ED 030 565 SE 006 890

By-Butts, David P.

Designs for Progress in Science Education.

National Science Teachers Association, Washington, D.C.

Pub Date 69

Note-109p.

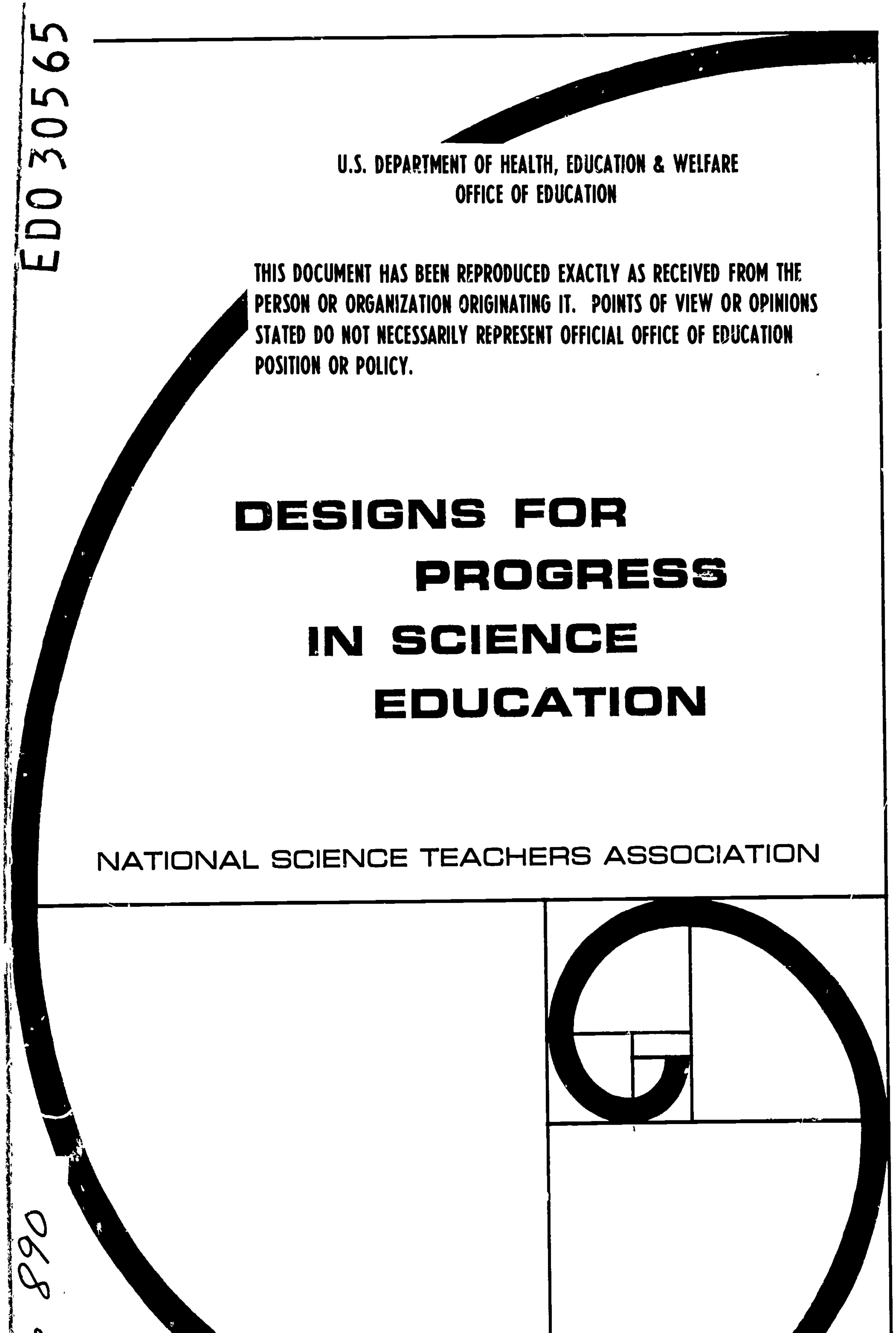
Available from-National Education Association, Publications Sales Division, 1201 16th Street, N.W. Washington, D.C. 20036 ($3.50 paper; $5.00 hard cover).

EDRS Price MF-$0.50 HC Not Available from EDRS.

Descriptors-*Curriculum, Educational Change, *Educational Objectives, *Instruction, *Science Education, Scientific Literacy, Social Influences, *Socioeconomic Influences, Supervision, Teacher Education, Teacher Role, Technology

Identifiers-National Science Teachers Association

This book, prepared as a part of the activities of the National Science Teachers Association (NSTA) Silver Anniversary Year, is directed at setting forth designs for the future of science education which will benefit as equally as possible those who see science as a life-long intellectual adventure and occupation, those who commit themselves to technology, and those (everyone) in need of greater understanding of their environment and the responsiveness of the environment to human actions. Section 1 deals with pressures and influences which have effect on education in general, science education in particular, and the teaching-learning situation. Section 2 discusses the changing role of the teacher, science supervision, educational objectives, designs for instructional programs, and science teacher education. Section 3 discusses change as it relates to science education, and opportunities and responsibilities for science education in the future. (RS)



DESIGNS FOR PROGRESS IN SCIENCE EDUCATION

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THE COMMITTEE ON
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The Commission on the 25th Anniversary of NSTA

Edited by
DAVID P. BUTTS
Committee Chairman

NATIONAL SCIENCE TEACHERS ASSOCIATION, INC.

Washington, D. C.

Library of Congress Catalog Card Number: 74-88308

Washington, D. C.

Stock No.
Paper 471-14584
Hard cover 471-14586

Publications Sales Division, National Education Association

1201 16th Street, N.W., Washington, D.C. 20036

$3.50 paper; $5.00 hard cover

Printed in the United States of America

Designed by Ivan X. Spear

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FOREWORD

THIS BOOK IS released on the 25th anniversary of the founding of the National Science Teachers Association, which came into being in 1944 through a merger of the American Council of Science Teachers, a department of the National Education Association and the American Science Teachers Association, an affiliate of the American Association for the Advancement of Science. In the past quarter century the Association has served a unified science teaching profession, elementary schools through the secondary schools and into the college level.

Throughout the past year, the Association has reviewed its history through a series of inserts in its official journals. Through a series of Silver Symposia, held at more than a hundred locations in April of 1969, the Association examined the relationships between science education today and the current problems of society.

Designs for Progress is at once the final event of NSTA's Silver Anniversary Year and the first event in the future history of the Association. Its view is toward the future, but with the greatest of empathy for the circumstances and for the individuals–administrators, teachers, students, and parents–caught up in today's educational problems while they strive toward the future. The authors have dealt with the present and future of science education from this perspective. Their recommendations are directed to the NSTA as well as to all others engaged in educational endeavors in science. As Elizabeth A. Simendinger points out in the final chapter, this is a task that can be accomplished only through the cooperation of science education and all other areas of the school program. The NSTA, therefore, leaves its anniversary year with the intention of embarking on the path counseled by the authors of the following chapters. It accepts the recommendations of the authors as authoritative counsel rather than as a statement of official adopted policy of the Association itself.

For the preparation of this book, thanks are due to the authors; to David P. Butts and Elizabeth A. Simendinger, who also served as editors; to John S. Richardson, Alfred B. Garrett, F. James Rutherford, Stanley E. Williamson, Norman Anderson, and Phyllis Magat who reviewed the manuscript; and to Mary E. Hawkins, NSTA associate executive secretary, for editorial work on the final manuscript.

ROBERT H. CARLETON
Executive Secretary
National Science Teachers Association

Washington, D.C.
April, 1969

INTRODUCTION

AT THE INCEPTION of the National Science Teachers Association in 1945, the nation was concluding a tremendous war effort, and energies of many kinds were being released for reallocation in society. Moreover, two great philosophical shifts had thrust the world into a new era in regard to science. One, of course, was the psychological effect of the atomic bomb and the idea that men could harness nuclear energy. This shift was so sharp and so devastating that equilibrium is not yet achieved. The other great change resulted from the upwelling of science-based technology and medical advances into every cranny of our lives and culture. Radar, television, transistors, plastics, computers, antibiotics, and DDT not only catapulted new discoveries into our lives in technological form, but they also set in motion great changes in teaching and learning science and in efforts to organize the flood of new knowledge. Perhaps even more important than the new situation in the sciences will be the communications and social revolution being created by our electronic devices—computers and television and, since 1957, satellites.

Many of the energies that flowed back into society after the war had been concerned with science-related research and development and naturally injected this science flavor into postwar life. They also brought a keen sense of the importance of highly and appropriately trained manpower.

The tremendous increase in scientific knowledge and the increasing rapidity with which new knowledge was added to, or superseded, the old made it evident that educational programs at all levels must be reorganized on two bases: pertinent content and self-renewal. For example, there was need for some built-in mechanism for a sort of molting process so that content no longer useful or pertinent, whether in practice or in the educational curriculum, could be abandoned in a smoothly flowing evolutionary process.

Persons and organizations, such as the National Science Teachers Association, were available and eager to attempt such a transformation of the educational program. The shifts in thinking brought about by nuclear energy and technology had created a receptive and interested public, and efforts for the reorganization of science sequences and curricula in the schools got under way rather easily. Another great impetus—the launching of the Soviet Union's satellite, Sputnik—and the subsequent crash programs of federal funds for educational improvement through the Office of Education and the National Science Foundation made possible curriculum innovation unprecedented in scale and speed.

The new science programs had two characteristics in common: preference for the abstract (theoretical) or "pure" science and involvement of the learner in direct inquiry. Scientists, particularly from universities and high schools, were heavily engaged in developing the new programs—first in physics, chemistry, and biology for secondary schools and then in programs for the elementary schools and junior high schools. In the past decade, thousands of schools have "adopted" the new programs, thousands of teachers have been given special training to teach the new programs or to update and upgrade their science knowledge, and millions of students have been introduced to science through the new courses. In addition to the new science curriculum programs, hundreds of school systems have become directly involved with their staff and pupils in local science curriculum revision. Publishing houses and the big "knowledge industry" combines have attempted to inject innovative approaches and materials into the educational process in science.

It is probable that a self-renewing system has been achieved to some extent. The leadership of NSTA and others has established the idea that the great conceptual schemes of science are the most enduring base around which the science curriculum can be organized and new knowledge integrated into a meaningful, continuing structure. Many administrators and teachers have become aware of the changing nature of science and of the ingredients necessary to maintain first-rate programs. The public, for the most part, is at least respectful of science.

Nevertheless, simultaneously with these achievements has come a realization that to some extent the curriculum makers have narrowed—or at least not broadened—the base of young people who grasp the relevance of science in their own lives. Nor have they achieved what is generally called "scientific literacy" on the part of the general public.

Science is a basic and important aspect of man's intellectual endeavor. It is also the basis underlying our technology as well as our increasingly frequent biological manipulations. Education in science cannot, therefore, be apart from the social and cultural turbulences which seem certain to be the characteristics of the next few decades. Accommodation with these forces and the continuing self-development of science programs will demand new designs for progress in science education.

In this era of widening responsibility, it is essential that all who have a part in science education should concern themselves not only with what should be taught at what level, but with what happens between science and the student, between student and teacher, and between the teacher and science. The focus of this widened responsibility falls on science and society, on the interaction of students and teachers, and on the preparation of teachers. What are the various dimensions of this widening responsibility? What are the issues and problems to which science educators must address themselves to provide the level of scientific literacy needed in the next quarter century? What specific kinds of action are demanded?

This book attempts to set forth such plans—designs that will benefit as equally as possible those who see science as a great lifelong intellectual adventure and occupation and those who commit themselves to technology. It must also serve those so desperately in need of greater understanding of their environments and the responsiveness of environments to human actions. And, above all, science must gain the attention of those who lead in cultural, political, and educational decision-making.

1

FORCES AND PRESSURES

1

HERMAN BRANSON
Central State University
Wilberforce, Ohio

AN ERA OF WIDER RESPONSIBILITY

"The art of progress is to preserve order amid change and to preserve change amid order." – Alfred North Whitehead

THE THEME OF THIS BOOK is the relationship of change and progress within the kind of order that permits responsible action and experimentation. The past 25 years have given science education a greatly enlivened domain within the total education scene, especially in the elementary and secondary schools. We have a viable base from which to continue to improve teacher competency and to innovate in curriculum and in instructional design. We have the beginnings of changes in education tactics and in motivation for the learner. We realize that competency within any narrowly defined domain is not all that is required of today's education. Knowledge should be a basis for decision making and for action. Science, for example, offers a rational base for decisions and for actions which, by the very nature of the interactions in society, will be taken with or without realization of or regard for the consequences.

