional wisdom, good intentions, and moral fervor are hardly adequate. The very success of technology in some areas has generated expectations which make its inadequacies in others seem the more glaring and inexcusable. The "if we can land a man on the moon" syndrome has transformed what we expect from technology, but, in fact, American successes in space carry relatively few lessons applicable to problems, like virtually all of those mentioned above, where conflicting interests and values play a large part. (Brooks 1978, pp. 127-128)

One of Brooks's points about the politicization of science and technology deserves further underlining: that a significant proportion of scientific and engineering talent is employed in military research. The connections between war and technology are not new; such connections have existed throughout history. And, whatever the disvalues of an increasingly powerful military science and technology in the augmentation of human destruction, it is true that "fallout" from military research has in the past contributed to nonmilitary science and to peacetime technology (Bernal 1965, *passim*). Nevertheless, the capacity of modern military technology to destroy irrevocably the earthly habitat of mankind sheds a new moral light on our continuing investment in military research.

Moreover, the concentration of scientific and technological talent in military research and development deprives people who are working on peace-serving problems of the resources they need in order to develop solutions to these problems. In another essay, Brooks commented on the economic and other disvalues that result from the concentration of expertise in military research:

> In 1970, the total research funds in the world devoted to military efforts were estimated at $25 billion, about 40 percent of the world total for research generally. Some 25 percent of the world's scientific and technical manpower was engaged in research which, however general its potential application, had been originally justified primarily on military grounds. This 25 percent probably represents the most sophisticated and highly trained segment of the technical community. The military devotes much more money than other economic enterprises to do research and development: it accounts for one-eighth of all world expenditures for military purposes, whereas in manufacturing industries in the United States, for example, it accounts for only about 4 percent of sales. From 1958 to 1965, 80 percent of the personnel additions to research and development occurred in just two industries, aerospace and electrical equipment, i.e., those most heavily involved in government-financed defense research. In 1968 roughly 43 percent of the physicists in this country with doctoral degrees were at least partially dependent on military budgets for support of their scientific effort. Moreover, a significant fraction, perhaps 20 percent, of the scientific recruitment in the 1960s was accomplished through a "brain drain" of trained people from the rest of the non-Communist world, including the less industrialized countries. . . .

There is now fairly wide agreement among economists that the American concentration of space and defense in the early 1960s had a depressing effect on innovation in the private economy, as well as on efforts for public improvement in such areas as pollution control, public transportation, and housing. A recent study by Boretsky suggests that in the Netherlands and Japan the number of scientists and engineers per equivalent dollar of GNP in civilian industries is more than two and a half times larger than in the United States. This gives a somewhat exaggerated picture, because there is some civilian "fall-out" from military and space research and development in the United States, but it does suggest one reason for the recent poor performance of this country in international trade, and it is indicative of the possible price paid for preoccupation with military research over the past two decades.

To the extent that science and technology and their wide diffusion are important components of world economic development, the statisitcs quoted above reveal that the diversion of human resources to military expenditures is much more serious than is the diversion of economic resources. (Brooks 1975, pp. 93-94)

Brooks has pointed out that some scientists have undertaken to act as the "conscience" of society with respect to the humane and constructive uses of science-based technologies. For example, a group of "atomic" scientists who were appalled by the awesome potential of the nuclear energies they had helped to release established the Educational Foundation for Nuclear Science in 1945. Since that time, this foundation has published the *Bulletin of the Atomic Scientists* as a "magazine for public affairs." Because of its analyses of the actual and proposed uses of nuclear energy and related social and moral issues, this publication has become an indispensable resource in the education of the public (*Bulletin* 1945--). Similarly, the Federation of American Scientists continues to publish its *FAS Public Interest Reports* under the caption "the voice of science on Capitol Hill" (*FAS*, 1964--). The *Newsletter on Science, Technology and Human Values*, produced under the auspices of the Harvard University Program on Science, Technology and Public Policy, provides reports of current developments in the interface between science and other parts of society and discussions of the moral implications of scientific and technological developments. This work is supported by a grant from the National Endowment for the Humanities. Such materials are important for teachers of social studies as they explore, with their students, the interrelationships between science, ethics, and social policy.

Closing the Communication Gap. The traditional time lag between discoveries in basic research and conversion of these discoveries into changes in production and practice is due in part to the lack of established communication channels between scientists and those who make decisions about policy and practice. The development of intermediate roles between those of basic scientists and those of "managers" and "consumers"--the roles of the applied scientist and the engineer--has already been noted. Efforts have been made by both governments and private corporations to develop systems which provide for continuing communication between occupants of these various roles (Havelock and Benne 1966; Havelock 1973).

One example of such an effort by government is the Agricultural Extension Service, which seeks to link basic agricultural research with the developmental work of agricultural experiment stations and, in turn, with farmers through the services of county extension agents. There is little doubt that the vast increases in agricultural productivity in the United States during the past few generations have been facilitated by the AES. Ideally, this system should provide for two-way communication between researchers and the consumers of the fruits, bitter or sweet, of research applications. Unfortunately, communication between researchers and producers has been more sustained and effective than communication between consumers and those who determine the focus and direction of agricultural research and development.

A comparable system for knowledge utilization under industrial control and supervision has been instituted by Bell Laboratories of the American Telephone and Telegraph Company. Described oversimply, the system provides for two-way communication between basic researchers and developmental engineers in Bell Laboratories, and, in turn, between the laboratories and the operating managers of telephone services. The system is supervised and managed by a linking agent in the form of a "systems engineer." This system has no doubt rationalized and regularized the adoption of knowledge-based innovations in telephone service. Again, the main difficulty has been a lack of an effective way of incorporating feedback about consumer needs and preferences into the production-oriented system.

3. METHODOLOGICAL CONSIDERATIONS

The Nature of Policy and Policymaking

When people in a situation are confronted with new alternatives to customary ways of doing things, ongoing action is blocked. A decision must be made before wholehearted action can be resumed. This decision may take the form of a choice from among various immediately envisioned courses of action. Or the decision may follow a process of deliberation in which new alternatives are invented and assessed and a synthesis of or compromise between apparently conflicting alternatives is created. If a group or organization is involved, subgroups of people normally support different alternatives. The process of deliberation then takes the form of negotiation between the various subgroups or their representatives in an effort to identify some plan of action which will elicit support and compliance across subgroup boundaries.

The need for decision is often precipitated by novel conditions that render established ways of acting unworkable or otherwise unsatisfactory. New potential benefits and/or threats lead people to seek new patterns of action. New scientific knowledge and technology often precipitate such decisions, requiring people to make choices unprecedented in contemporary society.

Because no two decision situations are exactly alike, the most appropriate decision will vary from situation to situation. However, it is equally true that, in an interdependent social system, similar decision situations confront people in various parts of society. People in Massachusetts will be affected by the way people in California decide to handle a given situation, and vice versa. In the interest of finding equitable and more or less coherent ways of handling similar situations across society, decisions at a more general level--decisions that prescribe ways of handling a "family" of situations--are often thought to be desirable. These general decisions are *policies.*

Ordinarily, policies do not dictate the same actions for all situations, whether by prohibition or by prescription; to do so would deny people the right and responsibility to shape decisions appropriately to situations that are unique in some respects. Wholesale policy *prohibitions* are usually made when some course of action is thought to be so prejudicial to the public welfare that it must be taken out of the range of individual choice--for example, trafficking in hard drugs or exposing other people to a dangerous contagious disease. Wholesale policy *prescriptions* are usually made when uniform behavior is thought to contribute significantly to public welfare--for example, driving on the right side of the road or stopping at red lights.

Most often, a policy leaves some leeway for variations in judgment and decision as to the best way to handle a particular situation. It then takes the form of a set of guidelines or limits. For example, before a nuclear power plant can be constructed in a given area, policy may require a study of the environmental impact of the proposed installation, may insist upon safeguards to the health and safety of workers in the plant and of people living in its vicinity, and may prescribe limits to permissible air and water pollution. Open public hearings may be required before final decisions on location and construction are made. The policy requirements must be considered along with the traditional economic components of industrial policymaking in our society--cost-benefit ratios, availability of funding, and estimates of profitability.

It is important that the intended outcome of a successful process of policymaking be kept in mind. The desired outcome is not new knowledge and information, as it is in the case of scientific problem solving--although, ideally, valid knowledge and information will be assembled and utilized in making the policy. Rather, the desired outcome is a workable and enforceable way of handling a given situation. The judgments that enter into a policy decision are pragmatic: they are value judgments about the best norms, procedures, and patterns of action. These judgments reflect social expectations about the "right" way of handling a practical situation of some specified kind, and the policies that result from them usually provide for sanctions against persons and groups whose actions do not comply with these expectations. The very stuff of such judgments is a set of "goods" and "bads," values and disvalues, which are at stake in the courses of action being considered. However, as will be made clear later, policy choices are seldom if ever choices between "good" values and "bad" values. Rather, they usually reflect decisions about how competing and conflicting "goods" can best be balanced and competing and conflicting "bads" can best be minimized or avoided. Since these various "goods" and "bads" are usually represented in the arena of policy deliberation by groups with differing and conflicting interests, policymaking often takes the form of reconciling the conflicting interests of the various groups. In this sense, policymaking is always a political process.

No distinction has so far been made between social policy and public policy. Very often in our society, policies take the form of legislation which purports to define the "public" interest in an area of action where competing and conflicting special interests are also involved. A law defines "public policy" in a general way. Those who are mandated to execute and enforce it usually flesh out the law through issuing a set of administrative guidelines which give operational meaning to the legislation. And the meaning of a "public policy" is further spelled out by judicial decisions concerning cases brought to court under the law. "Public policy" thus involves governmental actions, and these actions typically have legislative, executive, and judicial components. The participation of citizens in influencing public policy may focus on any or all of these components. Citizens may try to influence legislation. They may try to affect the administrative interpretations of the law by influencing those who are designated to execute and enforce it. And they may bring cases before the courts to test the fairness or constitutionality of a law or its administration.

"Social policy" has to do with the formation and articulation of public opinion concerning just ways of handling policy dilemmas which confront a society. It has to do with the definition of a common interest in handling and wisely controlling conflicting special interests with respect to a social issue. Sometimes social policy is strong enough to order and direct social practice without resort to legislation. For example, it is social policy in the United States to conduct schools in fall, winter, and spring with extended summer vacations. Compulsory-attendance laws usually prescribe a minimum number of school days without reference to the seasons in which attendance is required; it is unlegislated social policy which prescribes seasonal attendance.

Or, to take a science-impacted issue as an example, inoculation against polio waited for methods of effective prevention. When the Salk and Sabin vaccines were developed and tested, unwritten social policy motivated most parents to have their children inoculated. In many areas, legislation requiring compulsory vaccination was unnecessary. Whether fading public awareness of the horrors of polio will lead to universal laws compelling vaccination of all children is an open question. However, social policy, revivified through public education, may still be found preferable to prescriptive legislation as a means of controlling the problem.

Sometimes public policy, in the form of legislation, follows achievement of an agreed-upon social policy and is in effect a codification of it. At other times, public policy is one step in the formation and articulation of supporting social policy toward a new public consensus. Legislation may prove to be unenforceable when it runs counter to an articulated social policy, as witness the unsuccessful attempt of the U.S. government to prohibit the production and sale of alcoholic beverages.

In this monograph, we use the broader term, "social policy," in discussing education with respect to current social issues precipitated by scientific and technological breakthroughs. The formation and articulation of social policy is always basically a process of educating the public. However, we do not mean to deny the desirability--or, at times, the necessity--of legislating public policies to effectively resolve such issues.

We stated earlier that policy decisions are are seldom, if ever, simply choices between "good" and "bad." Rather, we pointed out that a policy is a decision based on trade-offs between competing or conflicting "goods." When different groups advocate conflicting "goods," the aim of policymaking is to merge conflicting interests into a commonly acceptable interest.

It may seem to some that "goods," or positive values, do not or cannot conflict. However, the fact that they are often in conflict is readily apparent if one imagines designing a tool--for example, let us say, a chain saw. One value which may be embodied in the design is durability. Another value is safety of operation. Still another value is light weight and easy handling. Yet another value is reasonable price. It is apparent that the value of durability and that of light weight and easy handling may be in conflict, because the most durable materials are likely to be heavier than would allow for easy handling. Wise designers would not try to maximize either value; rather, they would set standards of durability and weight which were compatible. Similarly, the value of safety and that of reasonable price may be in conflict. Again, the aim of designing is to reconcile these conflicting values by making some compatible and acceptable trade-off between the two.

The case is no different for policymakers. Policymakers who are concerned about making plans for controlling the construction and operation of nuclear power plants are likewise confronted with conflicting positive values. One such value is to utilize a fuel which does not further deplete our dwindling supplies of petroleum. Another value is the protection of workers and people who live near the plant from unhealthful levels of radiation. Still another value may have to do with the protection of marine life if water used in cooling the reactors is dumped into a river, ocean, or lake. Yet another value is ensuring the security of nuclear fuel from pilferage by terrorist groups. And still another value is production of electricity at a competitive price.

To try to completely eliminate even the possibility of radiation leakage or pilferage might run the costs of a plant so high that electricity could not be produced at a reasonable price. A cooling system that is completely devoid of danger to marine life might call for inordinate use of limited water supplies. Here again, the goal of policymaking is to find an acceptable balance between the competing values at stake in the policy decision.

Thomas Green formulated this central policy concept as "optimality," and defined it thus:

> By optimality, I mean to refer to the best composition of conflicting goods so that the optimization of the whole set may require something less than the maximization of each in order to get the greatest amount of them all in

> combination. The concept of "optimality" understood in this way is an interesting notion. There is a kind of duality in its logic that may well mark it off as unique. On the one hand it has to do always with what can be chosen. Therefore, it is always related to what is *possible*. "Optimal" means "feasible." But on the other hand, even etymologically, "optimality" relates to what is best. There is always that normative aspect to its logic. On the one hand, the concept of optimality deals always with what is possible; but, on the other hand, it touches on what is ideal, what is best. (Green 1978, pp. 3-4)

If Green is right, and we believe that he is, the aim of policymaking is to achieve an *optimal* resolution of a policy issue. But optimal resolutions cannot be reached without joint participation and deliberation by conflicting parties in a controverted situation. In one of the more comprehensive attempts to describe and analyze the process of policy deliberation for educators, the authors noted that participants in such deliberation must learn to function at least in three distinguishable moods (Raup, Benne, Smith, and Axtelle 1943 and 1963).

First, policymakers must function in the *optative* mood. This means that they must project into the future and invent alternative ways of handling the conflicting situation for which they are seeking an optimal resolution. What is required is a kind of practical utopian thinking--a spelling out of their action intentions and of their visions of what is best for their situation. Futurists of various sorts have emerged in recent years (Boulding 1973). The kind of futurist thinking we believe students should learn is not a value-free extrapolation of social or economic trends discernible in the present, but rather an exploration of values that they are willing to support in decisions about present and future issues. Such an exploration requires imposing personal or group priorities on various conflicting values. It is true that the help of experts will be needed in projecting the values and disvalues which will follow from various ways of utilizing available knowledge and technology. This process involves the construction of various scenarios illustrating the future effects of adopting various ways of using knowledge and technology. In a democracy, the choice between competing scenarios must be made by citizens, not delegated to experts. (Futurist thinking will be discussed further in the next section on teaching methodology.)

Policymakers must also function in the *indicative* mood. They must explore what actions are possible and feasible in any given situation. A policy which prescribes impossible or unfeasible actions is actually no policy but a utopian dream. The utopian thinking we suggested earlier must be *practical* utopian thinking: *optative* visions of the future must be tempered by *indicative* measures of what is possible and feasible at present. Citizens must depend upon experts for judgments about the possible and feasible uses of available scientific knowledge and technology.

Finally, policymakers must function in the *imperative* mood. They must choose from among alternative ways of acting which have been found to be both desirable and feasible, and actively support the chosen alternative. Making decisions is always risky, and risk cannot be eliminated from policy decisions. However, decisions may include provisions for evaluating the chosen policy as it is tried in action and a commitment to revise the policy in the light of these evaluations and of new knowledge and experience.

Several needs of citizens in policymaking have been identified. The first such need is for access to relevant expertise. In developing policies for managing social issues precipitated by innovations in science and technology, access to the expertise of scientists and engineers is essential, and the expertise of others--economists, lawyers, politicians--is also often necessary. Scientific and technological expertise is especially useful when citizens are functioning in the *indicative mood*--finding out what courses of action are possible and feasible.

Citizens may also need the help of experts as they think *optatively*--constructing scenarios of the future. (Actually, the invention of possible futures requires a type of imaginative thinking more often attributed to science-fiction writers than to scientists and engineers.) However, citizens should not delegate the invention of future scenarios to experts, since it is the clarification of their own values which is being achieved through optative thinking. And we must also caution against the delegation of final decisions (*imperative* thinking) to experts, since delegating this authority robs citizens of their rights and responsibilities in a democratic society. Of course, scientists and engineers should participate in making final decisions in their role as citizens.

The ability to think futuristically is an important aid to citizens in policymaking. Policy choices are sometimes made with little or no imaginative consideration of the consequences for the human beings who will be affected by them--their health, prosperity, even survival. The persons so affected may include not only those now alive but also those who have not yet been born. Choices made without such consideration run a good chance of being inhumane--even antihuman, in effect. Futuristic thinking should help citizens imagine and feel the human consequences of alternative ways of handling the powers inherent in science and technology.

A third aid to citizens in policymaking is the participation and counsel of relatively disinterested parties. People who have a strong partisan interest in the outcome of a policy decision often find it hard to understand the viewpoints of their opponents. Yet without some degree of communication and understanding between opposing groups in a policy conflict, an optimal resolution to the conflict is highly unlikely. The participation of disinterested persons can help bridge the differences between opposing groups and thus facilitate the creation and adoption of an optimal policy.

There are several important pitfalls in policymaking which citizen participants, young and old, should learn to avoid. One such pitfall is to view the policymaking situation as one in which conflicting persons and groups are trying to reach *a common belief about moral ultimates*. In a pluralistic society, groups differ concerning their basic moral commitments, whether these are defined in terms of religious affiliation or of political ideology. These differences in moral commitment persist throughout many policy conflicts and decisions. When the desired policy outcome is perceived as the adoption of a common belief, participants feel threatened by opposition and criticism and respond to each other defensively. Conversely, when the desired policy outcome is perceived as a decision about what to do in some specific controversial situation, the threat to group and personal security is reduced and the chance of open and constructive communication is enhanced. We do not mean to imply that moral beliefs do not affect a person's or group's stand on a policy issue--they often, perhaps always, do. We mean, rather, that if participants in policymaking can recognize and respect differences in each other's moral convictions and at the same time focus on practical and optimal ways of handling a conflict situation, the chances of achieving a rational policy outcome will be enhanced.

Another pitfall, closely related to the first described, is to polarize the policy conflict into a struggle between the "good guys" and the "bad guys" (the other side). In such a situation the focus of energy is on winning a game rather than on devising a solution that is possible and feasible, one which optimizes those values which best command the allegiance of all the parties involved. A policy conflict is always in some measure a power struggle. Opponents in a polarized situation are so wrapped up in the power aspects of the conflict that assessment of the merits and demerits of various proposals is neglected; exchanges between the conflicting parties is primarily directed toward enhancing the power of one's one group and weakening the power of the opposition. One effect of polarization in a conflict situation is that the potential contributions of disinterested persons in mediating the conflict are ignored.

When policymakers fall victim to one or both of the pitfalls already discussed, a third and deeper pitfall may emerge: the dehumanization of the policy conflict. The conflict then ceases to be a game of winning and losing and becomes a war to the death. Members of the conflicting groups cease to be human beings in the minds of their opponents; they become demons, undeserving of human rights. Their suppression, imprisonment--even death--come to be seen not only as beyond moral censure but actually as admirable and rightful. That all parties in such a struggle are dehumanized may not be apparent at the time. Those who point out and object to this dehumanization are seen as "the enemy" by partisans in the struggle.