Is this nation adequately aware of the great influence science brings to bear on the affairs of man? No one quarrels seriously with the contention that a society's technology shapes the lives and minds of its citizens and that our technology rests on science. But what rationale guides the progression from science to technology–who decides which path is to be followed or which application selected? As sociologist H. W. Eldredge states

> . . . one great aspect of the present world scene is the enormous contemporary explosion of our knowledge and the resultant technology. . . . We are not only developing greater stores of pure science but are incorporating this science very rapidly into the technology of our time . . . Unquestionably, the natural sciences are fructifying more rapidly than the social sciences. Our political and economic institutions are patently unable to control our new inventions; in any rational comprehensive sense, modern man has lost effective control of technology.[1]

The importance of science in the American enterprise has not received the attention it deserves, either from the educational community or the general public. True, we are thrilled by dramatic achievements in space exploration; we are duly proud of our countrymen who win Nobel prizes; we shudder at floods and bemoan air and water pollution. But, nevertheless, science does not loom large enough in our value scale. We need to take a closer look at studies of the type conducted by the Directorate of Scientific Affairs, Organization for Economic Co-operation and Development of the United Nations, in its "Reviews of National Science Policy." In the volume on the United States,[2] the Directorate authors state:

> The scientific and technological effort thus becomes the enterprise of the nation . . . The enterprise is indissolubly linked to the goals of American society, which is trying to build its future on the progress of science and technology. In this capacity this society as a whole is a consumer of scientific knowledge, which is used for diverse ends; in the last century, to increase agricultural productivity and to facilitate territorial development, then to back the national defense effort, to safeguard public health and to explore space. These are activities which have an impact on the destiny of the whole nation, and it seems natural that all skills should be mobilized to cooperate. [p. 346-7]

Farther along they continue,

> A process is thus launched, at each stage of which science and technology penetrate deeper into the American reality . . . All the driving forces of American society have been marked with a scientific orientation and all the skills have been mobilized. [p. 348-9]

And their final paragraph sums up as follows:

> We looked in the United States for a science policy; in fact there are many. But what we did find, in the formulation, implementation, and achievement of these policies, is first and foremost a convergence of interests and motivations to construct the future; the adventure of scientific and technical research appears as the main way of access to this future in which the drive and ambitions shown by a whole nation will be expressed. [p. 349]

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[1] Eldredge, H.W. *The Second American Revolution.* Washington Square Press, New York. 1966. P. 11.

[2] *Reviews of National Science Policies–the United States.* The Directorate of Scientific Affairs, OECD, Paris. 1968. 546 pp.

Many of us on the American scene may be less sanguine than the distinguished United Nations team of observers on several counts, especially that "All the driving forces of American society have been marked with a scientific orientation and all the skills . . . mobilized" with respect to education in science at any level. Nevertheless, this study provides valuable guideposts for us. If we do intend to build our "future on the progress of science and technology," we must bestir ourselves to insure that a considerably larger effort goes into education in the sciences and especially into illuminating their implications to our society.

We may speak of the high priority of science education, but such priority is often more evident in oratory than in action or changes. Let us examine four examples supporting this indictment.

There is, in the first place, a demonstrated shift in interest of students away from the sciences. This movement has been best documented in Britain. The Dainton report [3] revealed that in 1962, 45.9 percent of the students entered science and technology programs, while in 1967, the percentage was 40.6 percent–a sharp drop for such a short period. Simultaneously, the American Institute of Physics was announcing that the total number of physics bachelors was decreasing from a high of 5,611 in 1963-64. However, in 1969, the AIP expects a leveling off at somewhat above 5,000 physics bachelors. Whether the factors operating in Britain were the same as in this country would be difficult to determine; nevertheless, the trend is the same.

A look at the student minority which is leading the social and political activism might be one excellent means to find clues to dropping enrollments. These students express great dissatisfaction with what is being taught and how it is being taught. They talk of making the university experience relevant–so should everyone concerned with science education. One aspect of wider responsibility, therefore, is to determine and achieve relevancy at all levels of education. We are using the currently overworked term "relevance" to mean a perceived relationship between science (its concepts, knowledge, and processes) and the real-life environment and concerns of the student.

Directly related to dropping enrollments are manpower shortages in science-based fields. Consider the situation in medicine. Perhaps even more than engineering, medicine is the scientific area impinging most directly on the public. American medical schools graduate 8,000 doctors a year, but we need 12,000. Hence our hospitals have 11,000 interns and residents trained in foreign countries, about 27 percent of their full-time staffs. And for each of the past five years, 1,400 foreign graduates of foreign medical

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[3] Walsh, John. "Dainton Report: British Youth Swings–Away from Science." *Science* 159: 1214; March 15, 1968.

schools obtained permission to practice here. We cannot rejoice that our failure in this field of science education is at least being compensated for, because this influx plays havoc with other countries.

A second contrast between the high priority we claim for science education and what actually happens, lies in a change in the attitude of the nation's independent liberal arts colleges toward the nature of the education they offer. Among the more than 1,700 American colleges and universities in which physics is taught, about 800 colleges offer an undergraduate major in physics. These 800 colleges have naturally been most valuable feeders to the 160 universities granting the PhD in physics. But

> . . . teachers and administrators (in liberal arts colleges) . . . were growing more and more anxious about their ability to continue to provide effective science instruction for their students . . . . For the mounting costs of instruction and research, the accelerated growth of science, the increasing competition for science faculty, and public identification of science with big science–and big science with big institutions strongly supported by federal funds–all of these point to the conclusion that the action is elsewhere.[4]

Although these schools have exhibited a fine resilience and astonishing vitality in the past, so that we can expect them to adjust, their plight is serious; and aid must be found for them. These schools have the first requisite for a good science program–imagination. But for their second necessity–money–prospects are less bright, either through assistance from the federal government or from other sources.

With less support for educational programs, how can we truly meet the challenges of our third problem–the vast, complicated implications for the human race of the imminent powers of molecular biology in altering man himself? As Sinsheimer[5] predicts, "Eventually we will surely come to the time when man will have the power to alter, specifically and consciously, his very genes." There is little doubt that most people, including perhaps intellectuals other than biologists, will need the most careful and thorough educational preparation as well as sympathetic counseling for this eventuality. There is no hope that "the changes we introduce be orderly and with humanity aforethought" without an informed and participating public. In changes so directly related to man himself, we are dealing with attitudes and postures most impervious to change. However, neither science teachers nor educators can justify neglect of this area of wider responsibility. Those who plan and teach science programs will surely feel this strain. Another concern of a similar type is the "chemistry of learning," for educators are already hearing about enzyme-assisted

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[4] Stewart, Albert B. *Antioch Notes.* February 1968.

[5] Sinsheimer, Robert L. "Letter to the Editor." *Saturday Review* March 2, 1968. Pp. 19, 59.

instruction, protein memory consolidators, and transfer of learned behavior patterns by extracts of brain and other organs.

The fourth problem is the existing tensions within the sciences and mathematics over what should be taught. I.I. Rabi tells us:

> A young person in school now is going to be living maybe half his life in the 21st century. What are we teaching him to help him live there? Very little! What we need basically is a new look at the objective of education. And the most important subject we can get across to people is the role science has in shaping and unifying our 20th century culture. But we scientists ourselves are losing sight of the broad scope of things and the result is that instead of being the unifying element that could make some sense out of our fragmented culture, science has become just another fragment.[6]

These four problems indicate that, within science education, the next 25 years should be given to continued subject-matter competency with the important addition of some essential new concerns. Certainly we must broaden the range and depth of science education. And while we cannot hope for a fault-free prediction of what we must work toward, we can make certain selections appropriate to an era of wider responsibility. We can summarize the tactics as follows:

1. *We must foster continued innovation in curriculum and instruction.*

There must be more relevance in content for all pupils. The new media must be fully explored and utilized. Remember that Socrates once told Phaedrus that writing was a diabolical invention apt to ruin the memories of its practitioners.

2. *We must ask for great improvements in the manner of handling science in the schools, especially the secondary schools.*

This may mean laboratories in which equipment is set up and ready for operation and can be left in place until the experiment is completed; in which there are technicians to assist in keeping equipment in working condition; in which the teacher has a reasonable class load with time to experiment and innovate in science and in teaching methods; in which there are ample supplies, delivered promptly and in good condition; in which equipment is repaired quickly; in which modern and appropriate science books and a variety of other current materials are available in the laboratories and classrooms.

3. *The professional stature of the teacher must be improved.*

Teachers should be given twelve-month contracts with time for professional learning built into the year's schedule. During a twelve-month period, two months should be devoted to study, nine months to teaching, and one month reserved for vacation. This extension of contracts for study

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[6] Rabi, I. I. *Scientific Research* 62-63; September 1967.

would provide an excellent opportunity for the federal government to offer support without danger of federal control.

Teachers might work for two months each summer in carefully planned programs at colleges and universities, in the school unit itself, in science education centers, or possibly in field stations or research centers. Subject-matter requirements that now discourage college graduates who want to teach could be satisfied over a reasonable period, either through programs established by the school systems or in college programs. An influx of these teacher-students each summer would be a boon to the colleges in developing 12-month school years. But, most important, such a program of continued learning would recognize the dynamic quality of modern knowledge, educational methods, and evaluation standards.

4. *In all education, but especially in science education, there must be a heightened sense of urgency, of immediacy, to relate learning to our human and social problems.*

The student as well as the educational system must become self-renewing so that he continues to participate in the development of science in the future and is truly able to see that what he learns in science is indeed relevant–and indispensable–to his life and to the culture of his day.

A lamentable aspect of human society is that reasonable preventive measures are rarely taken to ward off disaster, when even the less sensitive among us know full well the exact nature of the oncoming calamity. Examples abound today in areas such as population, food, environmental quality, and social interaction. To insure that the teacher reacts with assurance and conviction, we must plan for deeper knowledge of the biology of man, of the physical environment, and of human resources as part of new curricula. The thesis of Barbara Ward's "Spaceship Earth" should be a guide to educators and an accepted concept to students.

2

FRED W. FOX
Oregon State University
Corvallis

FORCES INFLUENCING EDUCATION

IN ANY ERA, many social forces change educational practices. Some of today's forces are new, some old, some merely variations. The tensions and problems of our time intensify the forces and cast them into different forms.

Education historians tell us that the fundamental determinants of the educational scene at any point in time are economic, political, social, and religious in nature. To interpret education adequately, one must add man's view of nature and himself, his intellectual and philosophical stances, and his psychological and scientific understandings. Obviously, all of these forces are at work simultaneously, and it is difficult, if not impossible, to separate them completely, whether we are studying the past or planning for the future.

The lists of problems that beset mankind today are well known.

War and peace
Racial tension
Population explosion
Food and famine
Decay of inner cities
General inadequacy of urban life
The moral fabric of society
Misuse of natural resources

Environmental changes
The psychological and economic accommodation to a technological, cybernated age
International relationships
The knowledge explosion
Educational disaffection

We speak of them as problems and phrase them in negative terms. However, in considering the forces affecting education, we should not overlook how achievements of the past will also play an important role. We will try to solve problems, but we will also have many positive bases on which to build. Science through technology has freed man from much of the drudgery of physical labor and from fear of many once-fatal diseases. With a higher standard of living, man can direct his energy toward helping his fellow man as well as toward making a more satisfying use of his recently won leisure.

CHANGE

Pervading the recognizable forces, and indeed all of the problems on our list, is change—and of even more importance today is the rate of change. Change is so rapid that the character of a problem is often altered before the difficulty can be defined. War poses a new dilemma when, through the possibility of nuclear holocaust, our whole modern civilization complex is threatened. The human population has threatened explosion in numbers just at the time when territorial frontiers are exhausted, and food actually appears to be in short supply in many nations. Concomitant racial tension, social injustice, poverty, and other forces spawn rebellion in the streets, destroying life and property, and endangering the very structure of the nation. Exploitation and pollution of our natural environment have come full cycle, so that now our environment appears to pollute our lives by endangering our health and hence threatening our comfort, if not our very existence.

Harold Full thus summarizes the conditions and defines the challenges to education:

> Those who have anything to do with education in America today have a solemn responsibility to reflect on the revolutionary changes going on about them and to help prepare the children and youth to meet an ever-changing future. Instead of becoming engulfed by what is happening around him, each individual must be helped to see that man's intelligence can govern the changes taking place, can shape their direction, and can create enlightened attitudes toward desirable changes that are necessary for the growth of a dynamic society.[1]

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[1] Full, Harold. *Controversy in American Education: An Anthology of Crucial Issues.* The Macmillan Company, New York. 1967. P. 10.

Our problem now is to examine, in the midst of a period of awesome and rapid change, the forces which are at work today, selecting those which are most directly pertinent to science education and most likely to influence it.

TECHNOLOGY

The impact of technology on modern education has been such that it deserves special mention. In the U.S.A., technology can now be classified with the large categories of forces–economic, political, social, or religious. It is a dominant factor of our time.

Through technology we face an unusual dilemma. Never before has Western man had so much and had such wonderful prospects for even greater advantages for the future, but the type of future that he can predict is no more sure today than it was in the past. He senses possession of a power to get virtually anything he wants, but is unsure of what his wants should be. We have a fantastic array of options from which to choose, but we often tremble at the thought of the consequences of our choices. "The American society is now confused, insecure, and, from time to time, destructively irrational," states the chancellor of a large western university. "We wonder if we have lost the capacity to manage ourselves and find the future."[2]

While the impact of technology on education–and on other aspects of our lives–is extensive and obvious to all, there is little agreement about the appropriate relationship of the study of technology to the basic principles in educational curricula A strongly held view of some scholars in relation to technology is that change is so rapid in technology that knowledge about technology is quickly outdated, and students are better able to cope with the future if they have a sound base in concepts, rather than knowledge of applications or skills. Technological applications of science and consequent problems growing from such applications have deliberately been omitted, in the main, from the curriculum.

To the extent that many of the dominant and urgent problems of society have deep roots in technology, a justifiable criticism of modern science curricula as they relate to general education is that they have not illuminated the interrelatedness of science and technology and also that these new curricula have not been addressed to the components of our critical personal and social problems.

Are the overwhelming problems of our society the legitimate concerns of the schools? If so, then each subject-matter area must find its place in

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[2] Murphy, Franklin D. "The Delicate Balance." *Saturday Review* January 13, 1968. P. 113. At the time of the writing, Mr. Murphy was chancellor of the University of California at Los Angeles.

the total attack on these problems. It is important for science education to continue to seek an appropriate balance between content and process in the study of science. It is also of the greatest urgency that science extend its capacity into both the problems and opportunities of our time. To say that a citizen of our nation is adequately educated in science if he understands only its process and structure is a fallacious assumption. We owe more than this to the young people of our society.

The problem then is how to get "both and," not "either - or." We must find how to get a favorable balance between theory and application.

INFLUENCE OF SCIENCE ON MAN

The influence of scientific thought on man may well be as important to the condition of modern man as the technology-related influences. This influence reaches into the philosophy of the kind of world in which we live and into an increasing interest in attitudes and values of man, the most complex organism in this world. Some truly important influences of science on man go beyond technology and include *what he thinks about* and *how he views his place in nature and the universe.*

Bertrand Russell once suggested four ways by which science has had an impact on society. None has to do with technology, but all concern how man views his universe and his place in it:

(1) observation versus authority
(2) the autonomy of the physical world
(3) the dethronement of "purpose"
(4) man's place in the universe

Developing these ideas Russell states that "matters of fact are to be ascertained by observation, not by consulting ancient authorities" but that "there are still a great many respects in which the lesson has not been learned [by modern man]."[3] The concept of "purpose" has been important to man down through the ages to explain the nature of the universe and man within it, but "it has been found that 'purpose' is not a useful concept when we are in search of scientific laws."[4]

Russell is suggesting that modern scientific thinking has altered the fundamental criteria by which we examine and accept the universe in which we live. Whitehead uses an apt and delightful phrase when he says that the quiet growth of science "has recoloured our mentality."[5]

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[3] Russell, Bertrand. *The Impact of Science on Society.* George Allen and Unwin, Limited, London. 1952. Chapter 1, pp. 16, 18.

[4] *Ibid.* P. 21.

[5] Whitehead, Alfred North. *Science and the Modern World.* The New American Library, New York. 1948. P. 10. Original hardcover edition published by Macmillan Company, New York. 1926.

Secondary-school science teachers may unwittingly be challenging the basic presuppositions by which man has traditionally lived. The problem for science educators, of course, cannot be to deny what scientific modes of thought are actually doing to us; rather, we are confronted with decisions on curricular emphases and priorities regarding these matters.

Our current need in science education is an adequate analysis of the scientific enterprise. Schilling's analysis is useful:

SOME OF THE ASPECTS AND MODES OF SCIENCE
A. Science as a Body of "Organized Knowledge"
B. Science as a Way of Knowing
C. Science as an Area of Experience
D. Science as a Foundation of Technology
E. Science as an Intellectual and Moral Influence
F. Science as a Social Enterprise [6]

Recent emphasis in science education has been primarily on the first two elements of this analysis: understanding science as a body of organized knowledge (product) or content and as a way of knowing (process). With more than a decade of investment of federal resources in the development of new programs suited to these ends and with the prodigious effort made to help teachers with these curricular innovations, it may be reasonable to assume that science education is making fair progress toward these two objectives. However, we need to explore the last four areas of Schilling's categories, for it is here that science is related to the individual and society.

CONCEPTS OF IDENTITY AND ALIENATION

One can speculate that recent successes in space exploration and the highly moving earth-visions of our astronauts will transform man's view of himself in relation to the universe as well as his view of the delicacy and value of his home planet. We can hope that man's spirit will indeed be so refreshed.

For the present, however, we must still recognize that deeply involved in modern man's dilemmas—and particularly youth's—are self-identity and alienation. These are among the most disturbing influences on educational arrangements today and, we believe, underlie many of the failures of young people to achieve a satisfactory identity and self-respect. These themes run deeply through Kenneth Keniston's monumental study of American youth[7] and are integral to many other writings of the past

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[6] Schilling, Harold K. "Teaching Reciprocal Relations Between Natural Science and Religion." In *Teacher Education and Religion.* A. L. Sebaly, Editor. The American Association of Colleges for Teacher Education, Oneonta, New York. 1959. Chapter 5.

[7] Keniston, Kenneth. *The Uncommitted: Alienated Youth in American Society.* Harcourt, Brace and World, New York. 1965.

decade. They are as pertinent to science as to psychology, for they concern the total person and are interwoven with personality, social outlook, trust in the present, and expectations for the future.

Gaining self-identity, according to Rogers,[8] involves such tasks as finding what one is *not*, avoiding (or, better, evaluating) what others think one "ought to be," and (perhaps) moving away from what one thinks the culture expects of him. It means moving toward more autonomy, choosing one's own goals, and being increasingly open to the processes of life. As will be discussed in later chapters, instructional arrangements can provide for early practice in decision-making. To feel the sense of acceptance and to be "free to move in any direction" are part of self-identity. They are also part of a society which offers real freedom to its members.

What science education itself can contribute to easing the burden of alienation and to fostering the discovery of self is certainly open for exploration and experimentation, and both are needed. We can point out some peculiarities of science that can be introduced into the thinking of children and young people as an element to be used as they build their view of their world. Science offers a rational way of looking at the universe, man included.[9] Science demonstrates continuously that nature is neither capricious nor completely known. There is a sustaining framework of concepts and so-called scientific laws on which the student can depend, and yet the entire structure is not complete and can only advance toward completion through the discoveries that man makes using his own mind. Another line of reasoning[10] that can be used with older students is to build the concept of the interrelationships of man and environment and of man as a part of the universe. Alienation then becomes an untenable position unless one denies his own existence. Such an approach may help to alleviate the estrangement from nature which Eric Josephson describes thus:

> The flowering of science and technology gave man enormous power to control nature and thereby transform society. . . .when we speak of our power "over" nature we reveal a certain antagonism between man and the external world.
>
> Estrangement from nature is now the common experience. Isolation from nature is not just a matter of living in cities; even more important, it involves a momentous change in man's outlook on the world. Men do not simply coexist with nature, they search for meaning in it.[11]

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[8] Rogers, Carl R. *On Becoming a Person.* Houghton Mifflin Company, Boston, Massachusetts. 1961. Chapter 8.

[9] Refer, for example to *Education and the Spirit of Science,* as discussed in Chapter 5.

[10] Described by Professor Harold Cassidy, of Yale University, at a Conference on Interdisciplinary Science Education, held in Washington, D.C., January 23-27, 1969.

[11] Josephson, Eric, and Josephson, Mary, Editors. *Man Alone: Alienation in Modern Society.* Dell Publishing Company, Inc., New York. 1962. Pp. 35-38.

In this discussion we are still speaking of an impact of science that is separate from the impact of technology. We are speaking of a facet of science—one might even say science *per se*—that is having an enormous and *virtually unexamined* influence on man and society. It is an essential part of the story of science, and it has vital implications for science instruction of today's educated citizen. We are becoming increasingly adept at telling the story of modern scientific knowledge and scientific method. Of that there is little doubt. But if we are to examine and to guide the forces which are shaping education or which should be shaping it, these newly understood roles of science can no longer be overlooked. Science programs must deliberately include, throughout the school year, time to examine these facets and explore their relevance to the needs of their students.

A crucial factor is the teacher. He must be a perpetual student of the total scientific enterprise and its relation to the human condition. Unless he develops understandings, indeed, convictions of his own which stimulate and sustain his personal life, there is little likelihood that true change will be effected in the classroom. For the teacher whose conceptions of education mingle in both his tissues and his mind, methods, content, and materials flow easily for classroom experiences. To bring about the kind of change of which we have been speaking, we must start with ourselves.

Science instruction should accept as one of its functions to serve as a molding force to assist individual students to establish their own identities. We leave for later discussion the question of the extent to which science instruction should incorporate values for living.

3

HAVEN KOLB
Hereford Junior–Senior High School
Parkton, Maryland

PRESSURES ON THE TEACHING–LEARNING SITUATION

THE TEACHING-LEARNING SITUATION, as pictured by several generations of Americans, is James Garfield on one end of a log and Mark Hopkins on the other. It is an oversimplified image but one that does present two of the irreducible elements of a true educational situation: a learner and a teacher.

Learner and teacher are there, but the picture is motionless and silent. Yet the nouns imply action: A teacher must teach something; a learner must learn something. But *what*? How to chip an arrowhead? How to shoe a horse? The Nicene creed? The virtues of George Washington? Cheerful facts about the square of the hypotenuse?

Who shall say? Enter now a fourth factor. More than the log existed between Garfield and Hopkins, and more than the wildlife of the Ohio woods surrounded them. Pressing on them were a thousand interposing images from a thousand past experiences that scatter the sylvan scene: The Roman forum and the meadows of Runnymede were there, as were Sinai, Golgotha, and Olympus. The past and the present pressed upon teacher and learner: Victorian prudery, nineteenth-century optimism, sparks from bell-funneled locomotives.

No true teaching-learning situation is idyllic; each is a focal point for pressures—pressures that determine not only what is taught but how it is taught. From the springboard of the Garfield-Hopkins image, let us examine pressures that bear upon teacher-student interaction in science education today and speculate on their future. Later chapters will discuss accommodations with these pressures.

SOURCES OF PRESSURES

The nature of any educational enterprise, when viewed as a whole, is obviously dependent on the nature of the society that supports it. What can be discovered about education in ancient Greece conforms to what we know of ancient Greek culture. Likewise, the manner in which the young are educated in still-existing primitive societies conforms to the ethos and mores of those societies. It follows that when we look for pressures on education we should look first to the society that supports it.

Throughout its history as a human institution, education has been supported as a conservator of culture. Because it is not biologically inherited, culture can survive only through social transmission to each successive generation. Contrariwise, education in numerous instances has been the leavening for changes in culture. In these instances those who presume to education usually meet social hostility—the most celebrated secular case being that of Socrates.

The dual nature of education, as simultaneous conservator and instigator of change, has resulted in ambiguous views of the relationship between education and society. Among bees, a society may exist without education; but among humans, society is certainly a creature of education. Yet each culture creates a kind of education that is peculiar to itself. Though that education may get out of hand and ultimately destroy its creator, it is, for at least a time, dependent upon the culture and only to be understood in the light of the demands that its parent social system makes upon it. And because education is reducible to the sum of myriad teacher-learner interactions, every such interaction reflects those social demands.