This kind of dehumanization usually occurs in wars, but it is quite possible in "peacetime" situations as well. The persecution of witches in 17th-century Salem and the McCarthy "witch hunts" of the 20th century are dramatic examples from American history. No doubt thousands of examples of such dehumanization occur locally throughout the United States on a smaller scale, when the frustrations of unresolved policy conflicts are attributed to the existence of some visibly "different" group, and when it is falsely believed that the elimination of this group would bring relief from the pains of frustration.

The Holocaust in Nazi Germany, in which millions of Jews were exterminated in the horrifying hope of attaining an Aryan millenium, bears at least two important reminders for students of policymaking. The first is that people who are frustrated by unresolved policy issues can be led into deeply irrational and antihuman efforts to relieve their frustrations, and that none of us is immune to irrational behavior when the conditions are appropriate. The second is that such demonic movements can occur even in societies characterized by highly developed science and technology. Jews in Nazi concentration camps were exterminated by the use of advanced technological methods. They were used as subjects in scientific research. For Jews had ceased to be seen as human beings by their Nazi oppressors and by the functionaries who worked under the direction of these oppressors.

Methods of Teaching About Science and Social Policy

A discussion of teaching methods makes little sense without some attention to the learning outcomes which the methods are designed to produce. The authors have identified six general learning objectives in the study of science and social policy. More-specific objectives can (and should, of course) be derived from these in designing particular learning experiences.

1. Students should come to understand and appreciate that scientific and technological developments produce major effects in the lives of people--themselves and others. They should come to understand that these effects are both good and bad, and that social policies are required in order to optimize the uses and minimize the abuses of the power inherent in scientific and technological developments.

2. Students should come to understand and appreciate that citizen participation in policymaking is required if policies are to incorporate a common, public interest and are not to be overinfluenced by various special interests--among them the special interests of scientists and technologists--as policy conflicts are resolved. Students should come to recognize that, since scientific and technological research is supported largely by public funds, citizens have a valid claim to participation in decisions about how these funds are to be spent.

3. Students should come to understand the ways in which laymen are dependent on the knowledge and know-how of experts--scientists and engineers, among others--in making valid and workable policies. But students should also come to recognize that policies involve moral and value judgments about the best ways of controlling the human effects of science and technology. They should come to see that human value judgments cannot be properly delegated to experts but must instead be based on a wide sampling of citizen judgments.

4. Students should be encouraged to clarify their own values with respect to the social issues raised by scientific and technological breakthroughs. They should be encouraged to learn and use methods of clarifying their values anew as future scientific and technological developments

precipitate fresh social issues for public debate, discussion, and resolution.

5. Students should learn effective ways of translating their values into participative action. These ways involve such complex skills as (a) listening to and dealing with people who hold different and opposing views, (b) distinguishing between factual information and interpretations of information (this is especially important in using and learning from experts), (c) using the resources of experts without surrendering their own responsibility for choice, (d) effectively presenting their views in public debate and discussion in various media, (e) negotiating creatively with persons and groups with conflicting viewpoints, and (f) influencing decision makers, whether these be legislators, executives, administrators, or powerful citizens. Such skills can be learned only through experience in situations which require their practice and through reflection upon and evaluation of the meaning of such experience.

6. Students should develop commitments to exercise their rights and responsibilities as citizens through participation in developing social policies which affect the future quality of their own lives and the lives of other people. Many citizens are now blocked from participation, not only because they lack the understanding and skills outlined above but also by feelings of powerlessness and alienation, by lack of support from others in taking action, and by lack of available formats and forums for engaging in effective participation. Students will no doubt bring such feelings and doubts to the classroom. Part of the task of teachers is to help them air these feelings, to develop peer support for taking action as citizens, to discover available formats of citizen participation which are not being used fully or effectively, and to encourage students to invent, test, and evaluate new patterns and forums for citizen participation.

If these six learning objectives are accepted as desirable (the authors readily admit that they are debatable), we can appropriately consider methods for achieving them. However, we recognize that, as desirable as all of these learning objectives may seem in theory, attempts to achieve some of them may not be feasible in all school situations.

Some objectives may call for methods which teachers do not feel confident and comfortable about employing. In some cases communities, school systems, and schools may place limits on experimentation with novel methods of learning and teaching. Nevertheless, we believe that some of the learning objectives are achievable in nearly all school situations, and that some achievement is preferable to *no* teaching about science and social policy.

The discussion of methods in this section is general. Specific suggestions for teaching and learning are included in Part II of this monograph.

Objectives 1-3: Reading, Writing, and Debate

The first three learning objectives may, we believe, be attained by more or less traditional teaching methods or by modifications of these. The heart of traditional teaching methods is reading and discussion. Discussion, for the authors, means exchanges between students as well as interactions between teachers and students. Before assigning readings, the teacher should help the students realize how the issue to be studied presents itself in their own lives. If the issue to be studied has to do with the effects of electronic technology, for example, students might be asked to identify all of the ways in which electronic technology now enters into their lives--television, CB and other forms of radio, pocket calculators, digital clocks and watches, computers, etc. They might be asked to discuss what life would be like if this technology had never been invented, if the knowledge behind the technology had never been discovered. They could be asked to consider how life might be better or worse without these inventions.

The reading assigned should reflect varied and conflicting views about the issue being studied. Without varied and conflicting views, there is nothing "live" to discuss. Some students may find one view acceptable; other students may be attracted to a different view. Teachers should encourage such diversity of opinion because there is no one "right" answer to social issues which are still unsettled. However, teachers should expect students to learn to articulate the reasons and evidence which lead them to favor one view over another and to understand views opposed to their own.

Readings which show that experts disagree in their recommendations for resolving an issue provide opportunities for students to appreciate both the value and the limitations of expertise. They will find that there are some "facts" on which experts agree, but that differences arise in the interpretations of that information. Students will discover that these differences arise from the conflicting interests and value orientations of the various experts. In identifying these interests and value orientations, students may come to identify their own interests and values with respect the issue. At some point, the discussion should focus on how citizens--including the students themselves--might bring their own opinions to bear in resolving the issue, whether through voting for candidates with views similar to theirs, writing letters to their representatives in Congress or other public officials, participating in public hearings and demonstrations, or trying to educate others about the nature and importance of the issue.

Another traditional teaching method is that of assigning written reports to students. In writing reports, some students may be inclined to afford uncritical acceptance to statements made by prestigious experts, among them scientists and engineers. Other students may show the opposite behavior--they may reject the pronouncements of experts on principle and refuse to think about them seriously.

For some students, the very fact that people speak with the voice of authority automatically renders them suspect. By and large, however, the kind of automatic challenge to authority that was prevalent in the 1960s appears to have declined. What teachers are more likely to be faced with today is either total acceptance of expert opinion, numbness and apathy, or lack of trust in one's own judgment.

Thus, the kind of reports which we are suggesting should be assigned to students would focus on how the conventional wisdom of scientific experts has been overturned in the past. In each of the units developed in Part II, examples of these reversals of expert opinion are noted. Teachers and students can discover and pursue others. The object, of course, is to create a degree of skepticism about matters in which students obviously have little or no background. The attitude to be encouraged is a healthy skepticism toward statements made by experts. The danger, of course, is that such an attitude may lead to cynicism or encourage the automatic rejection of expert authority. Identifying the line between credulity and cynicism is a challenge to both teacher and students. If this balance is achieved, writing a report focused on the historic confounding of "scientific" predictions will be a healthy antidote to swallowing whole the opinions of experts.

One example of such a report might focus on the impact of nuclear power plants: Do they pose unacceptable hazards to present and future populations, or are they in fact safer than other kinds of energy sources? It is possible to quote eminent, respectable experts on both sides, with the result that the lay person is at times left breathless--looking back and forth between the pros and cons as if watching a tennis game. Yet, whatever conclusions may be drawn, it is clear that some assertions made shortly after nuclear energy was harnessed were later acknowledged to have been mistaken by nuclear scientists and engineers themselves. One important outcome of doing the research required to write such a report is that students will discover that even experts change their minds as they acquire new knowledge and insights.

Other report topics might be taken from the field of medicine. For example, the practice of performing cerebral lobotomies on seriously ill mental patients--once thought by many experts to be *the* answer--has been challenged and abandoned. Of course, this change in opinion was due in part to the development of psychotropic drugs which alleviate extreme anxiety or other symptoms of mental illness. Similarly, the history of the drug industry is replete with examples of "wonder" drugs which were produced, tested, and considered safe--but which eventually turned out to be cancer-producing or otherwise dangerous to the mental and physical health of persons ingesting them.

In writing reports about shifting fashions in expert recommendations, students should be encouraged to assume the honesty and good intentions of those who were later proved to be mistaken. This is essential, lest the students develop not only a chamber of "scientific" horrors but also a rogue's gallery of "evil scientists" who deliberately tried to mislead mankind.

Another teaching-learning paradigm in an adaption of the debate method, which almost all social studies classrooms have employed as a learning activity. In a typical debate, students bone up on the pros and cons of a given issue.

Obviously, the teaching suggestions in Part II allow plenty of room for taking pro and con positions, and it is often desirable to state these explicitly in order to bring into focus the issues involved. However, one of the goals of teaching these units is to raise questions about whether one or another extreme position, if adopted, would lead to desirable social or public policy. Thus we are suggesting a change in the traditional debate format. In our modification, the students in the class who are not assigned to "pro" and "con" teams are divided into three listening groups. One of these groups is told to identify with the "pro" position and another with the "cons." Each of these groups is instructed to listen to the arguments of its own side and judge whether these arguments are persuasive. Each group is also asked to consider what other arguments could have been utilized by the protagonist team to which it was assigned. The third group looks for a "middle" way--tries to decide which arguments on both sides make sense and whether it is possible to synthesize these arguments into a third, more acceptable, position.

The usual vote on who "won" the debate would not be functional in this activity. Instead, in a discussion following the debate, each of the reviewing groups reports its observations and conclusions. The two groups assigned to identify with the "pro" and "con" teams will note which arguments appeared to be overstated, understated, or omitted. The third listening group will report what integrative or compromise position, if any, they think may be more desirable than either extreme.

The learning goal here is obvious. In debates on public policy issues, a tendency toward polarization is inevitable. What we are trying to do is devise some means of inhibiting, or at least constraining, polarization. In this way the debate might encourage an attitude of critical detachment--obviously a requisite to making wise judgments about desirable social and public policies for controlling science and technology.

In advocating this classroom strategy, we want to point out that it is very unlikely that any student--or any teacher, for that matter--will be able to make a Solomon-like judgment that stills conflict once and for all. Each of the issues dealt with in Part II will generate partisan expressions from students in the course of discussion. Some issues will be more affect-laden than others. For example, discussion of the biological revolution, with its controversial implications in terms of abortion and genetic engineering, will at times provoke strong nonrational or irrational feelings which get in the way of an objective assessment of the pros and cons of the issue.

Objective 4: A Value Paradigm, Futures Invention

Achievement of the fourth objective requires less-traditional methods of teaching and learning. Traditional schooling did, of course, attempt to inculcate value orientations in students, and some of this inculcation took place through open exhortation and indoctrination. Probably more often, however, it took place incidentally and often preconsciously through the selection and slanting of cognitive materials in such subjects as history and economics and through institutional reward systems which encouraged some student behaviors, attitudes, and choices and discouraged others. Decisions about what values should be taught and learned were made by adults--most often by those in the teaching profession, less often by parents and other interested persons. Students played little conscious part in the identification and development of their own values.

As various groups in our pluralistic society have become more self-aware and vocally demanding, attempts by schools to inculcate certain values at the expense of others have come under increasing attack and criticism. This criticism has taken many forms--demands by blacks for the teaching of black history, demands by Christian fundamentalists for the teaching of biblical "theories" of creation in place of or along with theories of organic evolution, demands by patriotic organizations that the emphasis on internationalism in teaching social studies be reduced.

One possible response by school people to legitimate criticisms of this sort--a response which the authors regard as constructive--is to find ways of helping students to become aware of their own value orientations and to assume responsibility for the continuing development of their own value systems. The fourth objective--"Students should be encouraged to clarify their own values with respect to social issues raised by scientific and technological breakthroughs"--is in keeping with this educational response to the pluralism of group interests and value orientations in contemporary societies.

It is not easy for students or for anyone else to develop an awareness of the general beliefs that lie behind their specific choices and preferences. These views and beliefs are ordinarily assumed and taken for granted. Yet no one can become responsible for the continuing development of his or her views and beliefs unless these are lifted into consciousness.

There are several methods of value clarification now being employed in educational settings, and all have some merit. However, most of these have not been developed specifically to help students learn the discipline of responsible participation in policy decisions.

One paradigm which we recommend involves a value continuum with respect to social change. We have identified five value positions: 1B, no change; 2B, minimum change; 3, a middle position; 2C, moderate change; and 1C, maximum change. All five together make a continuum which can be utilized to help students choose those positions that best represent their own views. Of course, few of us have such well-articulated positions that we can comfortably situate ourselves at one or another point on the continuum. However, this difficulty can be used constructively to counteract the tendency of some students to automatically pick a position and then explain it by retroactively formulating an ad-hoc value orientation. Experience with the value contimuum may also be used to raise questions about whether most people really are fixed, or consistent, in their value orientations. (There are, of course, some ideologues so fixed in their positions that they might deny the existence of any real continuum.)

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No Change	Minimum Change	Minimum to Moderate Change	Moderate Change	Maximum Change
1B	2B	3	2C	1C

No Change (1B). A person who chooses this position might think about the social effects of science and technology in the following way: We have had more than enough change as a result of scientific and technological advances. It is difficult to see that people are any happier or better off than they were in the pre-industrial/scientific era. The multiplicity of personal amd family problems, many of which stem from social upheavals due to technological changes, could have been avoided if so-called progress had been averted or at least slowed down. Let us spend our tax dollars to reduce poverty, to ameliorate the conditions of our society's unfortunate. What is the value of scientific discoveries which prolong life when we thereby increase the burdens on the living? Why continue to support science and technology in destroying the life-support systems upon which human survival depends?

Minimum Change (2B). People in this position are willing to support a certain amount of scientific and technological change and experimentation. But they feel that society should be wary of encouraging such ventures as genetic engineering or behavior modification, because we do not know where these changes will take us--and the negative prospects are too frightening for us to take a chance. They believe that no scientific or technological advance which will open up radically new and only partly comprehensible frontiers should be supported by tax dollars. However, they are likely to support certain other scientific and technological research--for example, efforts to find and use renewable sources of energy in view of the disappearance of fossil fuel resources.

Middle Position (3). This position might appear to be a fence-sitting position, and to some degree it could be correctly characterized as such. People who choose this position seek to avoid either extreme, but they also hold some of the same views as people in positions B2 and C2. Thus, people in this position are eclectics; they base their opinions on the merits of specific issues and on the desire to avoid dangerous polarizations. One might see this position as a middle-of-the-road position which does not embody rigid ideological perspectives.

Moderate Change (2C). People in this position believe in the overall desirability of change, but they are reluctant to give a blank check to all scientific and technological proposals. Thus, they might support genetic engineering if it were regulated by policies providing safeguards against hazards to public health and potential birth defects, but they probably would resolutely oppose cloning and gene-recombining experiments. They would also tend to be guarded about further development of nuclear power.

Maximum Change (1D). People in this position are opposed to all restrictions on scientific and technological progress. They believe that the history of mankind proves that most of the world's population benefits from scientific advances. To inhibit these advances would be to restrict the possibility that all of the world's peoples could achieve or surpass the standards of living achieved by the Western nations. Even to suggest that scientific and technological progress should be controlled is perceived by many people in the Third World as a form of racism, or at least as discrimination against those who got a later start in the race than the older industrial societies. People who choose this value position sometimes feel uneasiness about eugenic proposals which might lead to the creation of subhuman, nonhuman, or partially human forms, believing that such developments might engender a new form of slavery. On the whole, however, they are convinced that it would do more harm than good to try to stop scientific experimentation and technological development. Moreover, they believe it is not possible to control all scientists and engineers. These people would advocate turning our efforts toward avoiding the untoward and unwelcome applications of scientific knowledge rather than toward restraining scientific and technological advances.

Teachers might use this value paradigm to encourage students to begin to *tentatively* align themselves with one position or another. Students should not be compelled to accept all five positions as tenable; rather, they should be encouraged to discuss and debate them--and, in so doing, to add further dimensions to these value positions, which are only sketchily developed here. Efforts should be made to prevent students from developing hard-and-fast commitments to the value positions they initially select. This paradigm may, of course, be used in studying any of the issues discussed in Part II to identify an optimal social policy for science. Remember that at some points along the way students should have an opportunity to review and revise their initially chosen value positions. The flexibility of the paradigm should be utilized to the fullest. Both students and teachers should begin to recognize the consistencies, inconsistencies, and contradictions in their own value positions. It is important to discourage students from developing value positions which are rigid or totalistic.

Another approach to value clarification is the method known as *futures invention*. Thinking in the optative mood, or prac al utopian thinking, was discussed earlier as part of the process of effective policymaking. Futures invention is designed to involve citizens, young and old, in thinking about the future they wish to bring into being (Ziegler 1977; Ziegler, Healy, and Ellsworth 1975). In futures invention people are asked to envision various aspects of a future society which they would find desirable. For example, they might envision how they would wish to see the resources of scientists and engineers employed in the year 2000. This sort of envisioning is first done individually. Then, as participants compare their various visions of the future, they begin to become aware of their own underlying preferences and value orientations.

The method of futures invention, as developed by Ziegler and Healy, was designed for use in developing "civic literacy" among adult citizens; thus the original version may need to be adapted somewhat for students. However, many of its components can be used appropriately in the classroom.

Students may be asked to think through the risks and benefits implicit in their visions of the future: What would be lost and what would be gained if their visions were to become real? What would they personally gain and lose? What would other people gain and lose?

Students could also be asked to write scenarios describing what might happen between now and the year 2000 to bring their visions into being. This activity could take the form of writing a "history" of the future from the standpoint of a historian in the year 2000.

Finally, they might be asked to think about what action steps, if any, they are prepared to take now to help transform their desired futures into reality. This step, of course, moves teaching and learning into the service of the sixth objective stated above--development of commitments to citizen particiaption.

The method of futures invention seems to the authors to be a viable strategy for encouraging students to become aware of and to assume responsibility for their own value orientations. This method is very much in keeping with the pluralism of contemporary society so long as the right of students to opt for differing viewpoints and preferences is respected. However, this method is more appropriate in teaching about some kinds of issues than others.

Objectives 5 and 6: Real and Simulated Practice

Achievement of the fifth objective--learning the skills required for citizen participation--depends on opportunities to practice these skills. The learning of a skill is facilitated if action is followed by analysis and evaluation, and analysis and evaluation are more fruitful in producing learning if they are informed by data fed back to the performer(s) by other participants and observers.

Skill practice can occur in real or simulated situations. Although students may occasionally have a chance to participate in real situations in which policymaking is actually under way, such opportunities are likely to be relatively few. Teachers can greatly extend the range and scope of skills practice by using simulations and role playing.

Before commenting further on the use of real and simulated practice in citizenship skills, it might be useful to provide a brief survey of the formats in which citizens can and do participate in influencing decisions on science-impacted social issues. The most familiar form of citizen participation is probably the act of voting; another common form is working on the campaign preceding an election. During the campaign, candidates may be questioned about their stands on various controversial issues and urged to give attention to neglected but important areas. More dramatically, though not necessarily more effectively, demonstrations are sometimes arranged in connection with the campaign appearances of candidates to draw attention to an issue with which the demonstrators are concerned. Often such demonstrations are directed as much to the eye of the TV camera (and thus to the eyes of the viewing public) as to the candidates.