Bearing upon every teaching-learning situation, then, are pressures originating from the nature of the society in which it occurs. Springing from sources that are sometimes vague, scarcely definable, and only indirectly detectable, these pressures, nevertheless, must be the point of departure in any attempt to discuss education.

The instruments through which the pressures of a society are directed upon its education are often the society's other institutions. Foremost of these in the United States in the 1960's is government—national, state, and local. We can see no reason for believing that government will be any less potent in the 1970's.

On tax-supported institutions, particularly the so-called free elementary and secondary schools, the pressures of local, state, and federal governments are direct and undeniable. During the sixties, arguments concerning the weighting of governmental pressures have declined in both frequency and volume. Federal influence has increased only slightly in appearance, but a great deal in reality. In many communities, local influence has continued its historical decline. He who hopes to turn back that tide in the next decade is likely to be no more effective than King Canute on the North Sea strand.

Private schools and colleges are ordinarily little affected by local government pressures, partly because their clientele is much broader than the geographical spot on which they happen to be located. But state governments have more effect upon them. And increasing federal pressures on colleges and universities are reaching the point where "spurious" may soon be the proper word to describe the independence of such educational institutions.

Because, in our present American society, government has come to be such an overriding instrument of social policy, other social institutions tend to apply their pressures upon education through government. The most frequent avenue of persuasion is the state legislature–and science education has frequently borne the brunt of resulting legislative prescription. Does the general adult society feel pangs of remorse for the deplorable example it is setting for its young? Expiation is easy: Who would oppose laws to force teachers into confronting learners with the evils of alcohol and tobacco?

Not all pressures are applied through government. Industry, labor, religious, and eleemosynary groups, and a host of special-interest organizations make use of varied publicity techniques. But all recognize the germinal effectiveness of specific approaches to those who operate the schools. Boards of education, superintendents and supervisors, principals, and teachers are continuously informed, advised, cajoled, and even threatened.

Other pressures from society are expressed in a diffuse way or are organized only casually and sporadically. Among these are pressures arising from the learner's position in the social scheme. Perhaps to some extent youth forms a special subculture in all human societies, though it seems to be minimal in most societies that have meager technologies. There appears to be no doubt, however, that youth in our society constitutes a well-defined subculture. And such is the nature of our general culture that the subculture, although economically dependent, can successfully challenge and even disrupt that which supports it. The pressures of the young learners on the educational enterprise are very real in American education. Strongest at the level of higher education, these pressures also now exist at lower levels and seem likely to increase there.

Finally, it is necessary to mention the pressures arising from the "racial" segmentation of our society. To some extent, these find expression through government, and to some extent they operate through organizations, but the most pervasive pressures on education from this source are nongovernmental and unorganized. They are, however, frequently confused with other forces more or less relevant to education, such as poverty, and they, too, are related to youth's pressures.

Looking into the near future of science education, it seems reasonable to expect that basically education will continue to be molded by the same forces that exist today, though their mode of expression may well vary from decade to decade. It seems likely that the channeling of society's educational activities will be directed increasingly through government. Almost certainly the federal aspect of government activity will increase. It is not unlikely that the next quarter-century will see some international component in the educational enterprise. Hopefully, those present pressures that embody some of man's higher ideals—a greater regard for rationality, a more profound sense of humanity, a wider appreciation for diversity—may actually feed back into society and result in greater pressures for their extension.

KINDS OF PRESSURES

It is customary to speak of pressures pejoratively. But without pressure no action occurs. In social situations pressures are seldom so balanced that a static equilibrium results. Certainly no teaching-learning situation is static; unbalanced pressures must exist. Therefore, no single pressure can be assessed as good or bad in itself; it can be judged only in the context of the whole situation.

The multitude of pressures that impinge upon the educational enterprise do not equally affect science education. Some—such as the pressure to furnish instruction in a child's home language—are peripheral. Here we must confine our attention to pressures that are central.

Scientific Literacy

A primary pressure on science education is the demand for scientific literacy. This demand issues from scientific and educational communities, but it is also supported, perhaps with differing interpretations, by commercial and industrial groups and by some governmental entities. The pressure may stem from recognition that ever-increasingly the support of science research has become largely a government function and, therefore, ultimately devolves upon the electorate. It is assumed that the electorate must understand and appreciate what it supports. Some experience may not seem to support the assumption. For example, it can scarcely be argued that the electorate in the United States had a high degree of scientific literacy when the National Science Foundation was established. Nevertheless, *continuity* of support may indeed be dependent upon a scientifically literate electorate. Present difficulties in continued growth of federal financial support for science and for strictly science education may foreshadow this.

The demand for scientific literacy may be expected to continue merely from the tendency of education to reflect the social milieu and also because the curious student wants to learn how to interpret his universe. There is no indication of any lessening of the influence of science on society, no matter how much or how little this influence may now extend to the voting booth. We can expect, therefore, a continued public demand for enlightenment concerning the relationship between science and our ability to deal with both physical and social environments.

What is not certain is how that term, "scientific literacy," will be interpreted in the teaching-learning situation. To some it means merely dissemination through the school population of miscellaneous ephemeral facts. To others it means inculcation of a spirit of inquiry. To still others, it requires abundant student experience with laboratory investigation—inquiry in action and not merely dry-runs or passive witnessing of colorful screen-shadows; and it may include appreciation of the work of scientists. To many the social relevance of science, and of the technology springing from it, is the only really important aspect. True scientific literacy, however, must be some combination of these.

These views are sometimes mutually supportive and sometimes antagonistic subpressures in the push for scientific literacy. But at present, a fairly clear picture of the meaning of scientific literacy can be obtained from the work of some of the science curriculum groups, from *Education and the Spirit of Science*[1], and from the work of the National Science Teachers Association.[2] The following statement of the characteristics of the scientifically literate person, by Paul DeHart Hurd, was prepared for the curriculum committee of the National Science Teachers Association.

THE SCIENTIFICALLY LITERATE PERSON

A statement of goals for an education in the sciences should describe what we mean by a scientifically literate person living in modern times. This person is the end product, as we see him, of ten to fifteen years of science education, beginning with kindergarten. Here are some of the ways by which we can identify this person:

- He has faith in the logical processes of science and uses its modes of inquiry, but at the same time recognizes both their limitations and the situations for which they are peculiarly appropriate.
- He enjoys science for the intellectual stimulus it provides, for the beauty of its explanations, the pleasure that comes from knowing, and the excitement stemming from discovery.

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[1] Educational Policies Commission of the National Education Association of the United States and the American Association of School Administrators. Published by the National Education Association of the United States, Washington, D.C. 1966. See page 41, Chapter 5 for pertinent excerpts.

[2] *Steps Toward Scientific Literacy*. National Science Teachers Association, Washington, D.C. 1968.

- He has more than a common sense understanding of the natural world.
- He appreciates the interaction of science and technology, recognizing that each reflects as well as stimulates the course of social and economic development, but he is aware that science and technology do not progress at equal rates.
- He is in intellectual possession of some of the major concepts, laws, and theories of several sciences.
- He understands that science is one but not the only way of viewing natural phenomena and that even among the sciences there are rival points of view.
- He appreciates that knowledge is generated by people with a compelling desire to understand the natural world.
- He recognizes that knowledge in science grows, possibly without limit, and that the knowledge of one generation "engulfs, upsets, and complements all knowledge of the natural world before."
- He appreciates the essential lag between frontier research and the popular understanding of new achievements and the importance of narrowing the gap.
- He recognizes that the meaning of science depends as much on its inquiry process as on its conceptual patterns and theories.
- He understands the role of the scientific enterprise in society and appreciates the cultural conditions under which it thrives.
- He recognizes the universality of science; it has no national, cultural, or ethnic boundaries.

Paul DeHart Hurd
Stanford University

Manpower Needs

A second pressure on science education is the demand for the preparation of scientists. Much of the tremendous governmental support that has characterized science education during the last decade and a half originated through this pressure. It is doubtful that a historian could untangle the relative roles of the pressure for scientific literacy and the pressure to increase scientific manpower, especially as they affected Congress during the fifties. At that time they may have appeared as one. Undoubtedly a more scientifically literate population might be expected to produce a larger proportion of scientists. However, the motivation of the manpower pressure was based on concern for a small segment of the population with a specific life's work in view—a training outlook. The motivation of the scientific literacy pressure arose from concern for the whole population—a general education outlook.

The pressure to train new scientists has not been steady. While it has usually been recognized that the main assault must be made on degree-granting institutions, subcollegiate education has received attention because of the widely held notion that decisions to enter the field of science are usually, though perhaps subconsciously, made at this level. Yet when high school physics teaching was redesigned to emphasize physics as a science and to illustrate the processes of physical research, the decline in physics enrollment was not arrested.

Finally, the pressure for the preparation of scientists has suffered a social problem from the beginning—an air of elitism. When Sputnik I was stirring nationalistic fears, the aroma was tolerable, but in the late 1960's new fears have arisen, breeding antagonism to elitism. The future of our society's pressure on most subcollegiate schools to generate scientists does not appear strong. Because of failure of the new science programs to produce more scientists we now turn to scientific literacy. At least for a time, science teachers may need to exert their own force on the still necessary aspect of manpower needs.

Information Explosion

Either of the first two pressures may involve a third–the information explosion–which can also exist independently. The exponential increase in the fund of information bears heavily upon attempts to train scientists, for it compounds problems of communication between investigators. It also burdens attempts to further public understanding of the scientific enterprise, for it confuses decisions that must be made concerning support.

Even before the proliferation of information became a matter of wide discussion, many science educators were working to counter the resulting problem of "coverage." Their efforts were directed partly toward the development of new techniques but more largely toward a reorientation that reduced the importance of information as an aim. Because of marketplace factors, however, textbooks continue to be constructed in an encyclopedic fashion, and textbooks continue to be the single most potent curriculum guide. Consequently many science teachers still attempt the impossible.

Sermonizing

Still another pressure on school science education is the demand that it correct the ills of society by sermonizing on selected topics. This pressure is sometimes expressed in explicit legislative acts. Health–especially the negative aspects of smoking, alcohol, narcotics, and stimulants–sex education, and conservation have been favorite fields for the application of such pressure. To the extent that investigation is called for, to the extent that objective evidence is sought from which rational conclusions are deduced, socially conscious science educators must welcome such pressure. But usually the directive is not an invitation to investigate, to hypothesize, and to seek evidence but rather a prescription to damn or to praise. One is tempted to believe that such pressure is declining. It would seem that popular faith in the efficacy of laws as a means of curriculum construction has declined considerably in the past half-century. Existing laws are frequently ignored or given only token compliance. Perhaps educational efforts to increase understanding of the nature of science are showing effect. Perhaps the clearly expressed social concern of many scientists is resulting in increased confidence that science teachers need not be dragooned into the abandonment of objectivity in order to display such concern in the classroom. It would be encouraging to think so. Yet almost every legislative session continues to see the introduction of measures enjoining the tax-supported schools to teach this or that.

Use of Educational Technology

Different in a number of ways from the preceding is the pressure for the use of new educational technology.[3] Since this technology clearly derives from science itself, science teachers probably feel a greater compulsion in this direction than do teachers of, say, English or graphic arts. And they probably respond to the pressure in greater numbers and to a greater extent. Indeed, they themselves may generate part of the pressure. Yet they also often recognize that some of this technology is antithetical to their goals, as is discussed in Chapter 2.

APPLICATION OF PRESSURES

All pressures on education, if they are truly effective, ultimately bear upon specific teaching-learning situations. There, at the basic educational level, they either work their effects or evaporate in impotency. At the teacher-learner interface, however, the sources or pressures are remote and the kinds of pressures are indistinct. Yet the pressures are nonetheless present; they hourly affect what teacher and student do and how they do it. He who would manipulate the educational enterprise to his own purpose or the philosopher who would employ education as an instrument of social reform must both reach this operational level.

The major, ostensible avenue through which pressures are applied is school management. This encompasses, in tax-supported institutions, a board of lay persons representing the tax-paying public and varying numbers of administrative levels staffed by professionals who report to the board. Pressures from legislation percolate through this hierarchy. In doing so they may be either enhanced or diluted. Unsympathetic boards and/or administrators can subtly thwart legislative intent. The history of school desegregation has clearly shown this. How much more extensively must this be true when legislation is not backed by strong enforcement agencies.