Public policy is also affected by influences brought to bear on elected officials between campaigns. These formats of influence are, of course, extremely various. Members of Congress may be lobbied by special-interest groups. Messages may be directed to officials and/or to the public through letters to the editor, TV and radio public-affairs statements, and paid political advertising. Citizens may testify at public hearings conducted by legislative committees or by administrative or executive agencies. Officials may be lobbied by individual citizens or by delegations of citizens. Letters may be expanded into petitions with many signatures and directed to officials--legislative or administrative.

It will be recalled that public policy is usually embodied in legislation, in guidelines laid down by administrators charged with responsibility for executing and enforcing the law, and in judicial decisions about the interpretation of the legislation. Citizen influence may be brought to bear through any of these channels of policymaking and policy interpretation.

When our distinction between "social policy" and "public policy" is recalled, other avenues of citizen action become evident. Action by concerned citizens may be aimed at citizens other than public officials or candidates for public office. Such action may be addressed to the general public--to the raising of the level of public consciousness with respect to one issue or another. The possible formats for such efforts range from small discussion groups to large public meetings. Radio or television programs may be directed toward proposing alternative actions or propagandizing for certain desired solutions. The former approach often leads to more continuing involvement on the part of the audience than does the latter.

So far, this discussion of the available formats for citizen participation has depicted "government," in one or another of its various manifestations, as the ultimately effective agent in controlling and directing the uses of scientific and technological expertise. However, as we stated earlier, industrial corporations are also major employers of scientific and technological talent and subsidizers of programs of research and development. Can citizens influence the research-and-development policies of industrial corporations, apart from legislative or government regulation?

Citizens' influence on the policies of private corporations may be brought to bear through their roles of stockholders or consumers. Stockholders' meetings often produce nothing more than *pro forma* ratification of the policies recommended by company management. However, if enough stockholder opinion can be mobilized and organized, changes in company policy may be placed upon the agenda of such a meeting.

A hypothetical example may help to make this point clear: Suppose a large oil company is spending almost all of its research-and-development budget on the location of new sources of petroleum, the extraction of petroleum from oil shale deposits, and the liquefaction of coal. No significant research-and-development program focused on solar energy is under way. Stockholders who are committed to the wider development and use of renewable energy sources might question the present R&D policy and press for greater company investment in methods of generating and using solar energy.

Consumer influence on the R&D policies of an industrial corporation that depends on high-volume sales may be exerted by a boycott of that corporation's products until some more-optimal R&D policy ("optimal" from the consumers' viewpoint) comes into being.

The very briefness of this survey of the possible formats for citizen participation in influencing social and public policy illustrates how seldom these formats are utilized today by most citizens. One desirable outcome of the widespread study of science and social policy might be a wider awareness and use of these available avenues for citizen participation and a corresponding reduction of feelings of powerlessness on the part of citizens. Practice by students in using at least some of these formats might not only raise the level of their skills in citizen participation (Objective 5) but also lead to stronger commitments to become active in citizen participation (Objective 6).

We mentioned earlier that students can practice the skills of citizen participation in either real or simulated situations. Although the opportunity to practice in real situations is likely to be limited for practical reasons, there is no reason why students should not, if they choose to do so, translate the results of their hypothetical participation into recommendations to relevant policymakers and policy administrators and to the public. These recommendations might be articulated in letters to newspapers and responsible public officials, in speeches at community meetings, or in testimony at public hearings.

The range of possible simulated experiences in teaching and learning about citizen participation is much wider. Students and teachers can plan, carry out, and evaluate simulations of congressional hearings, stockholders' meetings, lobbying efforts, court trials, interviews with experts, and demonstrations. An individual student might play several different roles--for example, jury member, expert, member of Congress, and protester--in a series of such simulations. It should be recalled that learning the skills of citizen participation does not occur through one activity alone, no matter how exciting and involving that activity may be. Learning will be optimized only if each activity, simulated or real, is followed by feedback from fellow students and the teacher about the effects and effectiveness of whatever behavior was practiced. The goal of skill development is to bring about greater congruence between the intentions and the effects of action. Such congruence can be attained only through combining intentional activity with responsible reflection on its consequences.

Another use of role playing deserves special mention. This use is designed to convey some understanding of how persons on the "other side" view a controversial matter. It is not difficult to construct such role-playing situations. One way of doing so is to compile written statements representing various arguments on a given issue and ask each student to use them to debate whatever side is opposed to the one he or she tends to personally advocate.

The use of this method may lead to some ticklish situations. For example, if the issue is abortion, a student who is convinced that tampering with a fetus is sinful may be both unable and unwilling to argue for any other position. Or, if the issue under consideration involves a current political controversy, discussion may become so heated that public passions may need to cool before students can confront the issue in a dispassionate way. However, the practice of reversing roles in role playing is important in achieving not only specific learning goals, but also a broader objective: that of creating citizens who are able to look dispassionately at issues in which they have an interest and to consider these issues with an understanding of and a respect for opposing views.

In all activity-based learning, evaluation of how well the activity served its intended purpose is an inherent and important part of the learning process. Self-evaluation plays its part, as students assess the ways in which their present levels of knowledge and skill are effective and identify areas in which they need to become more effective. Feedback in the form of observations by other students and the teacher help to objectify each student's personal interpretations of successes and failures. This kind of evaluation is important in achieving the learning outcomes outlined in this section.

Some educators believe that methods of grading which involve ranking students by criteria which are unrelated to the purposeful activities in which they are engaged may thwart the kind of evaluation described above. These educators fear that students may become more concerned about guessing which thoughts, feelings, aspirations, and values the teacher considers worthy of an "A" or "B" than about expressing their own thoughts, feelings, aspirations, and values. Assuming responsibility for their choices and behavior is essential if students are to grow into responsible citizens. Perhaps unfortunately, however, teachers are often required to grade students in ways which rank them in terms of achievement.

While we can offer no formula for resolving the value conflicts related to the processes of grading students, we do know that it is important for teachers to recognize these conflicts and to deal with them responsibly. Whatever grading policies are adopted, the authors believe that teachers cannot evade responsibility for setting learning standards in the classroom. They must defend the right of students to choose their own viewpoints with respect to controverted innues, but they must also insist that students accept responsibility for making clear their reasoning processes and for supplying evidence in support of their chosen viewpoints. Finally, teachers must demand that students try to understand the reasoning and evidence behind opposing viewpoints. The authors believe that nearly all students will accept such standards as just, though they might need some help in setting and maintaining them.

II. SPECIFIC CURRICULUM AND TEACHING SUGGESTIONS

UNIT 1: INTRODUCTION TO LEARNING ABOUT SCIENCE AND SOCIAL POLICY

This second major part of this monograph contains suggestions for developing teaching/learning units around the social effects of breakthroughs in three areas of modern science and technology: nuclear energy, electronic technology, and genetic engineering. How the power inherent in technological developments in these fields is used and directed will have much to do with future patterns of living in out nation and in our world as well.

However, students will better appreciate the importance of developing wise social policies for controlling the uses of these specific technologies if they have first grappled with a set of more general questions. These questions are designed to help students perceive science and technology as dynamic elements in contemporary social change. As we emphasized in Part I, scientific and technological developments not only have revolutionized the conditions of contemporary living, they have precipitated many complex and controversial issues of social policy. Citizens must depend on scientific and technological expertise in resolving these issues, even as they make decisions about how this expertise can best be utilized, controlled, and limited. Before they can begin to consider policy issues associated with specific scientific and technological breakthroughs, students need to acquire a general understanding and appreciation of the relationships between science, technology, and society.

Some background for developing an understanding of the role of science and technology in contemporary society was presented in Section 2 of this monograph. How can teachers begin to involve students in the study of these issues?

In Section 3, some general methods for teaching about issues of science and social policy were suggested in connection with six suggested learning objectives. Three of the four units in Part II describe learning activities which we consider especially appropriate for specific issue areas. However, these suggested activities do not begin to exhaust the educational approaches which may be possible and useful in the study of science and social policy. We hope that teachers will adapt the activities in this monograph to fit their particular situations and go on to invent new and better activities. We also hope that, as students become involved in policy thinking about science and technology, they will be invited to participate in choosing and designing learning activities that fit their own concerns and interests.

The balance of this introductory unit in Part II is devoted to a description of teaching strategies designed to help students develop an an understanding of some general issues related to science and social policy. Because we expect that many teachers will not be using all of these units, there is some repetition in the strategies suggested. However, we believe that most of the strategies we have included are well suited to teaching about any or all of these issues.

Suggested Learning Activities

1. <u>Making an Inventory of Change</u>. Most Americans understand in a general way that many changes in our lives have come about as a result of the replacement of old technologies and the addition of radically new technologies. And they understand, perhaps more vaguely, that most major changes in technology are due to revolutionary additions to scientific knowledge. But it is probably true that relatively few Americans have systematically assessed the pervasive influence of scientific and technological developments in altering the conditions and patterns of human living. Nor have they considered what is good and bad about these changes or thought seriously about how the "goods" can be optimized and the "bads" minimized in the future.

A good way to begin involving students in such assessments is to engage them in making an inventory of recent changes in patterns of human living. Although some of these changes have occurred within their own life spans, many high school students tend to take them for granted. To get some perspective on these changes, students may enlist the help of two kinds of informants: (1) older people who have experienced several decades of adaptation to social changes and (2) persons whose vocational roles are heavily impacted by technology and science.

Older citizens may be invited to the classroom to be interviewed, or students may, after preparation, interview such people in their homes and bring their interview data back to the classroom for compilation and analysis. The interview subjects might be asked to respond to five questions: (1) What are the most dramatic changes which have occurred in patterns of human living in your lifetime?, (2) How, if at all, have these changes been influenced by the invention of new machines, appliances, ways of communication and transportation, drugs, materials, etc.?, (3) What do you consider bad and good about the changes that have taken place?, (4) How much control have you had over these changes in the patterns of your life?, and (5) If if were possible, would you prefer going back to conditions of life that were less dominated by technology? Or do you prefer living in today's world?

As students compile the data from these interviews and reflect on their meaning, they will begin to develop mental pictures of the human effects of technological innovations. They will learn which of these effects are judged to be bad and which are perceived as good by people who have experienced them, and they will get some idea of how much control citizens feel they have over changes in the patterns of their lives. In order to achieve a better awareness of the scientific developments that lie behind the technological innovations identified as influential by their informants, students might invite a science teacher into the classroom.

The second set of informants might include a doctor, a farmer, a factory executive, a labor-union leader, and a building contractor; the exact composition of the list would depend on the community in which the school is located. Like the older citizens, these informants might be invited to the classroom or interviewed at their places of work. Each of these informants might be asked to respond to the following questions: (1) What specific changes have technological innovations made in your work in recent years?, (2) Which of these changes do you believe to be good and which do you perceive as bad?, (3) How much control did you have over the introduction of these changes?, and (4) As you look ahead, which scientific and technological changes now on the horizon do you look forward to? Which ones disturb you, and why? As students compile and analyze the data from these interviews they will enhance their awareness of the effects, good and bad, of technological innovations from the viewpoint of producers of goods and services.

Such efforts by students will not ordinarily meet the requirements of social research with respect to sample size and construction, and students should be cautioned against overgeneralizing on the basis of their findings. Nevertheless, this kind of activity can be very useful in helping students understand the human effects of technology.

2. <u>Looking at the Future Through Science Fiction.</u> Students may be helped to take a "futuristic" look at science and society by reading a work of science fiction which pictures both changes in technology and changes in social patterns and organization. (See "Recommended Readings"

for this unit.) A science-fiction film might be used to kick off a discussion of the fictional future presented in the film. In what ways is this future desirable or undesirable? How plausible is it?

Each student might be asked to write an essay about what citizens of the society described in the science fiction might have done 50 years earlier to optimize the "goods" and minimize the "bads" depicted in the story. As students share their essays, they may begin with the help of the teacher to identify several possible scenarios for citizen participation in the control of science and technology.

3. Simulating a Trial of "Science" and "Technology." To dramatize the positive and negative effects of scientific and technological "progress," students might simulate a jury trial. In this trial, "Science" and "Technology" are the defendants, and the prosecutor represents the plaintiffs, the citizens of the United States. If the trial is to be a fruitful learning experience, several days should be allocated for casting and preparation, conducting the trial, and analyzing and evaluating the learning experience afterward.

The simulation will require students to be cast in a number of roles: the prosecuting attorney, two or more plaintiffs, the attorney for the defense of "Science," one or more "scientists," the attorney for the defense of "Technology," one or more "engineers," the judge, and the jury. (The purpose of trying "Science" and "Technology" separately is to clarify the distinctions between basic and applied science and engineering.) Although the parts may be assigned on a volunteer basis, the teacher should explain that students who volunteer to play the roles of the plaintiffs and their attorney should have some serious doubts about the human effects of modern science and technology. Similarly, the students who act the parts of the defendants and their attorney should believe that, on the whole, science and technology have had beneficial effects on society. The "judge" and "jury" should have genuinely open minds about the social costs and benefits of modern science and technology. If the value continuum with respect to science, technology, and social change presented in Section 3 has been used with the class prior to the mock trial, the value positions of many students will have already been identified.

Students may prepare for the trial in subgroups. The plaintiffs and their attorney will work up a case for the condemnation of "Science" and "Technology," formulating questions to be put to the defendants as they take the witness stand. The "Science" defendants and their attorney will work up their defense, trying to anticipate the questions that will be asked by the prosecuting attorney. The "Technology" defendants and their attorney will plan their defense. The jury and judge may try to list the good and bad effects of science and technology on people's lives, being careful not to make up their minds before the trial. The teacher should work with the judge beforehand on rules of procedure for the trial.

During the simulated trial, the plaintiffs and defendants will be questioned by attorneys, and the attorneys will then make their pleas to the jury. The judge will sum up the pros and cons of the case against Science and the case against Technology. After deliberation, the jury will render its verdict and the judge will pronounce sentence. (The authors predict that in most simulations, the jury will fail to reach a verdict--a result that probably reflects the actual case with U.S. citizens today.)

In the analysis and evaluation of the simulated trial, all participants should be encouraged to talk freely about what they learned through the experience.

4. <u>Assigning Priorities to Research and Development</u>. One of the issues presented by Brooks, as quoted in Section 2 of this monograph, has to do with the priorities which should guide the allocation of governmental subsidies to scientific and technological research and development. After describing the heavy concentration of government expenditures in efforts related to weapons research and development, Brooks pointed to other areas where research and development efforts are badly needed--"for the alleviation of poverty on a global basis, for better management and protection of the world's resources with minimum detriment to economic development, for the achievement of greater social justice, for the more reasonable allocation of the biosphere toward sustaining a decent human life for all people" (Brooks 1978).

Brooks's list of areas now neglected in government-subsidized programs of research and development, perhaps modified to fit the vocabulary of high school students, might be posted in the classroom along with a list of the kinds of research now heavily subsidized--for example, aerospace, health, military, and energy. Students discuss and debate which areas of research and development should receive the largest subsidies and which should receive little or no support. Each student should be encouraged to develop an individual ranking and to give reasons for his or her priorities. Students might also be asked to discuss how government priorities in employing scientific and engineering talent might be changed.

An alternative way of engaging students in serious deliberation about government priorities in subsidizing research and development would be to ask them to debate the following questions: "Should the federal government have spent billions of dollars in putting men on the moon? If not, what other programs of research and development should have been supported instead?" Students should be reminded that space research not only put men on the moon, it also yielded new knowledge about various kinds of non-space-related science and technology. The debate format described in Section 3 may be employed, with one group of students listening to the opposing arguments in an attempt to find ways of integrating and optimizing the pro and con positions.

Students should be encouraged, on a voluntary basis, to translate the results of their study of science and technology into social action. As we have already pointed out, such action may take many forms--letters to newspapers and to members of the Congress, speeches at school assembly programs, participation in public meetings or demonstrations. No student should ever be pressured to act against his or her own value orientation except in the make-believe of role-playing, and whatever value positions and actions emerge from these activities should be accepted and respected.

Recommended Readings

The following readings are recommended for teachers and students in addition to Section 2 of this monograph, parts of which may be duplicated for classroom use. (For information about locating or ordering publications with ED numbers, see page 129.)

Relationships Between Science, Technology, and Society

Bernal, J.D. *Science in History,* 4 vols. Cambridge, Mass.: Massachusetts Institute of Technology Press, 1965.

Bernal's work is different from most histories of science in that it emphasizes both the influence of social and political developments on science and technology and the influence of scientific and technological developments on the processes of social and political history. This scholarly work is written from a Marxist orientation. Volume 3, which deals with modern developments in science and technology, is especially recommended.

Znaniecki, Florian. *The Social Role of the Man of Knowledge.* New York: Columbia University Press, 1940.

Znaniecki offers a readable account of the different uses which various societies and their rulers have made of the expertise of men and women with special knowledge. His book puts into historical perspective the dependence of contemporary citizens and policymakers on the expertise of scientists and technologists.

Current Issues in Science Policy and Relations Between Scientists and the Public

"Science and the Public: The Changing Relationship." *Daedalus* 103, no. 3 (Summer 1974).

This issue of the journal of the American Academy of Arts and Sciences provides an assessment of the attitudes of the American public toward science and technology. In particular, "counterculture" and "established culture" positions toward science and technology, as these developed through the 1960s, are explored.

"Limits of Scientific Inquiry." *Daedalus* 107, no. 2 (Spring 1978).

This issue is devoted to a study of arguments about the adequacy of self-regulation by scientists and to an exploration of the possibilities for citizen participation in determining the directions of scientific research. Some authors distinguish sharply between social control of technology and social control of science.

Ethical Issues in the Utilization of Scientific Knowledge

Zaltman, Gerald, ed. *Processes and Phenomena of Social Change*. New York: John Wiley & Sons, 1973.

Especially recommended in this book is the chapter "Ethical Issues in Social Intervention" by Warwick and Kelman. These authors attempt to clarify the ethical issues involved in applying scientific knowledge and technological know-how in such areas as the control of population growth.

Newsletter on Science, Technology and Human Values.

This periodical, published four times a year, is recommended to teachers as a continuing source of materials on the value and policy questions raised by current developments in science and technology. Useful listings of new publications are also included. To order one or more copies, write to Aikman Computation Laboratory 232, Harvard University, Cambridge, Mass. 02138.

Futuristics in Teaching and Learning About Science and Social Policy

Futuristics: Secondary Education 11M Social Studies. Honolulu: Office of Instructional Services, Hawaii Department of Education, 1971. ED 054 001.

This publication offers a series of simply written essays on ways in which the future of mankind may be affected by developments in science and technology. The authors outline the choices now confronting men and women as they face the prospect of living in a radically changing social and physical environment. Suggestions for classroom use of the readings are included.

Hollister, Bernard C., and Deane C. Thompson. *Grokking the Future: Science Fiction in the Classroom*. Dayton, Ohio: Pflaum/Standard, 1973. ED 084 554.

This sprightly book was written with two objectives in mind: to demonstrate how science fiction can be used to generate new insights into current social issues and to help students become more creative in their thinking about the future. Among the books discussed which seem especially useful for this unit are two classical novels, Edward Bellamy's *Looking Backward* (Hendricks House, 1946) and Samuel Butler's *Erewhon* (Penguin, 1974), and two contemporary novels, Isaac Asimov's *The Caves of Steel* (Fawcett, 1976) and Frederik Pohl's *The Best of C.M. Kornbluth* (Ballantine, 1977).

UNIT 2: THE PAST, PRESENT, AND FUTURE OF NUCLEAR ENERGY

Scientific Background

The scientific observations which led eventually to the release of the vast energies bound up within the atoms of material substances occurred within the lifetimes of men and women alive today. In 1895 Wilhelm Roentgen, a German physicist, produced and identified the X ray, a penetrating form of radiation with a wave length much shorter than that of light rays. In the following year Henri Becquerel, a French physicist, wondered whether there were not X rays as well as light rays in the radiation given off by fluorescent substances--substances which emit radiation after exposure to sunlight. To his surprise, he found that a uranium compound gave off radiation constantly even when it had not been exposed to the light of the sun.

Marie Curie, a Polish-French scientist, discovered that most compounds of uranium and those of another heavy metal, thorium, give off radiation ceaselessly; she called this phenomenon *radioactivity*. For our purpose, the most significant characteristic of natural radioactivity is that it involves the disintegration of atoms--elementary particles which once were thought to be indivisible and lacking in internal structure. This process of disintegration, it was found, involves three types of radiation: alpha particles, which are high-speed ionized helium atoms; beta particles, which are high-speed electrons; and gamma rays, a form of electromagnetic radiation similar to X rays.

In addition to the disintegration of atoms, natural radioactivity involves the transmutation of one chemical element into another element, a change which is accompanied by the release of radiant energy. Such transmutation of elements had been one of the dreams of the early alchemists, who had tried to transmute base metals, such as lead, into expensive and highly valued elements. The methods of the alchemists were magical, verbal, and unsuccessful--very different from the methods of today's scientists, who depend on experimental manipulation and detailed and refined observations and measurements. It was the scientists who mapped the radioactive series for the transmutation of such unstable elements as uranium and thorium through various intermediate products to a stable element, lead. Scientists have also measured the *half-life* of each radioactive element--the time required for half of its atoms to disintegrate. These half-lives vary from 4.5 billion years to a fraction of a second. Knowledge about the half-lives of radioactive elements has made it possible to estimate more closely the ages of Earth and various kinds of geological phenomena. The fact that some radioactive elements have very long half-lives has created some vexing practical problems related to the disposal of various kinds of radioactive wastes.

As American and European physicists bombarded various substances with the emanations from natural radioactivity and observed the disintegration products released by the bombardments, they discovered that atoms embody two distinguishable components. One part is very difficult for neutrons to penetrate. This part is very small compared to the total volume of the atom; it is positively charged; and it accounts for nearly all of the mass of the atom. This part is called the *nucleus* of the atom. The outer part of the atom, which is much larger but which has a much lower mass, is filled with orbiting electrons, the arrangement of which can be mapped.

In 1919 Ernest Rutherford, a physicist who worked in England and Canada, produced the first artificial nuclear disintegration by bombarding nitrogen with alpha particles to produce oxygen and protons (the nuclei of hydrogen). Similar experiments produced a new radiation first thought to be a gamma ray but later (in 1932) identified by Sir James Chadwick as a neutron--an uncharged particle with the mass of a proton.

The discovery that radioactivity could be artificially induced paved the way for a new science--nuclear physics--within the older disciplines of physics and physical chemistry. This new science was international in scope, as the names of a few of its pioneers attest, and it developed through the free exchange of findings, ideas, and theories across national boundaries. Before the rise of Nazism in Germany and the outbreak of World War II, the notions that mass could be converted into energy and that vast amounts of potential energy were bound up in the nuclei of atoms were generally accepted by scientists.

One of the authors of this monograph recalls that, when he taught high school chemistry in the early 1930s, he and his students calculated how many times the potential nuclear energy in a glass of water, if it could be released in a usable way, could drive the *Queen Mary* back and forth across the Atlantic between Southhampton and New York. The formula for this calculation came from Albert Einstein's famous theory of relativity. This theory was based on a formula representing the relationship between mass and energy: $E = MC^2$. In this formula, "E" represents energy (in ergs), "M" represents mass (in grams), and "C" stands for the speed of light (in centimeters per second). When the energy that could be released by one gram of uranium (if it were to break down completely in its radioactive decay to lead) is compared to the energy released by burning one gram of gasoline, the energy yielded by uranium is found to be 420,000 times as great.

Although nuclear physicists knew as early as 1939 that nuclear fission could produce energy in vast quantities, they knew of no practical way of tapping this source of energy. In fact, Rutherford, one of the great pioneers of nuclear science, once stated that the practical exploitation and use of nuclear energy was an idle dream. Rutherford died in 1937.

During World War II practical political needs, especially military needs, contributed greatly to the acceleration of developments in nuclear science and engineering in the United States.

Leo Szilard was a nuclear physicist, born in Hungary, who had come to America as a refugee from Nazism. Along with two other Hungarian-born physicists, Edward Teller and Eugene Wigner, Szilard attempted to persuade President Franklin D. Roosevelt and his advisers to invest in the development of a bomb based on nuclear *fission*--the splitting of an atomic nucleus.

These nuclear scientists were motivated to promote American development of a fission bomb by the not-unjustified fear that German scientists were working on developing a nuclear device for use by the Nazis. Knowing the destructive capability of such a device, they were afraid that such an achievement might convert Adolf Hitler's dream of world domination into a horrifying reality.

Albert Einstein, though he was reluctant to do so because of his pacifism, lent his great prestige to the project by writing a letter of recommendation to the president. The efforts of Szilard and his colleagues were successful: President Roosevelt signed the executive order launching the Manhattan Project on December 6, 1941, the day before the Japanese attack on Pearl Harbor.

The full story of the monumental efforts by nuclear scientists, engineers, and technicians to overcome the practical difficulties which Rutherford had thought to be insuperable cannot be told in a few pages. However, a few highlights of this effort are worth noting, since they have some bearing on still-unsolved social issues surrounding nuclear energy.

By the summer of 1941 it was known that the nuclei of one isotope of uranium, U235, were more fissionable than those of the more abundant isotope U238. (*Isotopes* are variant forms of an element with the same atomic number, representing the positive charge in the nucleus, but with different atomic weights. For example, the uranium isotope U235 has an atomic weight of 235; U238 has an atomic weight of 238. Both have an atomic number of 92.) It was also known that bombardment of U238 with neutrons produced a new element with an atomic number of 94 and a mass of 239. This new element, plutonium, behaved much like U235 in its fission properties.

Since both U235 and plutonium were considered capable of producing fission bombs, the Manhattan Project had two major goals in addition to the manufacture of the bomb itself: separating out the more-fissionable U235 and concentrating it in an enriched-uranium fuel.

The fission process is essentially a chain reaction: the neutrons released by the splitting of a few uranium atoms go on to split still more uranium atoms in a continuous and self-sustaining spiral of nuclear disintegration and energy release. Because of the presence of U238, plutonium is created as a by-product. In order to prevent an explosion, this chain reaction had to be controlled.

The first self-sustaining chain reaction was achieved under the football stadium of the University of Chicago in early December of 1942 in a so-called atomic pile weighing 1,400 tons, of which 52 tons were uranium. This atomic pile consisted of layers of uranium, uranium oxide, and graphite. The reaction was controlled by inserting rods of cadmium through holes in the walls of the reactor. (Cadmium is a metal that has the capacity to absorb large numbers of neutrons.) This first nuclear reactor was constructed under the supervision of Enrico Fermi, a nuclear scientist in exile from fascist Italy.

Meanwhile, the practical difficulties involved in encasing and delivering the nuclear bomb were being overcome. By 1945, sufficient uranium isotopes and plutonium had been produced to construct three fission bombs. On July 16 of that year, a plutonium bomb was exploded in a New Mexico test. On August 6, a uranium bomb was detonated by the U.S. Air Force over the Japanese city of Hiroshima, and on August 9 a second plutonium bomb was detonated over Nagasaki.

With these events, the inhabitants of Earth moved into a new period of history. The awesome effects of these bombs--and of the much-more-powerful bombs which have since been developed--have graphically demonstrated that man now possesses the scientific knowledge and technological know-how to destroy all forms of life as we know it. The destructive potential of such bombs is not due entirely nor even primarily to the shock and fire storm produced by the initial explosion; more insidious are the effects of the lingering radiation produced. The long-range effects of heightened levels of radiation are thought to cause not only cancer but also genetic mutations which could conceivably make monsters of the offspring of humans and other species. John Hersey's book *Hiroshima* (1946) provides eloquent documentation of the human effects of the nuclear explosion over that ill-fated city.

An even greater release of nuclear energy can be produced by the fusion of lighter atoms into heavier atoms (for example, hydrogen into helium). This *fusion* process is the source of the sun's energy. In spite of the opposition of many scientists the U.S. Atomic Energy Commission authorized work on such a thermonuclear device, and in 1952 the first H-bomb was exploded near the Marshall Islands. This bomb had the force of 50 million tons of TNT, whereas the force of the fission bomb that was exploded over Hiroshima was equivalent to that of 20,000 tons of TNT. At present, nuclear fusion has only military significance. Efforts to harness its energy for peacetime uses have so far been unsuccessful.

A Risk/Benefit Analysis of Nuclear Energy

The risks and benefits of nuclear energy can be dealt with most intelligently if the discussion is divided between military uses and peacetime uses, difficult as it may be to make and maintain this distinction.

Military Uses

The military advantages which possession of nuclear bombs gave to the United States vis-à-vis other nations was short-lived. Within the decade following Hiroshima, the Soviet Union had built and tested both fission bombs and fusion H-bombs. Fission bombs are now in the arsenals of Great Britain, France, India, and the People's Republic of China. The basic science on which nuclear weaponry is based is known to scientists in all nations. Only technological and financial difficulties stand in the way of any nation--or any terrorist group--that wishes to manufacture a nuclear bomb.

The use of some weapons is inhibited when military leaders recognize that their destructive effects will not be limited to the people and property of "the enemy" but are almost certain to backfire, visiting destruction upon one's own people and property as well. Such is the case with nuclear bombs. No nation can "win" a nuclear war. All nations would lose in such a conflict. At stake in any large-scale nuclear war is the very survival of people on Earth. Both the United States and the Soviet Union now have more than enough nuclear devices stockpiled to annihilate each other many times over, and it is doubtful that the peoples of neutral nations could survive the radiation effects of a nuclear war. Each major power has lavished billions of dollars (or rubles) on the development of systems for delivering nuclear warheads to the population and industrial centers of t[illegible] ther. No fail-safe detection and defense systems against nuclear attack have been developed, and perhaps such systems will never be feasible. So our primary "protection" depends on an ominous balance of terror.

Some policymakers in America argue today that nuclear weapons research and development should continue, so that the balance of terror is not tipped to the other side's advantage. And no doubt some policymakers in the U.S.S.R. make the same argument.

Other policymakers believe that there is no safety or security for mankind in the present balance of terror. They fear that the very existence of a nuclear arsenal puts mankind in jeopardy because of the always-present danger that an accidental or impulsive action by a single individual could unleash a nuclear war. They believe that the safety and security of mankind can only be achieved through the total dismantling of nuclear weaponry by all nations and an international pact to forswear the development and use of such weaponry in the future.

Still other policymakers advocate compromise solutions: international agreements to ban further proliferation of nuclear weaponry, treaties limiting the number and destructive capabilities of the nuclear weapons possessed by any one nation, agreements that would limit the range of delivery systems.

It is generally agreed that effective control of nuclear weaponry awaits the development of more open, trustful, and cooperative relations between nations. Some people believe that working to improve international relations is the most realistic approach to abolishing the threat of nuclear extinction.

It is probably fair to say that it is impossible to do a risk/benefit analysis of nuclear weaponry. Its negative effects are so inimical to human good that the only effective control of its production and use is prohibition. However, since nuclear military capabilities are now possessed by several nations, any effective system of prohibition must be international in character. Rational men and women all over the world may wish that the genie of nuclear weaponry had never been let out of its bottle. But this is an idle wish: the genie is among us. The different strategies sketched above represent varying views of how modern man can best cope with an ominous reality.

Peacetime Uses

When the issue is the development of nonmilitary applications of nuclear energy, risk/benefit analysis becomes possible. Perhaps the best known--and most controversial--of these applications is the nuclear reactor which produces electrical power for commercial use. However, there are other uses and benefits of nuclear energy that are not so widely known.[49]

The use of knowledge about the half-lives of radioactive isotopes in dating past events has already been mentioned. Tracer elements, like radioactive carbon, when compounded into organic molecules, enable scientists to better understand such physiologic processes as the assimilation and metabolism of fats. Nuclear power has been used to drive ships and submarines. Radioactive cobalt has been used in the treatment of cancer. The irradiation of foods can contribute to their preservation.

The growing reliance on nuclear reactors as an important component of our national energy system is due in part to the failure of our supplies of petroleum and natural gas to meet ever-rising demands for energy. The fact that we are rapidly using up our limited deposits of fossil fuel compounds the need to develop alternative sources of energy. Electricity produced by nuclear power plants now flows into homes and industries throughout our country. This is an undoubted benefit. However, proposals to build more nuclear reactors to meet a greater percentage of our energy needs have stimulated public concern about their actual and alleged dangers to the safety and health of both people who work with the reactors and people who live in the vicinity. One such danger would be that a malfunction in the reactor or in its cooling system might release radioactive materials to the environment. Another risk often cited by those opposed to nuclear power is that such materials as plutonium and enriched uranium might fall into the hands of criminals and political terrorists who could conceivably use them to manufacture weapons.

One source of opposition to the expanded use of nuclear energy comes from persons who are committed to achieving a more "natural," less "artifactual" way of life. These people urge that we channel our research efforts into the development of naturally renewable sources of energy--water and wind power, geothermal power, and solar power. (Such sources of energy are "renewable" in the sense that they draw upon continuing natural phenomena--falling water, blowing wind, steam from beneath the earth's crust, and the radiation of the sun.)

Those who support the construction and use of new nuclear generators point to the encouraging safety records of nuclear reactors already constructed and in operation. They are convinced of the adequacy of the standards of safety and security established by the Nuclear Regulatory Commission and of the provisions for maintaining and enforcing these standards. Nuclear proponents argue that society needs to find and use sources of energy to replace our dwindling supplies of petroleum, natural gas, and fossil fuels, and they doubt that solar power and wind power will ever be realistic alternatives.

The adequacy of existing standards for permissible radiation levels, from a public health point of view, is still in dispute. Scientists, laymen, and various government agencies are in disagreement on this issue. Other unresolved questions are related to the disposal, transportation, storage, and decontamination of the radioactive wastes produced by the operation of nuclear reactors. Since such materials will remain dangerous to living organisms for many thousands of years, selecting the best plan from among the various strategies that have been proposed is a critically important policy decision.

The future of nuclear energy in the United States is dependent in large part on decisions about how our energy research-and-development dollars should be allocated. Every citizen has a legitimate stake in these decisions.

Suggested Learning Activities

Military Uses

The authors believe that citizens need to be reminded of the human effects of nuclear explosions, even though we have a natural tendency to avoid thinking of these effects because of their gruesomeness. If citizens are not reminded of the awful consequences of the use of nuclear weapons, they may cease to work toward ensuring that such weapons will never again be used against human beings, as they were in Japan.

1. Role-Playing a Survivor. To better appreciate the personal impact of a nuclear explosion, students might be asked, after reading Hersey's *Hiroshima* or other accounts of the bombing of that city in 1945, to imagine that they are survivors of a nuclear attack. In that role, they might be asked to write letters to officials of the country that had launched the attack, describing their thoughts and feelings. These letters might then be shared and discussed with other members of the class.

2. Debating the Past. On a more-cognitive level, students might organize a debate, using the modified paradigm of debate described in Section 3, on the following question: "Should the United States have dropped nuclear bombs on Hiroshima and Nagasaki in 1945?"

3. Debating the Future. To turn their thinking toward future arms policy, students might debate the following question, again using the policy-oriented format for debate: "Should the United States take the lead in forswearing use of nuclear weaponry and in dismantling her nuclear arsenal?" After the debate, students might be encouraged to write a letter to the president stating their opinions. (This should be a voluntary activity.)

Peacetime Uses

4. Reporting Personal Concerns. To personalize the health and safety issues involved in the building and use of nuclear reactors, after hearing and discussing some of the pros and cons students, either indi-

vidually or in small groups, might be asked to write reports representing their responses to one or both of the following questions:

a. If you were offered a good job in an electric generating plant using nuclear reactors, what would you think about in deciding whether to accept it? How would you probably decide now? Why?

b. If you were asked to join a peaceful demonstration against the building of a nuclear-generating plant in your locality, what would you think about in deciding whether to participate? How would you probably decide now? Why?

If available, "experts" with definite pro and con views about the expanded use of nuclear energy might be invited to the classroom to comment on the student reports as these are discussed by the class. Or students might interview such experts prior to completing their reports.

5. Applying a Value Continuum. The value contimuum presented in Section 3 may be applied specifically to the issue of nuclear energy. An extreme negative position might be to ban all research and development in the nuclear field. A less-extreme negative position might be to ban all research and development work on nuclear weaponry and nuclear power generation but to permit strictly controlled research on radioactive isotopes and other nuclear aids to medical diagnosis and treatment. A moderate position might be to ban or limit research on nuclear weaponry but support research and development on peacetime uses of nuclear energy under adequate safety controls. An extreme positive position might be to support unfettered research and development on nuclear science and technology, provided that reasonable safety precautions are observed. This continuum can be used to help students locate their initial value orientations with respect to the further development of nuclear science and technology.

6. Sizing up the "Experts". Ernest Rutherford, one of the pioneers in nuclear science, predicted less than 50 years ago that the energy bound up in atoms would never be released for practical use. Of course, this prediction was disconfirmed by the Manhattan Project and its aftermath.

After Hiroshima the mass media were flooded with predictions, both optimistic and pessimistic, about the future of nuclear energy. Students might be asked to study newspaper files and popular magazines published between 1946 and 1950 to collect "expert" predictions about the uses of nuclear energy and to report to the class on which ones have been confirmed or disconfirmed by subsequent events. (The aim of this activity is, of course, to encourage a healthy skepticism about the pronouncements of experts.)

7. Creating Scenarios of the Future. Discussions about whether or not to expand the peacetime uses of nuclear energy often become intertwined with another far-reaching policy issue: growth versus no-growth. This issue is also related to the value orientations toward human dependence on science and technology described in Section 3.

Those who wish to reduce our dependence on science and technology often oppose the expanded use of nuclear technology as well. Accepting a *no-growth* orientation toward economic production, they are willing to accept a less-affluent standard of living which would mean not only less money with which to buy artifacts and gadgets but also less involvement in the competitive struggle for income and affluence.

Those who perceive improved and expanded uses of science and technology as leading to a way out of poverty and drudgery for poor people, both in technologically underdeveloped countries and in our nation, often favor a *pro-growth* orientation. Thus, many black leaders and labor leaders in our nation and many political leaders in underdeveloped countries favor the expanded use of nuclear energy. These people tend to see those who advocate a no-growth orientation and who put "environmental quality" above "expanded production" as trying to maintain the present inequitable distribution of wealth and power.

Students might be asked to imagine two scenarios for the future: one scenario would involve dramatically expanded uses of nuclear energy; the other would prohibit the use of nuclear fuel. In each case, students should consider who would lose and who would gain--jobs, income, health, safety, a livable environment, a satisfying way of life. As these scenarios are developed and discussed, students might be asked to think about how, if at all, their attitudes toward peacetime uses of nuclear energy have been changed.

8. Debating Our Energy Priorities. Many controversies related to nuclear energy involve different views about how government dollars for energy research and development should be allocated. Often, such arguments are focused on the relative emphasis that should be placed on renewable and nonrenewable sources of energy. Clearly, nuclear energy is a nonrenewable source because supplies of uranium are limited. (The case might be different if fusion reactors are ever developed, since "heavy water" is relatively abundant.) On the other hand, energy generated from wood and cellulose (as in alcohol fuels), from wind and tides and falling water, and from trapped sunlight is renewable.

Students might be asked to organize a policy-oriented debate around pros and cons of future dependence on nuclear energy as opposed to renewable energy sources. This debate should include attention to current priorities in our national energy research-and-development policies. Students need access to conflicting "expert" opinions about the feasibility of depending primarily on renewable sources of energy. These conflicting opinions might be made available through readings, through assigning students to interview advocates of various positions, or through inviting experts into the classroom.

At the conclusion of this study, some students might want to write to their congressmen or senators about desirable directions for a national energy policy.

Recommended Readings

In addition to the first two sections of this unit, which may be duplicated for classroom use, the following readings are recommended. (For information about locating or ordering documents with ED numbers, see page 129.)