Nevertheless, the power of management is limited. An American classroom is not as effectively screened from public gaze as a voting booth, but neither is it likely to be "bugged." Teacher and learner usually feel a considerable degree of freedom, and supervisory personnel generally acknowledge a lack of compulsive power. Therefore, managerial pressure is most frequently applied by exhortation and persuasion.

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[3] For amplification of this topic, see Chapter 6.

Perhaps as important as the official managers of a school are the educators of the teachers. What and how a teacher trainee has been taught may be as potent in determining the responses of a teacher to pressures in the classroom as the attitudes and wishes of administrators. True, this is an oversimplified view since in many school systems much inservice training occurs under the direction of school-system personnel.

To say that through both preservice and inservice programs teachers have learned to recognize pressures would be pleasant—but less than accurate. Tasks for the future include developing in teachers an awareness of the pressures under which they operate and giving them practice in the evaluation of these pressures. Even more important, teachers themselves should become a part of the decision-making team for which they must develop skill in dealing with pressures.

Probably more important than either management or teacher educators as transmitters of pressures is the within-school community—teachers and learners in the aggregate. Through this body, folk-pressures that may not reach legislative enactment and may be unrecognized on unsophisticated campuses are expressed. The relative values of basketball and physics find expression. The blue haze in the faculty room and the cigarette stubs in the student lavatories are silent commentaries on instruction in the evils of tobacco.

Teachers are subject to one set of biases, learners to another. Learners, for example, are under parental influences, to which they react either positively or negatively. Parents are likely to approve science instruction that resembles the instruction they can recall. Because they make up a large part of the electorate, they are also likely to approve pressures that have strong governmental backing.

Learners are also under the influence of their peers. The class "climate" is a potent factor in every schoolroom. So far as science teaching is concerned, however, learner groups still apply little direct pressure at the subcollegiate level, although declining enrollment in specific courses may represent a species of student pressure. At higher levels, student unrest is a portent of many things, but it may be significant that in many cases the involvement of science students seems to be less than that of other students.

Potentially the most incisive application of pressures—hopefully pressures that have been competently examined and selectively adopted—can come from organized professional teachers through their professional association. The next quarter century will surely witness an increasing sense of responsibility among organized science educators. While recognizing the interest of society as a whole in the control of education, science educators will seek to further the application of their knowledge and expertise to the development of education in science.

THE OVERRIDING PRESSURE

It would be pleasant to close a festival discussion on this optimistic chord. But in 1969 a realistic biologist cannot do so. All of the pressures we have been discussing originate in one way or another from a functioning human society. But there is abroad in the world today one overriding pressure of an altogether different character; it is a pressure that threatens the existence of all human societies.

No thoughtful person can look into the future of any social institution without recognizing that the entire fabric is erected on a biological foundation. Man as a species depends, as does every other organism, on the resources of energy and materials afforded by his environment. Today, the paramount pressure on education, on all social institutions, on man as a species, is the pressure of a human population that threatens to overwhelm the resources of the environment. Every vista of the future—even the future of science education—is obscured by unfilled mouths, by multitudes suffocated in their own wastes, by the collapse of institutions.

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NEW DESIGNS

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DAVID P. BUTTS
Science Education Center
The University of Texas at Austin

OPENING THE WORLD TO THE STUDENT

IF STUDENTS ARE to gain from experiences in science, they must see a link between their own lives and science; they must question the relationship of their experiences as *human beings* to their experiences as *students* in the science laboratory or classroom. Seeking this relationship should begin with the very young child and continue with increasing depth as the student progresses through school. Learning science will be at its best when the student himself initiates action and interprets the results of his science experience. With expanded freedom for initiation or interpretation the student becomes less dependent on the teacher. He has greater insight into both the question and the answer he seeks because they represent his action.

Learning is an event analogous to a collision between the student and the structure of the subject. This collision will have its greatest impact when there is a readiness on the part of the student to meet the subject matter. As the "engineer" of the collision, the teacher assists in identifying the student's readiness or the inventory of the student's past experiences that are relevant to the structure of science. The student's past experience limits the extent to which any present experience will be meaningful.

In order for learning to occur, the student must have:

1. A meaningful goal, a question or frame of reference to guide his activity

2. An interest in life and alertness to what is going on about him
3. A disposition to act
4. The means by which he can act; that is, a fund of knowledge and a set of skills by which he can process the information of his experience in a meaningful interpretation.

The student must also be able to make meaningful observations from chance experiences.

Relevance and responsibility in his encounter with reality are inescapable requirements for a student's learning in science. The smaller the base of experience, the longer the time before the student can accept the responsibility for directing his own actions. The challenge then is to provide a sequence of experiences that will enable the student to enlarge his base of knowledge and improve his skills to process information into meaning. This will enhance his ability to accept the *responsibility* for initiating action and interpreting its results.

If an experience is appropriate, the student will find it relevant and find himself capable to act on it. If the student does not find an experience relevant, or if he is not capable of acting on it, then the expected learning is largely diminished and the appropriateness of this experience must be questioned.

The teacher is needed to enhance meaning through the skillful structuring of the situation. The student is the star. It is he on whom the spotlight is focused. In this role, he must have a stage upon which to operate. Setting this stage, equipping it with desirable materials, making sure it fits the student's needs, and showing a supportive and trusting attitude are significant contributions of the teacher.

Like the director in a theatrical performance, the teacher selects appropriate means to help the star improve his performance. Through watching, listening, and observing, teachers diagnose the student's performance and select experiences appropriate for each student. The student may have difficulty in the use of inference; he may be unable to express himself; or he may lack skill in manipulating apparatus. All students will not have the *same need,* but each student will have *some need.* The learning situation itself is the means through which the teacher can diagnose the student's "experience-relevancy" and his "responsibility capacity."

There are many sources for students' experiences in today's science programs. The traditional procedure of telling on the part of the teacher is being superseded by the more direct involvement of the student. Sources for student experiences may range from an aquarium in a first-grade classroom to the pressure chamber in a high school laboratory—not to mention the TV set in the home and the ever-changing natural and man-made environment of everyday life wherever it is lived.

Ideally the student's responses are handled in such a way that he gains a new respect for his own ability to deal with the situation. Within the context provided by a skillful teacher-director, the student initiates and accepts responsibility for actions. He explores his environment; he handles and manipulates it. He explores the largely untried realm of thinking by relating events of his experience, developing ideas about those events, and testing their validity. Learning about his environment and his thinking are extended through organizing himself to *explore.* He must deal not only with knowledge but also with the logistics of material and time and with evaluation. Exploration, therefore, is accomplished through evaluating his own deductions, through making mistakes, and through refining his approach to the search for understanding. In this way the student's role is one of learning to manipulate and control his environment through guided exploration.

Such an approach might be described simply as the student learning to do by *doing,* but this is not quite complete. The student learns to do by *guided* doing. The teacher, the parent, the club leader, or whoever may be fulfilling the teacher role structures the learning situation, carefully watches and listens to learning activities, stimulates and encourages the learner, provides the background and the direction for the learner—through skillful questioning, challenge, and relevant experiences.

STUDENT INVOLVEMENT

In recent times many groups of professional scientists and teachers have cooperatively developed science curriculum materials. Two threads are common to programs for the elementary school, such as the *Elementary Science Study,* the *Science Curriculum Improvement Study,* the *Minnesota Mathematics and Science Project,* and *Science—A Process Approach.* One is early involvement of students with many objects rather than with symbols or pictures of these objects.

A second thread is the respect for himself that a child gains as he builds his own base of stored and retrievable information. While the objects selected differ in various programs, the child experiences small segments of the real world held between his hands. This world he finds intriguing, especially in such programs as Headstart before which his opportunity to smell, see, feel, and listen to much of the real world has been limited. When discussing how the shapes of objects are alike, there is a potential for the teacher to use shapes in a child's everyday world. Regardless of where the child lives, a wealth of experiences is possible if his senses are alerted to this potential.

In the secondary-school science programs such as *Biological Sciences Curriculum Study,* the *Chemical Education Material Study,* and the *Physical Science Study Committee,* how information fits together becomes as significant as the information itself. Laboratory investigation assists the student in acquiring insights which are operational guides for further exploration in his environment. Gradually the pupil himself becomes more strongly involved in setting his own objectives and in planning experiences, schedules, and tactics through which he can reach the objective.

Because experience is a prerequisite to development of both knowledge and skills, the structure of that experience becomes a significant factor in science instruction. Students must feel that they are studying something of value and not merely executing intellectual minuets. They must actively do something with material, carrying out *their own* action and then have reason and time to stop and examine the *results* of their action. This means designing curriculum materials in which the student's experience is a personal thing, stimulated from direct observation of an event. This experience leads to inferences about relationships and to the testing of these inferences. This design contrasts sharply with the situation in which a student solves a puzzle that has been imposed on him by the teacher, the solution of which has for its main reward the completion of an external requirement. Only when given the opportunity to struggle with conditions of an event first hand and to seek and find his way out will a student experience both relevance and self-directed responsibility.

Students must have an opportunity to seek questions as well as answers. Their search can roam widely in a variety of resources that the teacher brings in for their use. They become the creators of their own textbooks as they synthesize the interpretation of *their own* experience.

From experiences that suit their interests, learning style, and experience base, students get some framework into which they can fit their knowledge. They also get some idea of how fragmentary their knowledge is and extend their perceptions of what it is possible to know or discover.

The kindergarten child who has living things to observe and to care for will soon ask "why" about their behavior and their needs. He will quickly learn that he can communicate about animals more easily and with greater extension of his own knowledge if he has an adequate vocabulary of names and descriptive terms. Through observation and communication, he will discover that many aspects of his environment are predictable and to some extent can be manipulated. He can learn the simple needs of plants and small animals and observe the consequences if these needs aren't met. Gradually, thereby, he will get the idea of cause and effect. We can hope and plan that as he has similar experiences in later years he will develop not only an objective way of looking at the environment, but some skill in evaluating its physical and aesthetic quality. From films, reading, TV, and discussions with others, he will learn that different people value different environments and that life will demand give and take. Gradually he will draw his own conclusions without being sermonized. The older child who feels the tug of space may delight in making a model of the moon or venture outside of the school for specialized help on his investigations. If he finds an encouraging teacher and a responsive community, he will extend and deepen his learning pattern. If he is free to have many opportunities to try out his ideas on other students or to find companions in his explorations, he may quickly achieve self-identity and self-respect as well as broaden the range of persons with whom he feels comfortable and to whom he can relate. Conversely, depending largely upon teacher attitude, he may learn instead to stop asking questions. When this happens, creativity goes out of science, and motivation, too, is largely lost.

Learning will be at its best when the relevance of an experience is apparent to the student because he has had the responsibility for initiating, managing, and interpreting his own experiences. The persistent challenge is how to structure the learning encounter so that the student will close the gaps in his experience.

EXTRACURRICULAR ACTIVITIES FOR STUDENTS

In the tradition of American schools, co-curricular activities in science have an important place in introducing young people to activities similar to those carried on in their future occupations as well as providing an outlet for hobby-type or avocational interests. Such programs for students in science include science clubs, research activities, conferences, congresses, seminars, science fairs, symposia, and other activities that spill over from the classroom. Many of these programs are highly organized and lead to national activities, handsome financial awards, conferences with working scientists, and in some instances contact with students in other countries, such as is provided each year at the International Youth Science Fortnight held in London and attended by a delegation of students from the United States and about twenty-five other countries.

Youth programs for the future should be extended to a wider spectrum of students; more emphasis should be placed on "science and humanities"; nonschool programs (in industry during the summer, for example) should be encouraged; and greater use should be made of outdoor education centers and laboratories as places for science involvement for all students in the community. Secondary school and college cooperation could well be increased for greater sharing of facilities and specialized personnel.

The schools themselves should increasingly provide facilities and encouragement for students to conduct investigations on their own with adequate supervision from the school faculty and with access to consultants and advisers outside the school for specialized activities. Such activities can be helpful in developing scientific literacy as well as in encouraging the young person who may be considering science as a career.

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RICHARD J. MERRILL
Mt. Diablo Unified School District
Concord, California

and

DAVID P. BUTTS
Science Education Center
The University of Texas at Austin

VITALIZING THE ROLE OF THE TEACHER

CHIEF INTERMEDIARY in the science program is the teacher. In the programs of the future—and indeed at present in some especially innovative schools—the teacher's role will be that of an expert diagnostic decision-maker. As a decision-maker, the teacher's role includes three types of responsibility—diagnosis, guidance, and rediagnosis—a function resembling the activities of a physician diagnosing and treating a patient. The teacher and the physician meet the student or patient, evaluate his condition, project the condition to be achieved, prescribe a treatment, and, after an appropriate interval, again diagnose the student or patient.