Scientific Background

Armstrong, David. "Thermal Pollution: Background Material for a Mock Trial." *Environmental Law Reporter*, February 1977, pp. 27-30.

> The author of this article has adapted an actual New Jersey court case for instructional use. (The plaintiff is the state Department of Environmental Protection; the defendant is the Jersey Central Power and Light Company. The heated water from a nuclear power plant has killed about a half-million menhaden, a commercially important fish.) Briefings for the students who will play the roles of plaintiff and defendant are included.

Asimov, Isaac. *Understanding Physics*. Vol. 3, *The Electron, the Proton and the Neutron*. New York: New American Library, 1966.

> This is a readable account, written for intelligent laymen, of investigations into atomic structure and their principal findings. Teachers and advanced students will be able to read this material easily, and average students should be able to handle the section dealing with the release of nuclear energy.

Controversies Related to the Development of Nuclear Power

Commoner, Barry. *The Closing Circle: Nature, Man and Technology*. New York: Knopf, 1971.

> Commoner offers an excellent discussion of the impact of modern technology on the environment of human beings and other living things. While the whole range of technology is dealt with, the author gives special attention to the effects of nuclear energy on the environment. This book can be read with understanding by nearly all high school students.

The Environmental and Ecological Forum, 1970-71. Washington, D.C.: U.S. Atomic Energy Commission, n.d. ED 070 649.

> This publication contains 12 papers on the environmental effects of the nuclear generation of electricity. The focus of most papers is on the radiation effects. Order from the National

Technical Information Service, U.S. Department of Commerce, Springfield, Va. 22151 (publication no. TID 25857; $3.00).

McDermott, John, ed. *The Environmental Impact of Electrical Power Generation: A Mini-course for Secondary Schools and Adult Education.* Harrisburg, Pa.: Pennsylvania Department of Education, 1973. ED 099 200.

These materials, prepared by an interdisciplinary group of educators, physicists, and environmental scientists, analyze the risks and benefits of several forms of energy production in a format that can be used for both science and social studies instruction. A glossary of terms is included.

Tanner, Thomas. "Teaching About the Nuclear Power Controversy by Simulation." *Social Education,* November/December 1976, pp. 588-89.

This article describes a simulation by high school students of a congressional hearing on the budget for the federal Energy Research and Development Administration (now the U.S. Department of Energy), during which decisions are being made about allocation of funds to the development of nuclear and other forms of energy. The article contains good references to arguments supporting and opposing nuclear energy alternatives--solar, geothermal, and wind.

The Human Effects of Nuclear Warfare

John Hersey's *Hiroshima* (New York: Knopf, 1946) has already been recommended for "humanizing" the tragic experience at Hiroshima in Japan. Other useful materials which can be used to stimulate student appreciation of the effects of nuclear warfare are R.J. Lifton's *Death in Life* (Simon and Schuster, Touchstone Books, 1976), Michihiko Hachiya's *Hiroshima Diary* (University of North Carolina Press, 1955), and Jonathan Harris's *Hiroshima: A Study in Science, Politics and the Ethics of War* (Addison-Wesley, 1970).

UNIT 3: ELECTRONIC TECHNOLOGY AND THE "INFORMATION REVOLUTION"

Scientific Background

Some commentators on modern life believe that the most basic changes resulting from recent scientific and technological advances are due, not to the release of nuclear energy or to breakthroughs in engineering, but rather to developments in electronic technology. We now find ourselves immersed in an ongoing "information revolution," and we are only beginning to learn how to swim.

It is impossible to deny that ways of collecting, storing, retrieving, processing, and transmitting information have undergone drastic changes during the past generation or so. Microphones and tape recorders, radio and television, photoelectric cells and electronically programmed microwave ovens, communication satellites and computers--the mention of any of these reminds us of the revolutionary changes which electronic technology has brought to our private and public lives. And such developments continue. "New" artifacts become obsolete in a few short years--FM radio supersedes AM radio, color supersedes black-and-white television, tape cartridges supersede phonograph records, faster and smaller computers with more-capacious memories supersede models which were billed as "advanced" only a few years ago.

Whatever developments on the "software" side have contributed to the "information revolution" (to borrow from computer jargon), advances on the "hardware" side are rooted in discoveries in the science and technology of electronics. The study of electronics is, of course, a part of the larger field of electrical studies. In the unit on nuclear energy we explained that the atoms of all elementary substances, in addition to their relatively massive positive nuclei, contain outer shells of orbiting electrons--tiny, negatively charged particles. Electrical phenomena involve the movement of electrons from one substance and place to another substance and place.

Early studies of electricity were concerned with ways of generating a flow of electrons, whether through chemical action (as in batteries) or through the mechanical movement of conductors of electricity through a magnetic field--powered by falling water, moving air, burning fuels, or, more recently, nuclear reactors. It was recognized early that metallic substances--for example, copper and tungsten--were excellent conductors of electricity. Scientists explain this fact today by noting that in the atoms of metallic elements the outer shell of electrons is relatively incomplete, containing only a few electrons. These outer electrons are free to move from atom to atom in an electric field just as water runs downhill in a gravitation field. In the atoms and molecules of nonmetallic substances--for example, sulphur, mica, glass, or rubber--the outer shells of electrons are more nearly complete. The electrons are not free to move from atom to atom or from molecule to molecule. Such substances are known as insulators or nonconductors.

Electric energy can be transmitted from places where it is generated to places where it is put to work through an arrangement consisting of conductors (usually in the form of metallic wires or cables) and insulators (to prevent or reduce the dissipation and loss of energy to the ground or the surrounding atmosphere). One great advantage of electric energy is its ability to be transmitted and readily converted into other forms of energy--into mechanical energy, through motors; into light energy, through lamps; and into heat energy, through stoves and ovens. For many years the focus of development in electrical technology was on finding more-efficient methods of generating, controlling, transmitting, and using the flow of electrons through conducting metals.

In electronics, the primary focus is still on the movement and flow of electrons and on putting the controlled flow to work in various ways. But it is the flow of electrons through vacuums, gases, and semiconductors which has been the subject of electronic investigations.

A convenient place to begin a brief history of electronic science and technology is with a discovery by Thomas A. Edison, one of America's most ingenious inventors, in 1883. Edison found that when one filament in a vacuum tube was heated, a flow of electric current was induced in another unconnected filament in the same vacuum tube. The explanation for this phenomenon is that as electrons flow from the heated filament through the vacuum, some are captured by the cool filament and flow through the latter.

It is ironic that Edison--who was essentially a technologist, not a scientist--did not see the practical possibilities in his only contribution to the basic science of electronics.

In 1904 Sir John Fleming, an English physicist, perfected the diode vacuum tube with its two elements--the filament (heated element) and the receiving plate. When, in 1907, Lee DeForest inserted a grid circuit between the filament and plate of a diode tube, the heart of a system for radio (wireless) transmission of electronic signals was complete. DeForest's tube is called a triode, since it contains three elements. The third element is a device for translating sounds into distinctive patterns in the form of pulsating electronic currents. When this patterned flow is introduced into the grid of a vacuum tube, it may be reproduced in amplified form in the plate current. The pattern of pulse can be transmitted in the form of radio waves from a transmitter and reconverted into sound waves in a receiver, again with the aid of vacuum tubes.

For several years, DeForest's triode vacuum tube was at the center of developing electronic technology. Of course, the triode was improved and refined: additional grid circuits were introduced into the vacuum tube; the size of the tube was reduced, and its efficiency was increased. The versatility of the vacuum tube, as it was used in the circuitry of radio transmitters and receivers and in early computers, was due to its ability to rectify (change alternating current into direct current), amplify, modulate, switch, and control electronic signals.

The invention of the iconoscope by Vladimir Zworykin, a Russian-born engineer working in America, paved the way for the development of television. The iconoscope included a device for scanning lighted objects and converting the scanned images into electronic currents. This pattern of signals could be transmitted in the form of radiation (using a band of the spectrum of Herzian waves which was different in wave length and frequency from that used in radio transmissions) to receivers, which reconverted the radiation first into electrical pulses and then into images projected on a specially treated screen. In early television, vacuum tubes, interconnected in complex circuits, were essential elements in both transmitters and receivers.

World War II gave strong impetus to developments in electronic technology in a number of ways. Radar sets which emitted radiation and received and interpreted "echoes" from solid objects in the vicinity of the transmitter were developed to detect and anticipate enemy air and surface attacks. (Radar is now an important aid in the navigation of planes and surface ships and to traffic policemen in measuring the speed of moving automobiles.) Methods of wireless transmission of messages were improved, leading to such devices as the teleprinter and long-distance facsimile reproducers of pictures, maps, and diagrams. Computers were developed to control the aiming and firing of guns, automatically calculating the effects of such factors as the speed and direction of wind and moving targets more accurately and quickly than human gunners could do.

The year 1948 witnessed a momentous breakthrough in electronic technology when the transistor was invented in Bell Laboratories. This invention turned the attention of electronic technologists from managing and controlling the flow of electrons through vacuums and gases, as in electron tubes, to electron flow in semiconductors of electricity.

Behind the development of the transistor were years of research by physicists, metallurgists, and crystallographers into the various structures characterizing matter in its solid state and into the properties displayed by these structures. It was scientific knowledge of the properties of impure crystals of elements like silicon which led to the invention of the transistor.

A simple example will make this point clear. Each atom of silicon has four electrons in its outer shell. When atoms of silicon unite to form silicon crystals, the atoms arrange themselves so that each atom shares eight electrons in its outer shell. Since eight electrons constitute a stable shell, a pure crystal of silicon is a nonconductor of electricity. However, if an atom of arsenic is substituted for an atom of silicon in a crystal, its electronic properties are changed, because each atom of arsenic has five electrons in its outer shell. Such an impure crystal, which has an extra electron that is free to move and to be moved about, is called a negative, or N, crystal. If a boron atom is substituted for a silicon atom in a crystal, a positive (P) crystal is formed, since the boron atom has only three electrons in its outer shell; the presence of a boron atom in a silicon crystal, in effect, produces an electronic "hole." If a P crystal and an N crystal are united, a P-N junction is formed. When such a junction is placed in an electrical circuit, it acts as a rectifier: electrons can flow only from N to P and not the other way around. When two P-N junctions are placed back to back, a transistor is formed. A transistor has all the capabilities of a diode vacuum tube. Crystals may be made to function as triodes and as resistors and capacitors (electron-storing devices) as well. In this way, tiny crystals--which don't have to heat up in order to function, as vacuum tubes must--can replace bulky and slow-reacting vacuum tubes in various electronic devices, from radio and television transmitters and receivers to computers.

The trend in electronic technology since 1948, when semiconductors and solid-state circuitry began to replace vacuum tubes and soldered-wire circuits, has been toward miniaturization. Smaller and smaller devices have replaced larger and bulkier devices. This trend has also affected prices. A calculator which cost $390.00 in 1971 retailed for $10.95 in 1978, and the cheaper model is said to be more "sophisticated" than the earlier version (*Time* 1978). Without miniaturization, the wide array of electronic devices now offered for sale as consumer items--pocket radios and calculators, digital watches, and minitelevision sets--would not be available at all, let alone at relatively low prices.

Miniaturization has been aided by lavishly financed research and development activities, particularly in the United States, Japan, Great Britian, and West Germany. Some of this research has focused on the improvement of electronic circuits. The old circuits, which were made by soldering metal wires to the external connections of vacuum tubes and other electronic elements, were initially replaced by circuits printed on cards. More recently, in so-called integrated systems, the circuits are imprinted directly, by etching or lithography, on the silicon chips which have replaced vacuum tubes in many electronic devices. Computers can be programmed to manufacture these tiny, intricate circuits for use in new computers or other electronic devices.

The electronic computer is perhaps the most awesome artifact of the "information revolution." The computer might be thought of as a "mutation" in the centuries-long evolution of machines designed to make arithmetic calculations more rapidly and accurately than human hands and brains. Such machines date back to the Chinese abacus. In modern Europe, a Scot, Sir John Napier, invented a mechanical calculating device in the 17th century. The line of evolution goes through Leibniz in Germany and Pascal in France. (Napier is best known as a mathematician, Leibniz as a mathematical philosopher, and Pascal as a mathematician and theologian.) Perhaps the most ingenious of the mechanical calculators was the Analytical Machine, which was invented by an Englishman, Charles Babbage, in 1835. This machine incorporated, in embryonic form, many of the features of contemporary electronic computers--programming, branching, looping, arithmetic and memory storage units, and automatic printout of results. Babbage's work was lost until 1937.

Just as the development of calculators involved collaborative efforts between the disciplines of mathematics and logic and those of physical science and engineering, computer science and technology has its "software" and "hardware" sides. The software side relies heavily on applied mathematics and logic; the hardware side requires skills and knowledge related to mechanics and mechanical engineering and, more recently, electronics and electronic engineering. Thus, interdisciplinary collaboration has played a large part in the evolution of the modern computer.

On the hardware side, Hollerith, who worked with the U.S. Census in the late 19th century, introduced electromechanical sensors into a mechanical calculator which used information stored on punched cards. The information collected by the U.S. Census of 1890 was processed by such a device. In 1911 Hollerith, along with others, founded International Business Machines (IBM), now a giant multinational corporation which has become almost synonymous in the popular mind with computer research, development, and production.

After Aiken constructed and used the now-famous Mark I computer at Harvard University in the late 1930s, the evolution of the electronic computer proceeded with amazing rapidity. Eckert and Marchly, both of the University of Pennsylvania, developed the first all-purpose, all-electronic digital computer, ENIAC, in 1946. Von Neuman, who had been associated with the construction of ENIAC, published his definitive work on the mathematical logic of the digital computer in 1947.

Although it is impossible to deal with all the complexities of computer software or hardware in this brief historical summation, a few underlying concepts can be outlined in simplified form. The basis of the modern computer is a theory of algebraic logic developed by Boole, a German logician, in the late 19th century. In Boole's algebra, logical operations were reduced to a series of "yes or no" decisions. (For example, is the object a man or not-man? [illegible] man, is he American or not-American? If American, is he North Ame[illegible] not-North American?) Boole's algebra could be applied to verbal or numeral symbols.

Today's digital computers employ Boole's logic by means of a number system that uses only two digits: 0 and 1. These digits, which can be used to represent an infinite variety of "yes or no" decisions, are matched in electronic circuits with devices which can, in effect, say "electron flow or no electron flow." We have already noted that vacuum tubes, P-N junctions, and transistors in electrical circuits can perform this "yes or no" function. The capacity to say "no," "and," and "or" can be built into electronic circuitry. Complex and sophisticated systems of logical and mathematical operations can be built on the basically primitive concepts of "no," "and," and "or." Another kind of computer, the analog computer, is often used in conjunction with a digital computer in some kinds of computer simulations.

While early calculators could operate only with arithmetic symbols (numbers), modern computers can operate logically and mathematically upon any information, so long as it is provided in symbolized form.

Information theory, a semimathematical set of ideas which have developed along with computer science, conceives of atoms of information as *bits*. These bits can be combined in many ways to form complex bodies of information. A computer must be supplied with bits of information. This information is known as input. A simple or complex set of commands may be given to the computer to perform various kinds of operations on this *input* and/or on information already stored within [illegible] circuits or in supplementary storage to which it has access. This set of commands is known as a *program*. *Computer programmers* use one of several artificial languages to translate commands from ordinary language into computer language. As the computer complies with the commands in its program, it *processes* the information involved into the desired results, known as *output*. A computer's output can be displayed in various forms--as a printout (on paper), in microform (transparent film), as pictures and text on a television screen, or as spoken words. Output can be transmitted as radiant energy for thousands of miles and displayed on a television screen in a monitoring station. Thus, during manned space flights, technicians at the mission-control center in Houston were able to receive continuous computer information about the spacecraft and about the physical condition of the astronauts--their pulse rates, blood pressures, and body temperatures--to supplement voice communication.

In computers, as in other kinds of electronic devices, transistors have been substituted for vacuum tubes and integrated circuitry for soldered wires. These developments have produced computers of ever-decreasing size and ever-increasing speed and sophistication. Aiken's Mark I computer at Harvard, built around vacuum tubes, filled a good-sized room. The ENIAC computer contained some 18,000 vacuum tubes. Today, computers with vastly greater memories and processing speed now occupy only a few feet of space. Supplementary storage of information for computer scanning and processing takes many forms--among them, multitrack magnetic tapes, drums, and disks. The contents of a whole book can be stored on a reel of tape. A computer, properly programmed, can "read" a whole book in a few minutes and select and print out desired information and passages. Libraries, which have always been places for storing and retrieving information, have already been revolutionized and will be further revolutionized in the future by computer technology.

Two developments in computer technology deserve special mention because of their significant implications for both individual human beings and whole societies. The first of these developments has to do with the conversion of computers into "learning machines." Early computers were capable of carrying out their operations only in compliance with commands, supplied to them by human operators. Computers have now been developed which can modify their programs in the light of their own "experience." One line of computer research has involved the programming of computers to play such games as checkers and chess. A computer programmed to win at chess, for example, can review its memory of moves it has made in certain situations on the chessboard in the past. It can sort out which moves contributed to winning and which ones did not, and reprogram itself to eliminate losing moves and make winning moves in future games of chess.

This monograph is concerned with citizen participation in the making of policy decisions. Computers can be programmed to make decisions. Information relevant to some area of decision making can be supplied to a computer. The computer can then be instructed to explore the consequences of various policy alternatives and report its findings or even to actually select the "optimal" alternative, measured against standards of "optimality" supplied to it by human operators. For example, scenarios about different ways of conducting and defending against nuclear warfare, complete with statistics about millions of lives lost and billions of dollars in property destroyed, have been derived from computer simulations of policy alternatives. The learning and decision-making capabilities of computers have raised serious questions about the wisdom of depending on computer "brains" in the planning and conduct of various "human" enterprises.

The second development in electronic technology with significant implications for society is the increasing use of computers to direct and supervise systems for the production and distribution of economic goods and services. In addition to merely providing processed information to assist people in making decisions and doing their work, computers are being programmed in some cases to perform functions that would ordinarily be handled by human managers and supervisors.

Understanding this use of computers calls for a brief detour into the study of cybernetics--a science named and developed by Norbert Wiener, a mathematician working at the Massachusetts Institute of Technology. Cybernetics has to do with the guidance and control of various systems of operation. For example, if we think of a person driving a car as a single operational system, the driver may be thought of as the controlling mechanism and the automobile as the servomechanism. The driver continually receives information about operating conditions--curves, traffic, ruts in the road, fog and rain, highway signs, etc. The driver processes this information and adjusts the course and speed of the automobile accordingly by operating the steering wheel, brakes, and accelerator appropriately. If the human driver were to be replaced by a computer programmed for the purpose, a self-guided, self-controlled conveyance system would result. The theories of cybernetics form the basis for the automation of such diverse systems as missiles, factories, robots, teaching machines, warehouses, and libraries.

General-purpose computers can be used to design special-purpose computers which in turn serve as brain mechanisms in the automated operation, supervision, and quality control of productive and distributive enterprises. Automation challenges some of our most deeply ingrained convictions about the rightful place of human labor in society.

On the surface, the benefits derived from electronic science and technology seem overwhelming. The dreams of utopian thinkers about a world in which human beings are freed from arduous toil seem to be attainable when one considers the potential uses of electronic technology. Human beings now have (and soon will have more) mechanical slaves to do their work, perhaps even their thinking, for them. Computers can perform complex mathematical operations in an hour which an army of human beings could not accomplish in a lifetime. Doctors can diagnose diseases more quickly and dependably with the assistance of computers. Optimal designs for buildings and other artifacts can be developed quickly and efficiently by architects and engineers using computers. Musicians can use computers to compose electronic music. With the aid of television and communication satellites, we can watch events as they happen on the other side of the world or in places far from Earth. The "information revolution" is, to use McLuhan's phrase, converting the world into a "global village."

But deeper analysis reveals ominous serpents lying in wait in this electronic Eden. Many people believe that grave risks are associated with four particular effects of electronic technology: depersonalization of relationships, centralization of decision making, invasion of personal privacy, and automation of job functions.

Depersonalization of Human Relationships

Computers play important roles in hiring, keeping track of, accounting for, paying and otherwise rewarding, and dismissing persons in large-scale organizations ranging from factories to schools and hospitals. The tendency to depersonalize human relationships between supervisors and workers, doctors and patients, and teachers and students was growing even before computers were introduced into personnel work, and the use of computers has aggravated this trend. The kind of depersonalized relationships one tends to find in a large school, for example, contrast sharply with the close and meaningful relationships between people in a rural community, a family, or a commune, where "everyone knows everyone else" as a person.

The feelings expressed by protesting students in the 1960s that they were being reduced to IBM cards, that their personal feelings and preferences were being ignored, that processes of learning and development were being distorted to fit the convenience of computers--these were not entirely romantic fantasies. Who has not felt the frustration of receiving an unresponsive computerized form letter in "reply" to a complaint about defective merchandise or a miscalculated bill? We need to deal with the person behind the electronic gadgetry in order to achieve satisfactory communication.

One widely advocated use of computers in education is as machines for teaching basic skills and information. An individual student with access to a computer terminal can address his questions and problems to the computer. If the computer is well stocked, it can answer the student's questions and solve his or her problems more quickly, and often more accurately, than a teacher or fellow student could do. Such a computer can also correct errors in a student's calculations or thinking processes promptly and impersonally.

The question is not whether programmed individual learning has a place in future educational programs--it most certainly has a place. The issue is whether the use of "teaching machines" leads to the neglect of learning which can be achieved only by direct interaction and dialogue with others. Among the most important examples of this kind of learning are the skills needed to communicate with persons who belong to other groups or who are different in age, background, and value orientation. The need for such communication skills has already been stressed in this monograph as a prime need in a pluralistic and war-torn world.

The depersonalization of relationships has consequences for both individuals and societies. Can individual human organisms develop into rounded and morally responsible persons if they are continually deprived of personal relationships with other human beings? Can societies which depend for their survival on human relationships between their members be sustained by the kind of impersonal relationships which are fostered by dependence on communication through the use of electronic technology?

Centralization of Policy Decision Making

In a symposium on "Computers and the World of the Future" held at the Massachusetts Institute of Technology, C.P. Snow, an English novelist who is also a physicist, expressed vividly his concern about the possible effects of computer technology on the making of social policy decisions (Greenberger 1962). Snow deplored the tendency in modern societies toward centralizing public decision making--a tendency which antedates computer technology but which will, he fears, be accelerated by it:

> There it is. A handful of people, having no relation to the will of society, having no communication with the rest of society, will be making decisions in secret which are going to affect our lives in the deepest sense. . . . My worry is that the introduction of the computer is going to lead to a smaller circle still. . . . Instead of having a small group of scientists knowledgeable enough to have something to add to decisions, I am asking whether we are now running into a position where only those who are concerned with the computer, who are formulating its decision rules, are going to be knowledgeable about the decision. If so, instead of having a small circle of scientists and a large circle of administrators, we will have a tiny circle of computer boys, a larger circle of scientists who are not versed in the new computer art, and then, again, the large circle of politicians and administrators. I suspect . . . that the computer in certain hands could easily become a gadget. Gadgets are the greatest single source of misjudgment that I have ever seen . . . People get fascinated by gadgets. They love them. They want everything to be explained in terms of their gadget. . . . I suspect that computers in government are going to get into the hands of persons with mildly defective or canalized judgment and become gadgets.

Snow's concern embraces two interrelated issues. The first has to do with limited access by citizens to information which is collected electronically and stored in computers. In part, this problem is physical. Its solution, short of banning computers, would involve increasing the number of computer terminals available to citizens through which policy-relevant information can be retrieved. However, the solution also would also require educating citizens in methods of retrieving stored information and adding their own input to the stored data. Information about the feelings, attitudes, and values of large numbers of people concerning issues of social policy needs to find its way into computers used to assist in social policymaking.

One device used to deliberately narrow the circle of persons with access to computer storage is the classification of information as "confidential" or "secret." Only specially "cleared" persons are allowed access to classified information. Such limits to access are usually justified by governments on the basis of "national security"--to keep important information out of the hands (or computers) of "enemy" governments. A corporation may justify limiting access to information by the need to maintain its competitive advantage over other firms. The merits of these justifications need to be judged on a case-by-case basis. However, there is no doubt that such practices tend to encourage and maintain a climate of secrecy and exclusivity in the making of policy decisions, and to limit the scope of intelligent citizen participation which democratic policymaking requires.

The second aspect of Snow's concern is fear of gadgetry. This fear might also be expressed as a fear that humans may tend to idolize and idealize the new and powerful technologies which they have created:

> It is not surprising that with the human creation and development of computer technology, men are widely interpreting man's mental functioning after the model of computer functioning. Nor is it surprising that human efforts are *being widely coached* and *organized to conform* to the demand and to the image of the computer. Cybernetic man is an idol just as mechanical man was and is an idol to many. The difficulty lies not in the invention and use by men of mechanical or computer models and technologies in facilitating human projects. The difficulty lies in the tendency of man the creator to deify his own creations, to ascribe to them a reality prior to the reality of himself, and to put himself abjectly into the service of his own artifacts. In this process he comes to feel powerless before the powers he has released and loses faith in the power that lies within himself to use his artifacts in the service of personal and communal ends or to refuse to use them at all. (Benne 1975)

The best antidote to making an idol out of electronic science and technology and high priests out of their experts is widespread public education--education designed to demystify electronic expertise and to create a healthy skepticism about its authority in decision making. What is needed is widespread understanding of the virtues and limitations of electronic technology and technologists.

Invasion of Personal Privacy

Our discussion has stressed the desirability of widening citizen access to stored and processed information relevant to the making of public policies. Ironically, however, electronic technology also creates problems of the opposite kind so far as the private lives of persons are concerned. Electronic detecting devices are now being marketed which are powerful and sensitive enough to enable their operators to secretly listen in on telephone conversations and on discussions in homes and other places which the speakers regard as private. Invasion of privacy by governments and other agencies, both legitimate and illegitimate, has been greatly facilitated by improved electronic technology. In a society which values individuality, the right to private expression and communication should be protected. The use of "bugging" or electronic surveillance, whether by government officials or by private agencies, needs to be controlled in order to protect this right, whatever inconvenience such restrictions may create for zealous detectives, spy chasers, and blackmailers.

Computer storage of information may also threaten individuals' rights to privacy. Information about a person's debts and credit rating, divorces and romances, diseases and operations--all kinds of personal data may be stored in computers. There is continual pressure from some sources to interconnect these various computers. Anyone with access to such a computer chain could readily print out a dossier of information about another person--information which that person might prefer to keep private. The collection of personal information is facilitated if various kinds of information are stored with reference to a single identifying number, perhaps a person's social security number.

While ready access to stored information about an individual may be convenient to a variety of functionaries--among them law-enforcement officials, spies, agents of credit bureaus and insurance companies, employers, and school admission officers--the absence of controls on such access erodes the ability of individuals to decide what kinds of information should be communicated and to whom. We need social policies that clarify people's rights to individual privacy in an electronic age and that support the protection of those rights.

The Effects of Automation on Employment

One of the effects of introducing automation into an organization is the elimination of some jobs. While it is true that automation creates jobs for computer programmers, technicians, and service personnel, it usually reduces the total number of jobs in an organization. One of the main reasons for introducing automation is to reduce labor costs. The loss of jobs that results from automation is a source of anxiety both to individuals whose jobs are threatened and to a society plagued with problems of persistent and increasing unemployment.

In the 1960s one of the authors served as a consultant to an insurance company which had decided to automate its clerical operations. The author was employed to help the company deal with the human problems precipitated by this decision. In keeping with the author's advice, the management announced that no employee would be dismissed because of automation--an action that helped relieve employees' anxiety about losing their jobs. However, new kinds of anxiety were created by the management's explanation that employees whose jobs were eliminated by automation would be offered retraining for other jobs at company expense. Employees were now anxious about the necessity to change careers in midstream. Some felt a personal loss at having to forsake a job in which they had invested years of training and experience. In devaluing this investment by turning "their" work over to an inanimate machine, the company was, in effect, devaluing them as persons. Other employees felt anxious about their ability to learn a new job and do it well.

Whether in the long run automation will reduce the number of jobs in [illegible] is still in dispute. Some economists point to past situations [illegible] the introduction of labor-saving technology led eventually not to fewer but to more jobs. But there is no doubt, as the aforementioned example illustrates, that automation will change the kinds of jobs that people will be hired to do, that it will compel people to retrain themselves and to change careers--perhaps several times in a lifetime--and that it will change the overall pattern of employment. In general, mass-production methods, over the past half-century, have reduced the economic demand for the services of skilled artisans and craftsmen. Automation now promises to reduce the demand for unskilled and semiskilled workers, although it will create new demands for technicians of various sorts.

What will happen to persons who are not predisposed by interest or aptitude to seek careers as technicians? This is a fundamental question. Should jobs in a humane society be shaped to the requirements of a technology adopted by owners and managers, or should they be shaped to the interests and aptitudes of persons living in the society? Should the adoption of automation be determined by economic considerations alone? Or should this decision also be influenced by the preferences of workers? All these questions need to be deliberated in forging policies for using computer technology wisely and humanely.

Thus, automation raises policy issues related to both employment patterns and the character and quality of work--in addition to the question of whether workers should have to adjust their styles and preferences to the convenience of machines, rather than the other way around. The way people answer these questions is likely to be affected by a value orientation which is widely assumed by people in our culture. This value orientation leads many people to think that labor-saving devices per se are "good," and it is applied to homes as well as to factories, farms, and offices. A home is often thought to be unquestionably better if it contains such labor-saving devices as a dishwasher, a vacuum cleaner, a microwave oven. This value judgment is made even when those who do the housework actually prefer to wash dishes by hand, to clean floors with brooms and mops, and to roast meat in an oven heated by burning wood or coal.

This value orientation is related to our tendency to make idols out of artifacts--a tendency noted by Snow and Benne (see pages 93 and 94). On a larger scale, this value orientation is reflected in our preference for capital-intensive (technology-intensive) over labor-intensive methods of producing and distributing goods and services. Many ecologists, most notably Barry Commoner, have pointed out that the adoption of capital-intensive methods increases our use of energy, thus aggravating the energy crisis which people all over the world are facing. Does this value orientation need to be reexamined and changed? Specifically in regard to automation, which is largely made possible by the development of computers, we may ask: Should we automatically extend the use of electronic technology because it is fascinating, because it is available, and because it saves human labor?

Suggested Learning Activities

1. Imagining Life Without Electronics. No student now in high school has known a way of life in which radio has not played a part, and only a few have experienced living without television sets, phonographs, or tape cassettes. To involve students in assessing the human effects of these forms of electronic technology, they might be asked to keep logs of their activities for one or two days and to star those time periods in which such electronic devices played a part. As a further activity, they might be asked to identify the purposes for which they have used these forms of electronic technology at various times in their experience--recreation, sports, esthetic enjoyment, background to other activities, learning, relief from boredom, keeping up with the news, keeping "up to date" with their peer group, etc.

A next step in the assessment might be to ask students to imagine how they might have accomplished those purposes without radio, television, phonographs, or tape cassettes. In carrying out this imaginative enterprise, they might interview their grandparents or other older citizens who have lived part of their lives without access to at least some of these electronic devices. As a final step, students might be asked to assign comparative values to B.E. (Before Electronics) and A.E. (After Electronics) ways of satisfying enduring human interests. In what ways was life better and in what ways was it worse before the introduction of these forms of electronic technology?

As students discuss their logs and assessments, they should discover that the positive values of electronic progress--values which are taken for granted--are actually open to question, and that some people place different values on such electronic devices as radio, television, phonographs, and tape cassettes.

2. Constructing a Value Continuum. After it is discovered by students that they differ among themselves in their evaluations of electronic progress, they might be asked to construct a value continuum with respect to such progress. This continuum should allow room for extreme positions, from "ban all research and development work on electronic

technology" on one side to "encourage and generously support research and development in electronics and the practical application of its results" on the other. Make sure that at least three intermediate positions can be located between the two extremes as students identify the "pro" and "con" evaluations to which they are most attracted. Students should be asked to state their reasons for choosing the value positions they have identified.

3. Exploring Values Through Science Fiction. Students might be asked to read George Orwell's *1984*, with its picture of a closed society controlled by a dictatorial elite. These rulers rigidly limit citizens' access to important information and induce conformity to their rules and policies through continuous electronic surveillance of citizens' words and actions. Frequent reminders of this surveillance are given through loudspeakers with the message "Big Brother is watching you."

After discussing the values and disvalues of a society like that depicted in *1984*, students might be asked to discuss the following questions: How might computers and communication facilities be used and controlled in this country today to create a closed and dictatorial society like the one described in *1984*? What trends in our society are moving us toward *1984*? Should citizens try to reverse such trends? If so, how?

4. Investigating Employment Patterns. To help students develop an appreciation of the effects of computerization and automation on jobs, they might be asked to do research on the "Help Wanted" and "Jobs Wanted" advertisements in a current daily newspaper and in an issue of the same newspaper published ten years ago. (For this purpose, the Sunday edition of a metropolitan newspaper containing several pages of such advertisements is desirable.) The students' research should be guided by the following questions: How many of the ads in "Help Wanted" listings are looking for technicians? Which of these ads specify that these technicians should know how to operate, program, assemble, install, and repair electronic devices, especially computers? In the "Jobs Wanted" listings, how many advertisers are looking for the kinds of jobs which are likely to be threatened or eliminated by computerization and automation?

As students discuss the results of their research, they should look for evidence of trends in employment opportunities which are related to automation. To personalize this activity, they might also discuss how these trends square with their own career aspirations. If the prevailing trends run counter to the career aspirations of some students, what might those students do to reverse or modify the trends?

5. Debating a Proposed Social Policy. Many social issues are raised by the development of electronic technology, particularly computer technology. Some of these issues can be considered by means of the kind of policy-oriented debate described in Section 3. One such question for debate might be stated in the following way: "All further automation of industries, businesses, and government operations should be banned by law until every employable person has found a job."

6. Envisioning an Educational Future. Some prophets of electronic progress predict vast changes in programs of education in a fully developed electronic age. One such futuristic scenario envisages a home education system featuring a computer terminal in every home and a two-way television system to provide communication between individual learners and computers in regional education centers. In addition to answering learners' questions, the computer would monitor and correct processes of speaking, calculating, and thinking. The individual learner would have no personal contact with the highly trained educators who program the computers and supervise their operation.

Students might be asked to write imaginative essays describing a day's experience in such an educational program. In these essays, students might be asked to include their reactions to the possible elimination of some of the elements present in a "nonelectronic" educational program--interactions with other classmates and teachers, face-to-face communication with people who are different in age, background, and viewpoint, etc.

After students have shared and discussed their essays, groups of students might be asked to envision an ideal educational program in which the positive values inherent in both traditional classroom instruction and computerized instruction are combined and integrated and the limitations of each are eliminated or minimized.

7. Simulating a Policymaking Situation. One kind of policymaking situation which might be simulated by students is a meeting of a congressional committee to consider proposed legislation that would allow greater latitude to policeman and intelligence agents in using electronic devices to collect evidence against suspected criminals and enemy agents. Specifically, the proposed legislation would permit police officers and federal intelligence agents to submit the telephones, homes, and offices of suspected criminals to clandestine electronic surveillance (bugging) without a court order. Officers and agents would also be permitted unlimited access to computerized systems in which personal information is stored--for example, the files of hospitals, credit bureaus, and schools.

Among the roles in which students could be cast are those of the chairperson and members of the congressional committee, citizens representing a law-and-order group that favors the proposed legislation, and other citizens representing a civil-liberties group which is very much opposed to it. The students who play members of the congressional committee will need preparation time to work out procedures for the hearing. Those playing representatives of citizens' groups will need time to work out their arguments and to select and brief their spokespersons. If student feelings become polarized on the issues involved, the teacher might suggest that the roles of the "law and order" and "civil liberties" advocates be reversed.

During the simulated hearing, the spokespersons for the citizens' groups will present their cases and answer questions put to them by committee members. Following this process, the committee will try to decide what, if any, changes in existing legislation are desirable. In the analysis and evaluation following the simulation, both teacher and students should devote attention to both the content of the issues debated and the processes of policymaking involved in the role playing.

Recommended Readings

The first two sections of this unit may be duplicated and used as basic reading on both the scientific background of electronic technology and related issues of social policy and ethics involved in its practices. In addition, the following readings are recommended. (For information about locating and ordering publications with ED numbers, see page 129.)

Scientific Background of Electronics

Asimov, Isaac. *New Intelligent Man's Guide to Science*. New York: Basic Books, 1965.

> Chapters 6, 7, 8, and 16 of Asimov's book explain the theories behind electronic developments. This book can be read with understanding by most high school students.

Bernstein, Jeremy. *Analytical Engines: Computers, Past, Present and Future*. New York: Random House, 1964.

> This excellent semihistorical account of the background and development of modern computers was written for a lay audience, and it can be read with understanding by both teachers and advanced students.

Bernstein, Jeremy. *Exploring Science: Profiles in Discovery*. New York: Basic Books, 1978.

> This is a book of well-written essays which appeared originally in *New Yorker* magazine. Both scientific innovations and the personalities of the innovators are discussed. The essay entitled "Calculators: Self-Replicators" is especially useful for this unit. Most of these essays can be read with understanding by average high school students.

Goldstein, Herman H. *The Computer From Pascal to Von Neuman*. Princeton, N.J.: Princeton University Press, 1970.

> The author of this book was an associate of Von Neuman's in the development of ENIAC, the first all-electronic computer. This semitechnical account of computer development is good reading for teachers and advanced students.

Social and Human Effects of Electronic Technology

Bagdikian, Ben H. *The Information Machines: Their Impact on Men and the Media.* New York: Harper Torchbooks, Harper and Row, 1971.

> This book offers a brief general discussion of the "information revolution" and its human and social effects. Most of the content deals with the effects of electronic technology on the collection and dissemination of news. This thoughtful futuristic look at the news media of tomorrow can be read with understanding by average students.

Greenberger, Martin, ed. *Computers and the World of the Future.* Cambridge, Mass.: Massachusetts Institute of Technology Press, 1962.

> This report of a conference held at the Massachusetts Institute of Technology in 1961 contains transcripts of the lectures given on that occasion and of the discussion which followed each lecture. Especially recommended for users of this unit are chapters 1, 3, 4, and 8. A useful bibliography of both technical and nontechnical resources is appended. Good reading for teachers and most students.

Hill, A.V. *The Ethical Dilemmas of Science.* New York: Oxford Press, 1962.

> This is a general treatment of the ethical problems raised by recent developments in science.

Learning About Electronic Technology Through Science Fiction

Hollister, Bernard C., and Deane C. Thompson. *Grokking the Future: Science Fiction in the Classroom.* Dayton, Ohio: Pflaum/Standard, 1973. ED 084 554.

> Chapter 4 of this book, "Fold, Spindle and Mutilate: Man or the Machine," discusses how science fiction can be used to help students understand the threats to human beings posed by recent technological developments, especially in computer technology.

In addition to the works noted above, students might enjoy reading Kurt R. Stehling's *Computers and You* (New American Library, 1973, paperbound) and Milton R. Wessel's *Freedom's Edge: The Computer Threat to Society* (Addison-Wesley, 1974).

UNIT 4: ALTERING THE BIOLOGICAL HEREDITY OF HUMAN BEINGS AND OTHER LIFE FORMS

Scientific Background

It has long been common-sense knowledge that hereditary traits are transmitted from parents to their children. And common-sense observation confirms further that the hereditary traits transmitted from parents appear in new combinations in their offspring. For example, a child may inherit "his father's" button nose and big feet along with "his mother's" curly hair and brown eyes.