Diagnosis

In the changing role of the science teacher, this emphasis on diagnosis becomes highly important. The teacher must quickly and skillfully involve students in diagnostic learning activities. There is need for an articulated sequence of activities or tests to aid in this diagnosis. Such activities may well include situations in which the student is provided with stimuli that encourage free discussion. Because of his past experience and training, the teacher is able to pick out relevant comments related to the student's previous experience. Selective use of objective tests at the beginning of a learning experience also enhances the professional judgment of the teacher as he decides what learning events are appropriate for which students or groups of students.

Guidance

As students go through their learning experiences, the teacher watches for changed behaviors. Frustration, triumph, boredom, anxiety, fatigue, or low self-esteem in individual students are signals to modify approaches. Periodically, the teacher checks on student progress, recognizing that learning is a highly individualized and personal event.

Figuratively, the teacher walks beside the student, providing encouragement as a partner in learning.

Rediagnosis

When a teacher observes in students those behaviors that he identified as goals, he institutes an appraisal activity. This is a specific learning situation in which the student is called on to demonstrate a specific skill in inquiry or laboratory procedure, etc. Using this objective evidence, the teacher again has a basis for deciding what learning experiences are appropriate for which students. Many students will be ready for new experiences. They may be directed toward new goals. Other new experiences will redirect students toward the previous goals which they have not yet attained.

KEYS TO A NEW ROLE

This model of the changing role of the science teacher suggests a series of key ideas, for example:

The direct transmission of information about the subject matter to students will and should become a progressively less important part of the science teacher's role.

The one-way lecture is dying as the main method of teaching science. Lectures about subject matter may be an efficient way of covering material, but students may learn more about authority-dependence through lectures than they do about science. The assumption that 30 students or 150 students in a class are all ready for the same information at the same time is rather shaky at best. It is much more likely that teachers, through careful and perceptive observation or listening, will identify which student is ready for what information and which level of this information may be best suited to the individual student. Making information accessible thus becomes a highly significant task for the science teacher.

Even though the teacher may not be transmitting subject-matter knowledge directly to the students, his subject-matter competence is even more important than it may have been in the past. Teachers will use what they know to structure effective learning situations rather than try to transmit a great deal of knowledge directly to their students. This proposition does not mean to imply that a teacher will never provide a fact or define a term, explain a theory, or demonstrate a technique to students. It simply means that this activity should not constitute a major part of the teaching-learning process.

The accumulation of factual information for its own sake has, as a major goal, been superseded by that of teaching the student "structure" and "process" of science. Structure and process are, in turn, seen as durable, essential tools to help the student continue learning for the rest of his life.

By "structure" is meant the conceptual schemes or major generalizations which are most useful in correlating a vast number of facts and phenomena. Structure enables the student to cope with new information by providing a framework in which he can relate new information to that which he already clearly understands; that is, it increases the chances that future learning will be relevant to the student.

By "process" is meant the cognitive and manipulative skills used by the individual.

By "cognitive skill" is meant the application of a principle to situations in which a more or less mechanical or repetitive procedure can be established.

The shift of the teacher's role from dispenser of information to a diagnostic decision maker represents an indispensable factor in progress in science education.

A greatly increased part of the teacher's time and effort must be spent in helping students establish and understand their goals and objectives and especially in helping students recognize the effect that various courses of action have in reaching these goals.

A patient generally comes to a physician with the objective of getting well and does not need to be convinced of the need for the objective. This is not so with the student. Establishing and clarifying course objectives are major tasks for the teacher.

A science philosophy well understood by the teaching staff and supervisors, administrators, and parents can be communicated to students together with objectives. Objectives stated in behavioral terms give specific help to both teaching staff and students in establishing and understanding the objectives and in knowing the extent to which objectives are being achieved. (See also Chapter 8.)

For a long time, science teachers have been vague and evasive in answering the occasional student (he may not be "occasional" if we wonder what the dropout was saying to himself when he felt trapped in a classroom) who has been bored enough to ask, "Why should I learn to name the parts of a flower?" or "What good will oxidation-reduction equations do me?" We have accepted objectives and tried to get students to reach objectives that have been handed down to us by tradition, textbooks, or national curriculum studies. We have done little to make these objectives relevant to students, nor have we explored the possibility that we may have been overlooking specific objectives that are much more relevant from the student's standpoint. At the high school level, we have clouded the issue by creating a false relevance based on such extrinsic rewards and punishments as grades, college entrance requirements, science fair prizes, etc. Many students have never been convinced that these objectives are valid. More and more students now seem to be seeking, even demanding, deeper and more specific answers to the question, "Why should I learn this?"

In education in the future, more effort must be spent on identifying the real concerns of students and how science may be related to them. Somehow, from the earliest years we must help students to recognize that a curriculum is a mixture of the immediately useful and of what must be "taken on faith" as being useful in the future.

If we are sincere in our desire to know students' concerns, then we must be prepared to accept the concerns as they are, help students broaden and deepen them, and build from them. This may result in science teaching that varies from the accepted pattern of the past. It might herald a science class that "fits" the students rather than a situation in which the students must attempt to "fit" the course. Ideally such a dichotomy would not exist.

A great deal of work will need to be done with students as individuals or in small groups to help them clarify their own objectives and to understand the relevance of objectives which curriculum makers and teachers feel are important. The question will become, "Why is this behavior important?" Answering it will be one of the most difficult and challenging, but also one of the most rewarding, parts of the emerging new role of the science teacher.

The selection of instructional equipment and materials in the future will become a larger part of the science teacher's role, both in intellectual effort and in time spent.

Selection of appropriate materials can be accomplished only by teachers who know their students and their objectives well and who have achieved a considerable amount of sophistication in evaluating teaching materials. The creation and production of instructional materials should become a less important part of the teacher's role than it now is in many instances.

If the teacher knows the level of student performance, then he can adapt material to individual student needs or select appropriate materials from those available. Such adaptation and selection requires that the teacher be familiar with available materials and with the needs of the students. Some of these student needs may be indigenous to a locality or the student population or related to a gap in previous experiences of the students. The task of selecting materials is much more complex and demanding now than it was during the period when an occasional textbook adoption study was the extent of a teacher's participation. The vast array of instructional equipment and materials available now or projected for the near future includes many excellent aids, but it also includes a multitude of items of ill-defined purpose or whose cost is not commensurate with the objective served. Wise selections will require great discrimination. (See the following chapter for a discussion of materials.)

In general, the actual creation of curriculum guides, work sheets, laboratory guides, transparencies, testing materials, etc. should not be done by teachers, for it is neither an efficient use of teacher time nor a particularly effective means of getting good materials. It should be resorted to only when appropriate materials are unavailable, inappropriately priced, or need to be adapted for use or supplemented with special items for use in the local situation. The actual physical production of such materials should be handled by teacher aides and clerical personnel. However, this recommendation should not be interpreted to discourage teachers from using all their imagination and innovative skill in enriching their programs.

Science teachers will and should become less autonomous than they typically are now in making decisions about what to teach, when, and how.

Students will be sharing these decisions and, in situations where team-teaching is practiced, so will other teachers. Student participation in instructional decisions usually results in an increased individualization of instruction and fosters independent learning.

In team-teaching, the problems around which relevant instructional objectives can be established are likely to demand a multi- or inter disciplinary approach. The science teacher thus increasingly finds himself working as a member of a team (or several teams) rather than conducting his course independently.

The organization of several staff members into a "team" in which each plays a particular role has the advantages in science programs of extending the talents and subject-matter strengths of several teachers, both in planning courses and in teaching science classes. This is particularly useful where the school is attempting to introduce or carry on certain kinds of "interdisciplinary" or "integrated" science programs.

Evaluation of student achievement and analysis of the teaching-learning process will and should become an increasingly central part of the science teacher's job.

This proposition is based on three assumptions. First, a great number and range of behavioral objectives, in both the cognitive and affective domains, must be identified and measured. Measurement of many of these objectives will involve observations by the teacher of individual student performance in addition to mechanical analysis such as "objective" paper-and-pencil tests. Second, both the identification and assessment of achievement of objectives will involve much conferring with individuals and small groups of students. Third, technology will make increasingly available to the teacher a great deal of objective information about both student achievement and the teaching-learning process. This feedback will reach the teacher soon enough to be useful and indispensable in day-to-day rediagnosis and further guidance of his students.

The maintenance of professional competence will and should become a built-in part of the science teacher's role.

If full-time teaching constitutes nine or ten months of a teacher's job, then full-time learning should constitute at least one month, and preferably two. Evenings, weekends, or occasional summer institutes are not adequate for the maintenance of professional competence, at least in science. Science teachers are faced with a tremendous task of keeping abreast of new developments in science and science education. Also, as suggested in the previous paragraphs, the science teacher must develop a wide-ranging expertise vis-à-vis materials and new skills in competency diagnosis, group interaction, guidance, plus actual research in education. A month or two set aside for full-time study each year is not enough, but it would be a good start. Such re-education should be recognized and supported financially as an integral part of the science teacher's job. The choice of professional growth activities should be directly related to the teacher's needs as cooperatively determined by himself, his teaching colleagues, and his administrators rather than being left completely to the discretion of the individual teacher.

Science teachers need to develop new competencies and new satisfactions as their role in the classroom changes.

Undoubtedly there is a great deal of satisfaction to be found in many activities which will be fading from the science teacher's role. The act of dispensing information, of being the central source of knowledge, is obviously very rewarding to the ego. Related to this is the satisfaction of showmanship associated with the demonstration that really works and the zest of keeping up with new developments to describe to students. These and other satisfactions associated primarily with what the teacher does will diminish in the changing role described here. They will be replaced by new rewards, subtler and perhaps more abiding, but dependent on success in human relations.

If science teaching is to affect the attitudes and behaviors of students outside the classroom, then a part of the teacher's rôle must be to have the desired attitudes and behaviors in all of his relationships with students.

For example, the teacher's approach to problems will reflect such values as the following identified by the Educational Policies Commission in *Education and the Spirit of Science* as underlying not only science but all rational thought:

1. Longing to know and to understand
2. Questioning of all things
3. Search for data and their meaning
4. Demand for verification
5. Respect for logic
6. Consideration of premises
7. Consideration of consequences[1]

The values so well stated by the EPC cannot be indoctrinated, but they can be the basis for a whole series of questions the science teacher should frequently ask himself: Do I long to know and understand? What evidence do my students have that I continue to learn and to search for data and their meaning? Do I question all things, or, perhaps more realistically, what are the things I do not question? Do I set a learning environment in which students are encouraged to question even those things I do not question? How do I react when a student demands verification of something I assert? Do I lead students to examine and evaluate their premises? My premises? Do I attempt to predict the consequences of my teaching acts beforehand, and to evaluate them afterward?

In Emerson's words, "What you do stands over you the while, and thunders so that I cannot hear what you say to the contrary."

In Jacob Bronowski's more recent words to the 1968 NSTA Convention (referring to the public official who fabricated the story about students being blinded by the sun while high on LSD):

> Like so many men with a sense of mission, particularly in public life, he believed that his convictions about good and evil had a higher status than the distinction between true and false. And we see the fatal results of that belief on every campus: not only do students distrust what their elders say about practical subjects like drugs and war, but they suspect our whole ethic to be a fraud. They think that our generation is constantly engaged in pretense, and what we call the generation gap seems to them literally a hypocrisy gap.[2]

With other teachers, the science teacher shares the responsibility for

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[1] The Educational Policies Commission. *Education and the Spirit of Science.* National Education Association of the United States. Washington, D.C. 1966. P. 15.

[2] Bronowski, J. "Science in the New Humanism." *The Science Teacher* 35: 72-73; May 1968.

decategorizing or destereotyping students and helping all students to feel some control over their own destinies.

Individualization of instruction in science and guidance in independent study help the student toward self-identity and accommodate differences without establishing categories such as science-prone, gifted, slow learner, disadvantaged, or high or low IQ group. Material and experiences from the background and environment of each student can be used as the base for some of his experiences in science. Other activities, by introducing unfamiliar experiences, will extend his horizons at the same time that they increase his knowledge of subject matter.