The modern science of genetics began with the work of Gregor Mendel, an Austrian monk, shortly after the middle of the 19th century. Mendel worked with pea plants in the garden of his monastery. By cross-mating plants which produced dark peas with plants which produced light ones and observing the colors of the offspring through several generations, Mendel was able to demonstrate that the transmission of hereditary traits is governed by mathematical laws.

Mendel's theory implied the existence of individual units of heredity which could pass information from one generation to the next. Various names were proposed for this theoretical unit of heredity by Darwin and others until the term "gene," suggested by Wilhelm Johannsen, came to be generally adopted by biologists in the early 20th century.

The understanding of genetic mechanisms was significantly advanced by the work of Thomas Hunt Morgan, an American biologist who began studying the processes of heredity in a tiny genus of fruit fly, *Drosophila*, in 1910. One advantage of the fruit fly over the pea plant as an experimental life form was its ability to rapidly reproduce: it could produce dozens of generations during the time required for a pea plant to produce its first set of blooms. Another advantage was that the flies could reproduce in glass bottles in a laboratory under highly controllable conditions. After studying wing size and eye color in his fruit flies, Morgan was able to confirm Mendel's description of the mathematics of heredity; he then proceeded to go much further, and eventually concentrated on studying natural mutants among his fruit flies. (A *mutant* is a rare and distinctive genetic variety which is markedly different from the normal in one trait or another. For example, albino characteristics are due to the presence of rare mutants in normally pigmented human beings.) Morgan was able to demonstrate that a mutation is due to the modification of a single gene.

It had been suspected for some time that genes were located in *chromosomes*--dark, rod-shaped structures which can be observed microscopically in the nuclei of animal and plant cells. (A fruit fly has 8 chromosomes in each cell; a human being has 46.) Chromosomes are observably active during the processes of reproduction. They separate in the germ cell and then come together in a fertilized egg cell during the process of exchanging genetic information. By watching this phenomenon microscopically in his mutant fruit flies, Morgan correlated chromosome inheritance with the inheritance of single gene mutants. He was able to locate the positions occupied by many mutant genes in a given chromosome. In 1926, Morgan published a map of fruit fly chromosomes showing the location of each gene that controlled a given function--wing size, eye color, etc. One of his students, H.J. Muller, was subsequently able to produce mutations artificially by bombarding a population of fruit flies with X rays, a process that greatly reduced the number of fruit flies which had to be examined in locating mutants for genetic study.

The ability to map genetic territory gave a new "reality" to the study of genetics. However, it did not answer the question of how a gene actually controls the shaping of a biological organism. A partial answer was provided by the work of George Beadle and Edward Tatum on an orange-colored bread mold known as *Neurospora crassa*.

The search for understanding of genetic functioning in living organisms, moving as it did from pea plants to fruit flies to bread mold and later to bacteria and viruses, was based on the assumption that the mechanisms of heredity are similar throughout the plant and animal worlds. Thus the choice of a life form for genetic study was often determined largely by experimental considerations. Beadle and Tatum searched for a mutant of *Neurospora* which could be identified and separated from a normal sample of mold. They chose a mutant form which could not make a required nutrient out of the normal mold diet of sugar and salts. They were able to prove that the inability of the mutant mold to manufacture this nutrient was due to the malfunction of a single gene and the lack of a single enzyme.

Most students who have had a physiology course think of an *enzyme* as a complex molecule which functions in digesting food. In fact, enzymes also function to facilitate various other kinds of chemical activity in cells and organisms. One way in which genes are linked to body chemistry is through their production of enzymes.

Significant breakthroughs in science often come when two independently developing scientific disciplines intersect. So it was with nuclear physics and chemistry and with computer science and mathematics, and so it has been with molecular genetics. The scientific discipline which intersected with genetics to spark a momentous breakthruogh in molecular biology was chemistry.

As long ago as the 1860s, Friedrich Miescher, a German chemist, discovered a substance which he called "nuclein" in analyzing pus from human wounds. Later he found nuclein in egg yolk and in the sperm of salmon. By 1920, nuclein had been factored into two principal nucleic acids: ribonucleic acid (RNA) and deoxyribonucleic acid (DNA).

The intimate connection between DNA and heredity was demonstrated by Avery and his colleagues at the Rockefeller Institute in New York. It had been found earlier that when a pneumonia bacterial mutant which was incapable of causing disease was mixed with an extract of dead lethal bacteria and injected into a mouse, the mouse developed pneumonia and died. In an effort to identify which compound from the dead bacterial extract transmitted the disease-producing instructions to the nonlethal bacteria, Avery and his colleagues removed one chemical compound after another from the bacterial extract--proteins, starches, fats. Finally, they decided that the minute fibers of DNA were carrying the disease-producing capacity into the cells of the previously harmless pneumonia bacteria.

Work on DNA and RNA culminated in 1953 with the now-famous discovery by James Watson and Francis Crick of the structure of the DNA molecule. The understanding of this structure and its implications for the reproduction and the functioning of the genes has been a key to the stupendous progress in molecular biology during the past 25 years.

The structure proposed for DNA by Watson and Crick was the double helix, which has become as popular a symbol for molecular biology as the positive nucleus surrounded by orbiting electrons has become for atomic physics. DNA consists of a spiral of two connected ribbons. The backbone of each ribbon is made up of sugar and phosphate. To each ribbon are attached four nucleic acids--adenine (A), guanine (G), cystosine (C), and thymine (T)--in various numbers and arrangements. T acids are attracted to A acids, and G acids are attracted to C acids. These attractions hold the two ribbons together in the double helix. However, the attractions are weak enough to permit each ribbon, in the process of cell division, to separate and join with two new molecules of DNA. The original ribbon carries the important genetic information necessary for shaping enzymes which facilitate body chemistry and proteins which make up the tissues of complex living organisms.

Geneticists now speak of the nucleic acids, A, G, T, and C, as the "letters" of a genetic "alphabet." These letters can combine, as in our verbal alphabet, to form many "words," and genetic "words" can combine to form various genetic "sentences." DNA "sentences" contain the information which distinctively shapes the skin, bones, lungs, heart, and other organs of a living organism in the image of the parents who contributed their distinctive DNA in the process of sexual reproduction. Geneticists have thus been able to decipher the "genetic code" of living organisms.

Much of the recent work of geneticists has been focused on the study of bacteria, and the bacterium most-often studied is one that normally inhabits the intestines of most, if not all, human beings: *Escherichia coli*. The genes and chromosomes of *E. coli* have been thoroughly mapped by geneticists. In this study, viruses have played a part. Some viruses, which are essentially DNA or RNA encased by proteins, have the capacity to inject their DNA or RNA into bacteria. Viruses can function and reproduce only within a host cell, and they can carry new genetic information into bacteria and other living cells. The invaded bacteria are instructed to produce more viruses according to the information carried in the DNA or RNA of the invading virus.

Geneticists have also discovered restriction enzymes which can cut DNA fibers into pieces. Under proper conditions, these pieces can recombine to form new DNA chains. Now that we have the ability to perform surgery on DNA fibers and make new DNA combinations, given that we know how these new combinations can be carried into living cells, *recombinant genetics*--in effect, the capacity to make new life forms--has become possible. Awareness of the risks implicit in the use of this power recently led to a self-imposed temporary moratorium by geneticists on recombinant genetic research, an action that focused public attention on the revolutionary potentialities for good and for ill in the findings and applications of molecular biology.

A Risk/Benefit Analysis of Applied Genetics

The three general forms which application of genetic knowledge has taken in the past and may take in the future are easily identifiable: (1) improving the quality of existing species through eugenics, (2) changing the processes of sexual reproduction, and (3) creating new life forms through recombinant genetics. Each of these forms will be discussed in turn, and issues related to social policy and individual ethics will be identified for each area.

Eugenics

The notion that the quality and character of living things can be improved through controlling their heredity is not new in the history of ideas. Ever since Plato toyed with the idea of mating the "best" males with the "best" females in pre-Christian Greece, the ides of eugenics has never been absent from the thoughts of some "reformers."

While the systematic application of eugenics to human beings has seldom been seriously attempted in the history of mankind (Hitler's attempt in Nazi Germany to "purify" the human gene pool by exterminating Jews and Gypsies was one of the notable exceptions), efforts to improve animals and plants through selective breeding and hybridization have been both widespread and effective. Of course, animal and plant breeding was carried on long before the modern science of genetics was developed.

What animal and plant breeders do, in effect, is to identify natural mutants with particularly desirable characteristics and foster their propagation through controlled selective breeding. Such characteristics might include drought resistance in cereal grains, a short growing season in corn, large milk production in cows, lush and distinctively colored flowers in decorative plants. Where different desired characteristics are found in different mutant strains of a plant or animal species, these characteristics can be combined through cross-breeding or hybridization. Thus a wheat variety which produces high-protein grain might be cross-bred with a drought-resistant variety to produce a high-protein, drought-resistant variety of wheat.

In the case of mammals, mastery of the art of artificial insemination--

implantation of the sperm of a male animal into the womb of a female animal--greatly extended the power of animal breeders to propagate desirable genetic strains. A single bull, for example, which carried genes for exceptional milk production in his sperm cells might "father" calves in whole herds of dairy cows. Once means had been developed to preserve sperm cells over long periods of time, sperm banks were established and sperm cells were transported all over the world. Thus an Iowa bull could conceivably "father" calves in Nepal and New Zealand months after his death. Artificial insemination is also practiced with human beings. In this case, the sperm may come from a woman's own husband or from another man. A woman who wishes to bear a child without getting married may seek artificial insemination with sperm from an anonymous male donor or from a sperm bank.

What scientific genetics can do for plant and animal eugenics is to make the results of sperm and egg combinations more predictable and the practices of selective breeding and cross-breeding more systematic and better controlled. Scientific breakthroughs in genetics often lead to proposals that eugenics should be extensively applied to human beings. H.J. Muller, who was the first to produce artificial mutants by bombarding fruit flies with X rays, later became an ardent advocate of applying eugenic measures to human beings in order to rid the human gene pool of hereditary defects. The hereditary defects which Muller and some other medical researchers had in mind were such gene-carried diseases and infirmities as feeblemindedness, hemophilia, sickle-cell anemia, and Tay-Sachs disease. The fact that the presence of such genes in the chromosomes of men and women can now be detected raises some complicated ethical questions: Should carriers of such defective genes be automatically sterilized? Or should they merely be given information about their defective genes and permitted to make their own decisions about sterilization? The genetic composition of a child can now be determined while the child is in the fetal stage through the process of *amniocentesis,* during which fluid is drawn from the fetal sac in the mother's womb. If one or both parents are known or probable carriers of defective genes, analysis of this fluid can provide information about the presence of a defect in their unborn child. The parents can then decide whether to abort the fetus.

Some people argue for compulsory sterilization of identified carriers of certain defective genes. (All of us carry some possibly harmful mutant genes.) Others argue for compulsory testing of every pregnant woman to determine whether there are serious genetic defects in the fetus and for compulsory abortion if such defects are found. Still other people might accept the idea of compulsory screening and testing, but would leave decisions about sterilization to the individuals involved. Similarly, these people might advocate compulsory genetic testing of all pregnant women but leave to parents the decision about whether to abort a genetically defective fetus. Many people who feel strongly about the "right to life" of unborn and even unconceived "children" might object to both sterilization and abortion on the ground that they represent an immoral interference with natural law.

Involved in this issue are difficult questions of social and individual ethics. Who decides which hereditary abnormalities are to be considered undesirable? Steinmetz, the genius who profoundly advanced the study of alternating electric currents, was a hunchback. What would have been the social effects if his parents had learned of this birth defect and decided to prevent his birth? Would the human gene pool have been purified or depleted by this decision?

Another profound question is related to who makes decisions about sterilization and abortion to prevent the propagation of genetic defects. Should the state make these decisions? Parents? Individuals? One state, North Carolina, passed a law 25 years ago requiring the sterilization of residents with serious mental deficiencies. So far, nearly 100,000 North Carolinians have been sterilized in comformity with this law. How do you react to the idea of having such a law? Would you advocate or oppose it in your state?

Alterations in the Processes of Sexual Reproduction

One man-made alteration in the process of sexual reproduction has made it possible to produce "test-tube babies." In the summer of 1978, Louise, allegedly the first test-tube baby, was born in London, England. One of her mother's eggs was fertilized by one of her father's sperm outside the body of her mother. The fertilized egg was later artificially transplanted into her mother's uterus, where the embryo developed in the usual way. This was a medical solution to the problem created by an anatomical condition in Louise's mother which made it impossible for her to become pregnant in the normal way. Both parents agreed to the use of the revolutionary procedure. The fact that hundreds of requests for similar treatment were received after Louise's birth was publicized reveals that the problem faced by Louise's parents is shared by many other people who would like to have children. So far, the procedures seem a benign addition to medical technology.

The social problems implicit in the further development and refinement of such a technology become apparent when we imagine not only conception but the entire process of gestation as occurring outside the body of a mother. Biologists have experimented with "artificial wombs" for lower animals, and embryos have developed through a good part of their prenatal cycle under such conditions. It is not implausible that such a technology could be perfected and applied to human reproduction in the not-too-distant future.

If such a way of developing babies were to become feasible, the temptation to control their genetic composition and prenatal environment, with the aim of producing the kinds of babies thought to be "desirable," would be very great indeed. The same ethical questions that were raised in connection with eugenics programs would then confront people with even greater force: Who should determine what kinds of babies are desirable? The state? Medical experts? Parents? By what standards should desirability be judged? Health? Intelligence? Physical beauty? What effects would this way of producing babies have on family patterns and structures which have developed around traditional processes of sexual reproduction?

Of course, such a technology has not yet been perfected. The policy question for the present is whether research designed to develop such a technology should be encouraged, discouraged, or banned. Should public money raised through taxation be used to support such research? Who should make decisions about its continuation and tempo? Scientists? The medical profession? The government? Citizens? Or some combination of these?

An even-more-drastic alteration of the processes of sexual reproduction is known as *cloning*. In cloning, the nucleus is removed from the egg of whatever species is being cloned and replaced by the nucleus of an adult cell. The egg is then implanted into the womb, and the process of gestation begins. The organism thus created would be an identical genetic copy of the adult from which the substitute nucleus was taken. Dozens, even hundreds, of "carbon copies" of an organism could conceivably be produced by cloning. Cloning, in effect, repleces sexual reproduction with asexual reproduction, which is characteristic of such primitive organisms as amoebae and bacteria.

Biologists report that cloning has been performed successfully in animals as complex as frogs. In 1977, a widely publicized book was published in which it was claimed that an elderly, eccentric millionaire had (with expert help, of course) produced an exact copy of himself through the process of cloning. While genetic experts unanimously questioned the authenticity of this report, none of them denied that the cloning of humans is a distinct possibility for the future.

Animal breeders might look with distinct favor on cloning. In the field of horse racing, for example, it might be seen as a distinct benefit if Seattle Slew or Affirmed could be copied a dozen or a hundred times without risking "contamination" of his offspring by mating him with a female partner. Similarly, advocates of cloning at the human level might point to the benefits of producing exact copies of an Albert Einstein, Mahatma Gandhi, Mohammed Ali, or Eleanor Roosevelt. To balance this optimism, Ira Levin's horror-science-fiction novel (which was released in 1978 as a motion picture starring Gregory Peck), *The Boys From Brazil*, should be recalled. In this story, a geneticist from Nazi Germany succeeded in producing a dozen clones of Adolf Hitler, using cells preserved from Hitler's body, and planting the clones, through adoption, in families in a number of countries.

Although it is impossible to anticipate all the problems which the cloning of human beings would precipitate in our own and other societies, some of these seem obvious. At the personal level, what would be the legal, social, and human status of a clone? Each would have only one genetic parent--a "mother" for a female clone and a "father" for a male. What problems of personal development would clones face? How would a clone develop a sense of personal identity surrounded, as he or she might be, by carbon copies?

At the societal level, already familiar questions would have to be faced. What individuals should be cloned? Should the choice depend on wealth--on the ability of people to pay experts to accomplish the process? Should cloning be limited to individuals who are socially desirable? Should the process of cloning be denied to socially undesirable persons? Should only social conformists be cloned, and the process denied to dissenters and rebels? Lying behind these questions is the most difficult one of all: Who will determine the answers to these unprecedented moral questions?

At a still-more-general level, with implications for the survival of the human race, an important issue would confront all societies. Widespread cloning would minimize the mixing of genetic strains and the ever-changing genetic combinations in people which sexual reproduction provides. While this process of genetic mixing has never been truly random because of socially imposed limitations on human mating, it has provided mankind with a variety of genetic potentialities to meet the demands of a changing environment. Cloning would tend, if widely used, to perpetuate limited number of genetic combinations--primarily those considered desirable for functioning in the environment confronting people at that period of history. However, the genetic combinations considered "undesirable" at any given time may be the very ones best able to adapt to a radically changed environment. Thus, through cloning, the survival of the human species in a changing environment might be jeopardized. And it is important to remember that decisions made about reducing the variety of the human gene pool would be irreversible.

Genetic Engineering--The Creation of New Life Forms

It has already been noted that molecular biologists now have the knowledge and know-how to produce new life forms. Using restriction enzymes, they can perform surgery on DNA fibers. The fragments from this surgery could conceivably, under certain conditions, be recombined with other DNA fibers to form new DNA "sentences" which could function to produce new species. And scientists have the means, in the form of viruses, to carry new DNA into living host cells.

The hazardous potential of recombinant genetic research led Paul Berg of Stanford University, a pioneer in this field, and other molecular biologists to declare a moratorium on this kind of research in 1974. This international group of scientists subsequently called a conference of molecular biologists at Asilomar, California, to assess the potential hazards of recombinant genetic research to public health and planetary ecology and to agree upon guidelines for reducing these hazards to a safe level. It was the hope of these scientists that by doing so they might achieve self-regulation and avoid governmental restrictions.

The hazard of which the participants in the Asilomar conference were most aware was that new, disease-producing forms of bacteria might be created, and that they might somehow escape from the laboratory to cause epidemics of disease in human and other organisms. If that should happen, there would be no known methods of controlling the diseases that these new virulent agents might produce. This fear seemed all the more realistic since, as already noted, the principal life form used in recombinant genetic research was *E. Coli*, a bacterium whose natural habitat is the intestines of human beings and other animals. Moreover, the principal agents for introducing new DNA into bacteria were viruses, including some that were known to produce tumors in human and animal organisms.

There are, of course, potential benefits as well as risks in recombinant genetics. Pharmaceutical companies have invested in recombinant research in the hope that bacteria can be produced which could manufacture such materials as insulin, a hormone used in the treatment and control of diabetes. And some medical biologists are hopeful that malfunctioning genes in human organisms might someday be repaired or replaced through procedures developed in recombinant research.

However, scientists at the Asilomar conference were primarily concerned about the hazards implicit in such experimental efforts. Their initial work led to a series of conferences under the auspices of the National Institutes of Health which produced guidelines prescribing security measures which must be maintained in laboratories conducting various kinds of recombinant research. Most of these security measures involved physical barriers to prevent the new life forms produced in the laboratory from spreading to the world outside. However, these scientists also wanted to ensure that the host bacteria developed for experimentation could not live outside the laboratory environment. The guidelines they formulated applied only to research supported by government funds, not to that conducted and supported by private industry. Research in recombinant genetics is now proceeding in the United States and in other countries under these kinds of controls.

As the work of the Asilomar and other conferences was reported in the press, concern about the production of "doomsday bugs" spread to the general public. Among the leaders in the effort to alert the public to the dangers of continuing and supporting such research have been scientists themselves--such men as Robert Sinsheimer, Erwin Chargaff, and many younger antiestablishment scientists.

When Harvard University proposed to erect a building in Cambridge, Massachusetts, to house projects in recombinant genetic research, the mayor and council of the city of Cambridge became alarmed and threatened to ban such research in their city. The resulting public furor led to the appointment of a committee of lay persons who, after thoroughly studying the risks and benefits, made recommendations to the mayor and council about the conditions under which such research might safely go on at Harvard.

The effort by scientists and the public to learn to control the vast powers implicit in genetic engineering has just begun. However, two conclusions can be drawn from the brief history just described.

The first conclusion is that, although genetic researchers are to be commended for recognizing the hazardous potential in their own research and initiating efforts to reduce, if not eliminate, this potential, for the most part they have confined their deliberations to technical questions related to laboratory security; they have not dealt with the broader social and human implications of their work. The critics of recombinant genetic research, some of them scientists themselves, have raised important questions which need to be faced by the public as well as by scientists. As Robert Sinsheimer remarked, "There was, at Asilomar, no explicit consideration of the broader social or ethical implications of initiating this line of research--of its role as a possible prelude to longer-range, broader-scale genetic engineering of the flora and fauna of the planet, including, ultimately, man" (Rogers 1977).

S.E. Luria, a professor at the Massachusetts Institute of Technology and a Nobel laureate in biochemistry, has given us a summary glimpse of the momentous questions raised by molecular biology:

> Projecting the present knowledge of biology into the genetic medicine of the future leads inevitably into controversial territory. Such practices as abortion to prevent the birth of defective babies or introduction of different genes into an individual's heredity raise serious questions of moral choice. Some day it may be in human power to decide, not only who will or who will not be born, but also what those born will be like, what genes they will and will not have, whom they will resemble. . . . In a competitive, caste-ridden, power-dominated society, the ability to refashion human beings by selection or manipulation of eggs, sperms and genes might become a tool to promote inequality and oppression. It might serve to create masses of obediently toiling slaves or to manufacture elites of identical rulers--in ancient Egypt, pharaohs married their sisters in order to generate successors as similar as possible to their own divine selves. (Luria 1973)

The second conclusion that may be drawn from this brief history has to do with the interrelationships between scientific experts and lay persons in making policy decisions about potentially hazardous research. The Asilomar conference was limited to scientists, as were the later conferences at which the NIH guidelines were drafted. It has been reported that the scientists at Asilomar distrusted both the public and the news reporters who were their only link to the public (Rogers 1977). It is probable that the panic with which some people react to the mention of recombinant genetic research has been amplified by the feeling that they and their interests are not sufficiently represented in policymaking on issues that affect their health and safety.

The effectivity of the committee of lay persons which helped to settle the Cambridge crisis should be reassuring to both scientists and ordinary citizens (Nelkin 1978). It is clear that scientific policymaking on issues which involve grave social and human consequences must be collaboratively done in the future, and both scientists and lay persons must be reeducated if such collaborations are to be sane and productive. Some scientists must abandon their dogmatic commitment to scientific "purity" (which has never existed, historically) and their contemptuous attitude toward lay persons who "don't know what they're talking about" when it comes to the directions that should be established for scientific research. And lay persons must avoid both blind subservience to and blind rejection of the authority of scientific and technological experts. This kind of mutual reeducation is of the greatest social importance, and it should begin early in the educational process--certainly not later than high school.

However, in dealing with the issues raised in connection with this unit, teachers need to realize that some of them have profound religious implications. The very mention of the word "abortion" in a classroom may provoke the wrath of parents, citizens of the community, and some students. The suggestion that the termination of human life at any stage may be considered a legitimate option in a continuum of values is deeply disturbing to many people. In planning and presenting this unit, teachers need to be aware that such reactions may occur and to consider the sensitivities of both individual students and the community as a whole. As in any of these units, of course, students should never be asked to defend a value position to which they are morally opposed.

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Suggested Learning Activities

1. Exploring Personal Concerns. Genetic research presents all societies with the need to make far-reaching policy decisions, some of which affect all of mankind. Before dealing with these larger questions, it is important that students develop some sense of the personal implications inherent in the processes and programs of genetic engineering. To accomplish this, they might be asked to write personal statements in response to one or more of the following situations:

a. You live in a state which has laws requiring the compulsory sterilization of persons with specified genetic defects. You have discovered that you have one of these defects. Would you willingly submit to sterilization? Give reasons for your decision.

b. You are married. You and your spouse have discovered that a baby is on the way. An examination of the fluids of the fetal sac shows that the unborn child has a serious birth defect. You and your spouse must decide whether to abort the fetus. What reasons against having an abortion come to your mind? Similarly, think of reasons favoring abortion. What would you decide to do? Why?

c. You are one of a dozen clones, "carbon copies" of an adult who is rearing you and your clone "siblings." How would you feel toward your fellow clones? Toward your "parent"? Toward other youngsters who were sexually reproduced? Toward yourself? What differences from "normal" development do you think you would experience?

Students might be asked to share and discuss their statements with the rest of the class or in small groups.

2. Constructing a Value Continuum. A value continuum with positions ranging from extremely negative to extremely positive can be constructed for genetic science and engineering as a whole or for specific aspects of it--eugenic programs to "purify" the human gene pool, human cloning,

or recombinant genetics. After reading and discussion, teacher and students might together construct a value continuum, filling in the value content for both extreme and intermediate positions. Students can then place themselves initially at one value position or another. This process will facilitate casting students in subsequent debates and role-play activities.

3. Debating Policy Issues. Many issues raised by genetic science and engineering can easily be dealt with using the debate format described in Section 3. Here are a few of the debatable issues:

a. Sterilization should be compulsory for men and women with serious criminal records.

b. Abortion should be required for a fetus when amniocentesis reveals serious birth defects.

c. Research on methods of human cloning should be denied public funding.

d. A young man and a young woman considering marriage should be required to undergo analysis of their chromosomes for defective genes and receive genetic counseling before they are allowed to marry.

e. Research and development work on the extrauterine conception and gestation of human beings should be prohibited by law.

If the discussion reveals that students are tending to become polarized on an emotionally charged issue, role reversal might be tried: some of those who have strong "con" feelings on an issue should be asked to develop and present arguments for the "pro" side. The "listening" group, which is trying to find ways of integrating the views of the extremist factions, should include at least one "pro" and one "con" extremist. The purpose of this activity and of the follow-up discussion is, of course, to help those who feel strongly about an issue understand and appreciate the viewpoints of their opponents.

4. Examining Predictions About the Future. In recent years, achievements in recombinant genetics have produced a flood of predictions about the consequences of such research for future societies. Some of these predictions have been made by scientists, others by nonscientists. Students

might be asked to collect such predictions from newspapers and popular magazines published since 1974 and prepare reports summarizing and analyzing these scenarios. While it is too early to say which of these predictions have been historically confirmed or disconfirmed, students might be asked to analyze them with two questions in mind: What is the factual basis for the prediction--what part is fact and what part is interpretation? What characteristics of the author of each prediction probably led to an optimistic or pessimistic interpretation of the facts?

5. Using Science Fiction to Explore Values. Science fiction, it has already been suggested, can be used to help students feel and think futuristically about the consequences, good and ill, of science and technology. Aldous Huxley's *Brave New World* is admirably suited for this purpose in the study of applied genetics. In Huxley's vision of a future world, genetic engineering was used to produce the kinds of creatures needed to meet the requirements of a carefully stratified and controlled society.

After reading the novel, students can profitably discuss Huxley's vision of the future from several perspectives indicated by the following questions: How plausible is the society of *Brave New World* in light of developments in modern biology? In what respects is that society desirable and in what respects undesirable? What alternative ways of life might people build, using Huxley's imagined science and technology? What can people now do to shape the use of technology in humanly desireable ways?

Ira Levin's *The Boys From Brazil* (see page 114) might also be used as the basis for this activity.

6. Simulating a Congressional Hearing. Policymaking for the control of genetic science and engineering can be simulated in a number of ways. One fruitful simulation might be built around a hearing before a congressional committee. The committee is conducting public hearings as part of the process of deciding whether to draft legislation which would ban recombinant genetic research. Students can be cast as members of the committee and as citizens appearing before the committee to try to influence the shape of the legislation being considered. Both "pro" and

"con" citizen groups will need preparation time to think through their positions and appoint and brief spokespersons. Students playing members of the committee will need time to work out procedures for the hearing. The hearing should include presentations by both citizen groups, with questioning by committee members following the presentations. After these presentations, the committee might try to reach a policy decision about the kind of legislation required.

In analyzing and evaluating the experience, teacher and students should focus on both the content issues dealt with in the hearing and the process of policymaking employed in the simulation.

7. Discussing the Implications of Human Eugenics. Eugenic programs for human "improvement" involve the application of methods which animal and plant breeders have used in developing new varieties. These methods primarily involve the propagation of desirable genetic strains and the elimination of undesirable strains through selective breeding and controlled hybridization. In the future, such powerful new technologies as cloning and extrauterine conception and gestation may become feasible.

Students might be asked to discuss the differences between applying such methods to "lower" animals and plants and using them on human beings: What ethical and legal safeguards should be built into eugenic programs at the human level to protect individual and human rights?

Students should be encouraged to carry the results of their study of genetic engineering into social action, so long as the rights of individual students to choose various value orientations (or inaction) are preserved. The actions undertaken might employ any one or several of the formats of citizen participation outlined in Section 3.

12_

Recommended Readings

The first two sections of this unit may be duplicated and used as basic reading both on the scientific background of genetic engineering and on related issues of social policy and ethics. In addition, the following readings are recommended. (For information about locating and ordering publications with ED numbers, see page 129.)

Scientific Background

Luria, S.E. *Life: The Unfinished Experiment*. New York: Scribners, 1973.

> This clear and vivid account of the concepts and findings of modern molecular biology, written expressly for the intelligent lay person, can be used by teachers and advanced students.

Packard, Vance. *The People Shapers*. Boston: Little Brown, 1977.

> In chapters 12-19 and 23, Packard is mainly concerned about clarifying the social and ethical issues raised by actual and potential applications of the growing scientific knowledge of human genetics and reproduction. In furthering this purpose, he presents an easy-to-read summary of the current state of genetic engineering.

Rogers, Michael. *Biohazard*. New York: Knopf, 1977.

> Rogers reports in accurate yet dramatic fashion on the efforts of recombinant geneticists to find policies and procedures designed to reduce the hazards to public health and planetary ecology which are implicit in their line of research. In his report, Rogers covers the Asilomar conference of 1975 and the succeeding conferences, sponsored by the National Institutes of Health, which developed the guidelines that now govern federally funded research in recombinant genetics, his reporting both humanizes the scientists involved and opens up the grave policy issues which genetic research presents to society. The book also contains a succinct history of scientific genetics. Good reading for all students.

Ethical and Social Issues

Packard's and Rogers's books are both useful here as well as on the scientific background, as noted above.

Grobman, Arnold B., ed. *Social Implications of Biological Education.* **Princeton, N.J: Darwin Press, 1979.** ED 056 893.

Chapter 4, "Genetics," includes a symposium on the social implications of genetics and genetic manipulation with contributions by geneticists and teachers of biology.

Hastings Center Report, published bimonthly by the Institute of Society, Ethics and the Life Sciences, Hastings-on-Hudson, N.Y.

This periodical is recommended to teachers as a continuing source on the social policy and ethical issues raised by developments in the biological sciences, including medicine. It also lists new books in the field.

Watson, James. *The Double Helix.* New York: Atheneum, 1968.

This story of the discovery of the structure of DNA, written by one of its discoverers, reveals the all-too-human competition among and fallibility of scientists. For advanced students and adults.

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Benne, Kenneth D. "On Learning to Believe in Persons." In *Mid-Twentieth Century American Philosophy*, ed. Peter Bertocci. New York: Humanities Press, 1975.

Bernal, J.D. *Science in History*, 4 vols. Cambridge, Mass.: Massachusetts Institute of Technology Press, 1965.

Birnbaum, Max. "Whose Values Shall Be Taught?" *Saturday Review*, June 20, 1964.

Boulding, Elise. "Futurism as the Galvanizer of Education." In *Education Reconstruction*, ed. N. Shimahara. Columbus, Ohio: Merrill, 1973.

Brooks, Harvey. "Knowledge and Action: The Dilemmas of Science Policy in the '70s." *Daedalus* 107:2 (Spring 1978).

Bulletin of the Atomic Scientists. Published monthly by the Educational Foundation for Nuclear Science since 1945.

Daedalus 107:2 (Spring 1978), "Limits of Scientific Inquiry."

Daedalus 103:3 (Summer 1974), "Science and Its Public: The Changing Relationships."

F.A.S. Public Interest Reports: The Voice of Science on Capitol Hill. Published since 1964 by the Federation of American Scientists.

Green, Thomas. "The Educational System," chap. 11. Unpublished manuscript, 1978.

Greenberger, Martin, ed. *Computers and the World of the Future*. Cambridge, Mass.: Massachusetts Institute of Technology Press, 1962.

Havelock, Ronald. *The Change Agent's Guide to Educational Innovation*. Englewood Cliffs, N.J.: Educational Technology Publications, 1973.

Havelock, R[onald]., and Kenneth D. Benne. "An Exploratory Study of Knowledge Utilization." In *Concepts for Social Change*, ed. G. Watson. Washington, D.C.: National Training Laboratory Institute, 1966.

Hersey, John. *Hiroshima*. New York: Knopf, 1946.

Kelly, George. "The Expert as Historical Actor." *Daedalus* 92:3 (Summer 1963).

Luria, S.E. *Life: The Unfinished Experiment*. New York: Scribners, 1973.

Nelkin, Dorothy. "Threats and Promises: Negotiating the Control of Research." *Daedalus* 107:2 (Spring 1978).

Packard, Vance. *The People Shapers*. Boston: Little Brown, 1977.

Price, Don. *The Scientific Estate*. Cambridge, Mass.: Belknap Press of Harvard University, 1965.

Raup, R.B., K.D. Benne, B.O. Smith, and G. Axtelle. *The Discipline of Practical Judgment in a Democratic Society*. Chicago, Ill.: University of Chicago Press, 1943. (A revised edition is available with the title *The Improvement of Practical Intelligence*. New York: Teachers College Press, 1963.)

Rogers, Michael. *Biohazard*. New York: Knopf, 1977.

Science, Technology and Human Values. Newsletter published quarterly at Cambridge, Mass., under the auspices of the Harvard University Program on Science, Technology and Public Policy.

Simon, Herbert. *The Science of the Artificial*. Cambridge, Mass.: Massachusetts Institute of Technology Press, 1968.

Time, February 20, 1978, "The Computer Society."

Ziegler, Warren L. *The Art of Futures Invention*. Syracuse, N.Y.: Syracuse University Research Corp., 1977.

Ziegler, W[arren].L., Grace Healy, and Jill Ellsworth. *Futures Invention: An Approach to Civic Literacy*. Syracuse, N.Y.: Syracuse University Research Corp., 1975.

Znaniecki, Florian. *The Social Role of the Man of Knowledge*. New York: Columbia University Press, 1940.

RELATED READINGS IN THE ERIC SYSTEM

The supplementary resources described in this section have been entered into the ERIC (Educational Resources Information Center) system. Each is identified by a six-digit number and two letters: "EJ" for journal articles, "ED" for other documents.

If you want to read a document with an ED number, check to see whether your local library or instructional media center subscribes to the ERIC microfiche collection. (For a list of libraries in your area that subscribe to the ERIC system, write to ERIC/ChESS, 855 Broadway, Boulder, Colorado 80302.)

If an ERIC collecion is not accessible, or if you want a personal copy of the document in either microfiche (MF) or hard copy (HC), write to ERIC Document Reproduction Services (EDRS), Computer Microfilm International Corporation, P.O. Box 190, Arlington, Virginia. All orders must be accompanied by payment in full, including prepaid postage. Prices (correct as of October 1, 1978) are cited for each ED document. (Note that for some documents hard copies are either not available or must be ordered from the publisher instead of from EDRS.)

If your local library does not have a journal article that you want, you may write for one or more reprints to University Microfilms, 300 North Zeeb Road, Ann Arbor, Michigan 48106. The following information is needed: title of periodical or journal, title of article, author's name, date of issue, volume number, and issue number. All orders must be accompanied by payment in full, plus postage.

Documents

Caldwell, Lynton F., ed., et al. *Science, Technology, and Public Policy*, Vol. 2. Bloomington, Ind.: Indiana University Department of Government, 1969. ED 045 366. 549 pp. MF $0.83, plus postage. HC not available from EDRS; order from National Science Foundation, Room 25, 1800 G Street NW, Washington, D.C. 20550 (free).

This publication, prepared with the support of the National Science Foundation, is a master bibliography of 2,700 journal articles published between 1946 and 1967 about environmental quality, pollution, science history, and the socioeconomic impact of technology.

Energy Education Materials Inventory. Part 1: Print Materials. Portland, Ore.: Energy and Man's Environment, Inc., 1976. ED 133 192. 102 pp. MF $0.83, plus postage; HC not available.

Prepared for secondary science and social studies teachers with the support of the federal Energy Research and Development Administration (ERDA), this is one part of a six-part annotated listing of available teacher's guides, curriculum materials, and background readings relevant to current problems of energy use and conservation.

Lahart, David E., and Rodney F. Allen, eds. *Energy and the Environment, Vol. 2.* Tallahassee: Florida State University College of Education, 1977. ED 143 593. 106 pp. MF $0.83, HC $6.01; plus postage.

Prepared by and for teachers of high school science and social studies, this is a report on teaching methods and materials in energy education. The suggested activities, which range from simple to complex, include games and other novel strategies for involving students in issues related to energy conservation and use.

Multidisciplinary Team Approach to "The Man-Made World," A. Denver: Colorado State Department of Education; Boulder: University of Colorado, 1970. ED 065 374. 121 pp. MF $0.83, HC $6.01; plus postage.

This is a report on the classroom testing of an instructional unit focused on the impact of technology in our society. The teaching teams included science teachers and social science teachers. Although few social and public policy issues are treated, there are many suggestions for decision-making games and other instructional activities. Because some of the decision-making games involve the use of computers, this document may offer suggestions to teachers for modifying some of the activities suggested in this monograph for situations in which a computer is available.

Role of Engineers and Scientists in a National Policy for Technology, The. Report no. NSB-72-1 of the National Science Board. Washington, D.C.: National Science Foundation, 1972. ED 141 120. 57 pp. MF $0.83, HC $3.50; plus postage. Also available from Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402; order stock no. 3800-0100 ($0.45).

This booklet, which may be used as a companion piece to the document cited next, offers five recommendations concerning government support of technological development, along with supporting facts and arguments.

Science and Technology in Presidential Policymaking: A Proposal. Washington, D.C.: National Academy of Sciences, 1974. ED 108 858. 63 pp. MF $0.83, HC $3.50; plus postage.

Important because of its semiofficial source, this document emphasizes the role of science and technology in the development of public policy in the areas of weaponry, energy sources, and pollution control. The proposal includes a brief history of past relationships between the

president and the scientific community and briefly treats the role of scientists in health, agriculture, and the modernization of transportation systems. Teachers can use this document to emphasize that scientific "experts" must play a limited role in making public policies.

Journal Articles

Samoilovich, Felix. "Ideology and the Protest Movement in Science." *International Social Science Journal* 27:4 (1975). EJ 135 250. $6.00 for first reprint; $1.10 for each additional copy.

This description and analysis of the current international protest movement in science was written by an Argentinian sociologist from the University of Buenos Aires. The author probes the interrelationships between ideology and science and compares the current movement against science and technology to various recent historical events. His description of the protest movement is international in scope. The article has been translated from Spanish into English. Unfortunately, the translation is not particularly adept.

Zimmer, George F. "Personal Reflections on Science and Social Science." *Social Education,* February 1977. EJ 152 389. $4.00 for first reprint; $1.00 for each additional copy.

The author of this article, a biologist and science educator, once believed that pure science is amoral and that only its applications through technology are subject to moral judgments. However, recent scientific developments, particularly in genetics, have led him to question this generalization. He has not lost faith in science, but he now calls for cooperation between science educators and social studies educators in discovering and testing ways of teaching and learning about science and social policy.