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RICHARD J. MERRILL
Mt. Diablo Unified School District
Concord, California

SELECTING INSTRUCTIONAL EQUIPMENT AND MATERIALS

A MAJOR CHARACTERISTIC of science education in the 1960's has been the sudden profusion of instructional materials. Some have resulted directly or indirectly from the major national curriculum projects. Others were independently developed to take advantage of a market expanded by the influx of federal funds to schools. The Lorelei of new materials has been irresistible to teachers and administrators seeking to produce quick improvements in classroom conditions and in student development.

Increasingly, science courses are being marketed in "packages"—textbooks, teachers manuals, kits of student work materials, evaluation sheets, etc. Evaluation, selection, and use of such courses require a very different approach than does a textbook adoption. Nevertheless, like textbooks, these prepared courses must be judged for themselves as well as for their possible effect on the goals of the curriculum. Should teaching materials determine the goals? Will the instructional materials now available and those soon to come enable us to educate our children in a clearly superior manner ten years from now?

To answer these questions, it is useful to review the functions that can be served by instructional materials, particularly in science, and to review the types of materials presently available or soon to be available. We can then make suggestions about selection techniques and about materials that we as a profession would like to see developed.

The major roles of functions of teaching equipment and materials in science education are:

To transmit or to make available factual information
To confront the student with science-related phenomena
To aid in development and practice of skills
To measure student achievement
To evaluate the effectiveness of the teaching-learning process

Transmission of factual verbal information. The verbal transmission of factual information, of content, has been and likely will continue to be an important aspect of science teaching, notwithstanding what has already been said in this publication about the decreasing relative importance of this aspect of learning science.

Factual information is essential in the learning of both structure and process. For example, if potential energy is to be seen as the concept relating such apparently diverse things as a stretched spring and a charged battery, then one must know something about springs and batteries, and also about evaporation of water, photosynthesis, and other phenomena to which the concept applies. Likewise one learns the useful process of communicating through graphs by having something to communicate, be it masses of marble dissolved by various volumes of hydrochloric acid or the population of the world at the turn of each century for the past 2,000 years. While particular facts may become obsolete, factual information will continue to be very important in science education as an aid to the learning of structure and process. Factual information and memorization of material are maligned for their overuse, not because they are unnecessary to the understanding or practice of any subject.

Providing information involves storage and access. Traditionally the two main reservoirs of such information in the science classroom have been the teacher and the textbook. The two main channels of access to the information for the student have been, correspondingly, to listen and to read. We now have or soon will have new alternatives for information storage and access, such as programed materials, tapes, single concept films, and computer memory banks.

Access to Phenomena. The kind of information just described may be thought of as the "verbal information input" of science education. All of the facts, theories, laws, symbols, equations, and other verbal manifestations of science are directly or indirectly related to phenomena—to objects and events that occur naturally or that can be made to occur in a laboratory. Indeed, the development of generalizations that relate observed phenomena to each other (induction), and the seeking of phenomena that should be observable if the generalizations are correct (deduction) are the essence of what scientists do. If students are to learn to carry on these activities of science, then they must have access to the phenomena that constitute both the raw material and the ultimate authority in science. The access may be direct, through laboratory investigations, demonstrations, and field trips; or vicarious, through recorded sounds, visual images, and the like. Regularly, in every classroom from kindergarten through high school such confrontations should be taking place, making imaginative use of the resources at hand to introduce far-away phenomena into the students' lives and to inspire insight into the phenomena of the immediate environment.

Development and practice of skills. Instructional equipment and materials play a role in helping the student learn specific cognitive and manipulative skills. Solving a Mendelian genetics problem, using a sliderule, balancing an oxidation-reduction equation, and plotting a graph of temperature versus depth are examples of such skills. Manipulative skills would include such techniques as preparing a microscope slide, using a balance, and photographing part of the sky through a telescope.

Evaluation of student achievement. The formulation of clear objectives for and the measurement of student achievement have been the twin Achilles' heels of education, science education not excepted. It is difficult for many teachers to identify the specific objectives of a particular lesson and even more challenging to describe the means by which the attainment of these objectives will be measured. Usually, the teacher has been prepared to describe evaluation in terms of (1) very general objectives like "scientific literacy" and "appreciation" that are never measured, and so expressed convey little meaning to either student or teacher, (2) very limited cognitive objectives, mostly factual recall, measured by paper-and-pencil tests, and (3) a more or less elaborate rationale for grading.

As we succeed in broadening the range of objectives which are defined with enough precision to be measured, we will find that a wider variety of materials and devices are needed to help us measure the achievements of these objectives. We will also find both the teacher and the student more deeply and continuously involved in gathering information about the latter's progress toward objectives that are mutually agreed upon. Such information will have much more importance as feedback for use in guiding and improving instruction than as the basis for grades.

Evaluation of the teaching-learning process. A final function of instructional materials is that of evaluating the effectiveness of the teaching-learning process—what the teacher does, what students do, and the interaction among students, teachers, and instructional materials. Efforts are underway to formulate more comprehensive models of teacher-student interaction and to correlate them with achievement or nonachievement of particular kinds of objectives. Recent years have seen notable progress in the development of such models and in techniques of systematic observation. The Interaction Analysis system developed by

Amidon and Flanders,[1] for example, permits classification of classroom verbal interactions into ten categories. After tape-recording a class session, a teacher can describe the interactions that took place as a sequence of numbers. Successive pairs of numbers are tallied on a matrix and may form identifiable patterns. The teacher can compare this objective, quantitative anlysis of what *is happening* in his classroom with what he *would like to have happen,* and experiment with ways of changing his own behavior. He is guided by a growing body of research relating student achievement (or nonachievement) to interaction patterns analyzed using this system.

In another technique, microteaching, videotape is the feedback medium. The teacher prepares a lesson and teaches it to a small group of students. Immediately afterwards, he views the tape and analyzes it with respect to some specific aspect, such as his questioning technique. He then plans the lesson again with appropriate modifications, reteaches it to a new group, and again evaluates the tape.

TYPES OF MATERIALS AND THEIR EMERGING ROLES

Textbooks

The textbook, along with the teacher, traditionally has been a principal repository of verbal information in the classroom. The textbook has also frequently provided whatever structure and sequence there has been for the presentation of information. In courses where fact-gathering has been the primary goal, the textbook has served these functions more or less well, depending on the degree to which the student has been able or willing to read it. Textbooks have also served the function of providing vicarious access to phenomena. A series of photographs is a convenient way to bring the Grand Canyon or the variations in finches into the experience of the student. Well-chosen pictures may be used to get the student to practice skills such as observation and inference. Problems and exercises also bring the student into an active learning role.

Textbooks have a number of real advantages as instructional materials. They are traditionally accepted. They provide a portable, low-cost, easily accessible source of information for teachers and students. They may be used independently, and the rate of interaction can be set by the student.

Textbooks also have serious limitations. Getting information from a printed page is a difficult task for a great many students. Even when the text successfully communicates, it does so in a way that casts the student in a rather passive learning role. Print tends to bully, and textbooks may encourage excessive authority-dependence on the part of students (and

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[1] Amidon, Edmund J., and Flanders, Ned A. *The Role of the Teacher in the Classroom.* Amidon & Associates, Minneapolis, Minnesota. 1963.

teachers). Authors often provide more information than the student needs at a particular time. Textbooks, *especially in science*, may long outlive the usefulness and accuracy of the information they contain. They may also, by virtue of the way in which they organize subject matter, tend to perpetuate obsolete curriculum structures.

The textbook is becoming less central in science education. This trend will continue as a direct result of (1) the ascending role of other types of instructional materials that perform other functions and even perform the same function better, (2) the emphasis on direct access to phenomena wherever possible, and (3) the shift toward changed behavior rather than information-gathering as the major objective. This is not to say that textbooks will suddenly become extinct. They may rather evolve simultaneously in several directions. One direction is the programed sequence; another is the almost completely pictorial course material, such as that developed by the Secondary School Science Project in *Time, Space and Matter.*[2] Another is separate reading materials to support individual units of study, such as those developed by the Physical Science Study Committee, Harvard Project Physics, and the Biological Sciences Curriculum Study.[3] Encouragement should be given to the development of inexpensive, one-use reading materials at an appropriate reading level. Students can interact with such books by writing in the margins, or whatever, and keep them.

Supplementary Printed Materials

Reading materials other than textbooks have served the same function as textbooks, except that of providing the course structure. They broaden the range of information and vicarious access to phenomena. Periodicals, reprints, pamphlets, and the like can provide current information, updating the textbook. More detailed information in a specialized area, such as chromatography or animal navigation, can be furnished in this way. Such materials should be made more readily available to students than is often the case at present.

Programed instruction materials deserve special mention, if only because they have come into prominence so suddenly within the past decade. A program is a sequenced exposition of information, interleaved with step-by-step assessment of learning according to the very specific tasks that the student performs. Imaginative programs are designed in a

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[2] Published by Webster Division, McGraw-Hill Book Company, Manchester, Missouri.

[3] The annual *Report of the International Clearinghouse on Science and Mathematics Curricular Developments,* J. David Lockard, Editor, lists and describes these and other curriculum projects. The *Report* is a joint project of the Commission on Science Education of the American Association for the Advancement of Science and the Science Teaching Center at the University of Maryland, College Park.

fashion that requires the student to perform in order to proceed; the designs also encourage him to take advantage of what he already knows and do not waste his time in undue repetitions. They are extremely useful for individualized instruction, remedial work, or to provide some special aspects of science teaching, such as concept development.

Printed materials for use in evaluation of progress—paper-and-pencil tests, for example, will become less and less important in the assessment of student achievement as "achievement" takes on a broader meaning. A printed question is a specialized kind of stimulus, and a written response is likewise a limited kind of behavior. Future evaluation of achievement should be based on a great variety of student performances stimulated by confrontations of several types.

Films

Many of the major roles for instructional materials can and should continue to be served by motion pictures, filmstrips, slides, and related visual aids. Films are also being used in new ways–one refreshing idea is to use films to match the learner's style rather than to replace the teacher. Matching the learner's style may be more successful than were the earlier attempts to put entire courses on film. Experiences with these "courses on film" indicate that films cannot substitute for a qualified teacher; when they attempt to do so, the really important functions that the teacher should be performing (other than presenting information) continue to go unserved.

The range of phenomena with which we can confront children is vastly increased by films. We tend to become jaded and forget how truly marvelous it is to be able to bring into the classroom at will a solar flare, a highly magnified view of a chaotically dividing group of cancer cells, a man walking in space, a baby being born, or a scientist actually conducting an experiment in his own laboratory. Confronting phenomena is at the very heart of science, and films are one of the best media for bringing to the student a broad range of realistic events.

A serious impediment to the effective use of films has been teachers' attitudes toward them, as evidenced by misuse. Too often, films have been thought of and used as substitutes for other types of teaching, as interruptions (or welcome relief) from the real work of the classroom, and sometimes simply as baby sitters. Films can and should do much more.

The vital ingredient to be encouraged in films is active participation of students in learning through a medium that has typically cast them in a very passive role. The short, cartridge-loaded film loop is invaluable for this purpose. Its very limitation in brevity, and sometimes silence, is an advantage in that it precludes introducing unnecessary material. Loops can also be rerun as many times as necessary for individuals or small groups.

Short, accessible, conveniently projected phenomena films can be used in individual and small-group instruction as well as in whole-class or large-group activities. They should become very useful in evaluating student achievement.

Imagine, for example, a short film presenting the following sequence of events: Two stoppered jars containing equal-size wads of steel wool are brought into balance on adjacent balances. The stoppers are removed. Both wads are ignited. One jar is immediately restoppered, but the other jar is left open and the stopper placed on the balance pan next to the jar. The student's response to the phenomena, or to questions he is asked about it, could aid his understanding of one or more of a number of important concepts, such as characteristics of a chemical reaction, limiting reactant, closed system, and conservation of mass, to name but a few. Such confrontations can also be used to assess processes such as observation, hypothesis formation, inference, design of experiment, and so forth. The questions a student asks and the experiments for proposes (and, ideally, carries out) to learn more about the phenomenon could tell us much about his attainment of some of the objectives we have long held but seldom measured. Since there would be no absolutely right or wrong questions or proposed experiments that the students would suggest, each child would succeed and by his very questions and suggestions would reveal something of his style of learning as well as his knowledge.

Motion pictures can, of course, also be a highly effective means of aiding concept formation. A few minutes of good filmed animation can quickly and clearly transmit what is meant by the probability distribution of an electron in an atom or the circulation of fluids in a tree trunk.

Films can also be extremely helpful in the teaching of manipulative skills and techniques. Preparing microscope slides, using a balance, starting a culture, are examples of skills students must acquire if they are to learn from their environment. To be most effective in this area, a film should be easily repeatable, interruptable, student operable, and uncluttered with information and techniques that the student does not need at the time. Viewing should coincide as nearly as possible with doing–the actual use of the skill by the student. The cartridge-loading, continuous-loop, eight-millimeter system with its highly portable, inexpensive projector fits these criteria very well.

Television

Many of the considerations just discussed for films apply equally to television. It performs such functions as presenting whole courses on tape, demonstrating techniques, providing access to phenomena, and evaluating achievement; the possibilities and limitations of TV appear to be similar to those of film. We may expect videotape recorders and players (including a TV equivalent to the cartridge film-loop projector), monitors, and tapes to become increasingly economical and accessible to teachers and students.

We may, therefore, forego general discussion of the role of television and concentrate on a few of its unique features.

One of these features is immediacy. Live television can give students access to something as it happens. The student may be at school or at home or in a hospital. The event may be occurring under a microscope, in another classroom, at the bottom of the ocean, or in orbit around the moon. It may be something carefully planned and led up to, or it may be something unexpected that is just too important or exciting to pass up. Immediacy can be a powerful motivator that the science educator should exploit to its fullest to demonstrate relevance to the students' real life.

Another advantage of television is that local production of video tape is more feasible, both technically and economically, than is the case with films. This makes it possible to record and store events that are of special, local relevance to science education. Phenomena that are important now but will not be in a year to two may be stored temporarily and then erased to make room for other events.

For evaluating the teaching-learning process, videotape allows the teacher to see what he does and what students do from the standpoint of a nonparticipating observer. This can be reviewed in complete privacy or in consultation with supervisors or colleagues. Knowing what his behavior is, the teacher can undertake to modify it and assess the effect of the modification on the teaching-learning process. Presumably, videotape can also be used to record student actions and interactions, and this may become an important function in guidance and in arranging individualized instruction.

Computers

The possibilities offered by computers as instructional tools include the functions of access to information and phenomena, development and practice of skills, assessment of student achievement, and simulation of laboratory experiences. The computer also offers great promise in the evaluation of the curriculum and the teaching-learning process. Like television, which can give the teacher a chance to observe and analyze the interaction between himself and his students, computers can provide detailed analysis of many aspects of student performance. Moreover, this feedback can come quickly enough that instruction can be modified before it proceeds too long in an unproductive manner. Both instruction for which the student is unprepared and instruction that is superfluous may be avoided more often in the future with the aid of computers. (See Chapter 8 for an illustration of a CAI program, "Preskills.")

The computer—which already profoundly affects all of our lives—will itself be an important object of study in the curriculum. Because computers are indispensable tools for the scientist, their use must be

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mastered by those of our students who will become scientists as well as by those who will become social scientists or businessmen, or will be engaged in many other professional and technical occupations.

The Laboratory

The laboratory is too often thought of only as the room or portion of a room in which students engage in those activities of science that involve direct access to phenomena. It is the place where observations are made, experiments conducted, and data gathered. All that has been said about the role of printed and audio-visual materials and computers by no means implies that direct access to phenomena will become less important in science education of the 1970's and 1980's. Hopefully, the opposite will be true. Laboratory activities such as those that have been central in the philosophy of the curriculum projects of the 1960's will continue to be a vital part of science education. Beakers, microscopes, balances, magnets, and living creatures will continue to be very much in evidence. Behavioral objectives associated with laboratory work will be better defined and measured than has been the case in the past.

The concept of laboratory should be associated more with a set of functions and less with a specific location. Whenever and wherever the access to phenomena occurs, there is the laboratory. We should, in fact, deliberately avoid giving children the notion that the methods of science can be practiced only in a special kind of classroom. For every commuting student in the city, the bus or subway car should at some time become a laboratory in which he collects data relating to acceleration, or correlation between hair color and eye color, or resonant frequencies, or perhaps human behavior under stress. The backyard and the fish tank are laboratories for the study of ecological principles. The workbench or kitchen table may be a laboratory for a student with a take-home kit for measurement of densities, surface tension, conductivity of solutions, or the vitamin C content of fruit juices. For the high school student who is (or should be) seriously considering a career in science, the best laboratory may be at the side of a research chemist in a refinery, a bacteriologist in a medical school, or an oceanographer aboard a research vessel. Such arrangements will become more feasible as traditional patterns of time and subject-matter scheduling are replaced by more flexible, functional patterns. Field trips, and study out-of-doors likewise, will become a more significant and deliberate part of the laboratory program when the daily schedule is such that they can be conveniently conducted without disrupting other classes.

The following chart summarizes the materials and functions we have discussed and indicates whether the importance of each type of material to each function it serves is increasing or decreasing.

Functions	Materials					
	Textbooks	Supplementary Printed Materials	Films Filmstrips Filmloops Transparencies	TV	Computers	Laboratory
Information Storage and Access	↓	↑			↑	↑
Access to Phenomena	↓	↑	↑	↑	↑	↑
Development and Practice of Skills: Cognitive	↓	↑	↑		↑	↑
Manipulative	↓	↑	↑			↑
Evaluation of Pupil Progress		↓	↑	↑	↑	↑
Evaluation of Teaching–Learning Progress		↓		↑	↑	↑

Increasing importance ↑ Decreasing importance ↓

This analysis is artificial, of course, because it suggests that the materials are used and each function performed independent from the others. Such is rarely the case. The greatest effectiveness will, in fact, be achieved where combinations of equipment and materials are brought together as "learning systems" to help students achieve particular objectives. Systems combining printed materials, films, television, and computers bring extensively individualized instruction into the realm of possibility, both because of what they can do and because of what they can free the teacher to do.

But there are concomitant effects for which we must watch. One is the grave danger that materials will set our objectives for us. In the past, textbooks have too often determined, or at least limited, course objectives. Without clear understanding of desired results, rational choice of materials will be impossible.

Another pitfall we must avoid is that of becoming so engrossed in the achievement and measurement of specific behavioral objectives that undesirable gross effects occur without our realizing it. One such effect might conceivably be overdependence on a rich learning environment. How will the student function in a situation where a computer or dial-retrieval system is unavailable? Another possibility could be an unconscious depersonalization. A conditioning of a student to interact well with materials and devices must not be allowed to cripple his ability and willingness to learn through direct interactions with people. Such depersonalization could come about if functions now being served by the teacher are taken over by materials and machines and if the teacher fails to assume a new role that assures humane and humanizing instruction.

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ELIZABETH A. SIMENDINGER
The Wheatley School
Old Westbury, New York

SUPERVISING THE SCIENCE PROGRAM— THE ROLE OF THE SCIENCE SUPERVISOR

WITH THE EXPONENTIAL GROWTH in scientific knowledge, increased emphasis on science in our schools, and with the proliferation of science curricular projects at all levels during the past decade, a new leadership role has emerged as a stimulating and unifying force.

No longer is the chief school administrator qualified for creative supervision of science teaching or for fostering and encouraging new ideas in curriculum development and innovative approaches to the teaching of science. Science education within a school or school system cannot be carried forward adequately by an already overburdened administrator or curriculum specialist. The old concept of the science department head, who often taught a full schedule of classes and attended to the administrative details of being quartermaster for a science department, is also untenable.

Consequently, there has recently arisen a relatively new position within the "decision team" [1] that of science supervisor, a position with a great deal more authority and influence than was previously assigned to the science department head.

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[1] For a full discussion of the "decision team," see Chapter 10.

The number of science supervisors has now reached about seven thousand. Many of these individuals have risen from ranks of either department heads or classroom teachers. However, accomplishment in either of the latter two assignments is not necessarily a prognosticator of successful achievement as a science supervisor.

The responsibilities of science supervision range beyond teaching or clerical experiences. In addition to the perhaps obvious need for an ability to work with other adults, a science supervisor must possess a broad, philosophical view of science education. He must not only be thoroughly familiar with what is now common practice, but also be aware of new developments in the field.

The science supervisor must have more than knowledge of science education; he must also be creative in his outlook toward the improvement of science curricula, teaching approaches, and the relationship of science and science education to the other disciplines. In short, the science supervisor must be a visionary, a "dreamer," if you will. He must be able to see beyond the confines of the classroom and into the future role and responsibility of science education in the world of tomorrow.

Perhaps even more important than the role of the visionary, is the function of the science supervisor as a gadfly. As such, he has several targets: the administration, the school board, the community, his staff, and his professional colleagues, both within and without science education.

To play the gadfly role successfully, the science supervisor should possess several other characteristics, among them: (1) the courage to "stand one's ground" in the face of unpopular reception, (2) the capacity to "state his case" effectively, (3) the sensitivity to recognize the time and place for this role, (4) the ability to perceive the point at which to change targets, and (5) the capability of acting by precept on occasion.

Beyond his gadfly role, another characteristic of a good supervisor is his ability to recognize and appreciate the capacities, special talents, and interests of the individuals within his bailiwick, and to employ each of these to the fullest extent. This characteristic implies the ability and patience to listen to the views of others before accepting or rejecting them, to praise where praise is due, to criticize constructively when appropriate and not to ignore the problem, to build upon individual strengths to develop a cohesive whole and to delegate responsibility whenever and wherever feasible. When teachers in a department are secure in the knowledge that they are respected professional colleagues who are responsible "members of the team," they develop an invaluable *esprit de corps* and are open to experimentation. When fear of failure and subsequent supervisory disapproval are banished from the scene, then, and only then will teachers take the first step from the "tried and true" and venture out into the unknown of "trying something new." Where such attempts are encouraged and where failure in such a trial does not represent a threat to the teacher's position, either tangible or intangible, there one will find the beginning of change in the "system." Above all, the responsibility of the supervisor rests in inspiring teachers.

As a teacher directs the learning activities of his students, so must a supervisor guide the continuing professional growth of his staff, whether it be in additional university study, professional reading, research, or activity in professional organizations.

It is also incumbent upon the supervisor to identify those teachers with latent leadership qualities and encourage them to prepare themselves for careers of leadership and supervision. Where possible in his delegation of responsibility, the supervisor can begin to nurture and develop these leadership qualities in promising staff members.

While some of the characteristics of this relatively new member of the "decision team" are personality-based, others of them can be developed in a well-planned educational program, combined with appropriate supervisory experience.[2]

Science teacher education programs have existed for a long time in this country,[3] but this is not true of education programs for science supervisors. All too often, only a few years of experience in teaching science appears to be the one qualification deemed necessary by many administrators. Others would add a second qualification—that of "rubber stamping" administrative decisions and a tendency to avoid "rocking the boat" with new ideas. There are, of course, notable exceptions to this. There are many sincere administrators who are eager to improve the quality of science education in their schools. However, even these administrators face the dilemma of selecting a supervisor when there are few measurable criteria available to aid in the decision.

Only a few state education departments seek to examine the credentials of aspirant supervisors as they do those of classroom teachers and school administrators. For these few it is common practice to grant professional certificates for general supervision with little regard for the applicant's content competence outside his own field of specialization.

Although the number is growing, there are few universities which offer even one course in science supervision, much less a planned program of studies in that direction.[4] When a certification requirement was passed

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[2] See Barnard, J. Darrell. "Educating the Science Supervisor." *The Science Teacher* 33:15-17; April 1966.

[3] See Chapter 9 for a discussion of science teacher education programs.

[4] A notable exception to this is the summer workshop in science supervision, offered annually by the University of Colorado, under the joint sponsorship of the National Science Supervisors Association and the National Science Foundation.

by one state legislature, a group of practicing science supervisors had to petition a nearby large university to offer a specific course in science supervision in order to avoid taking a course in the supervision of English or social studies, both of which were available. It is interesting to note that since that time (1964) this university has offered the course at frequent intervals and has never failed to attract sufficient enrollment by both aspiring and practicing supervisors.

Courses for the training of supervisors should include: (1) supervision of science instruction; (2) leadership in science curriculum development; (3) evaluation of science learnings. It is quite possible that the third course might have been part of the science teacher preparation in some universities, and duplication is not recommended.

Finally, as in the preparation of teachers, an internship program is highly recommended. The same difficulties which pervade intern programs for teachers are perhaps more acute at the supervisory level. The identification of "master" science supervisors is even more difficult, primarily because of the smaller population from which to draw and because such individuals, as "master" teachers, must also have another quality—the ability and the desire to assume the responsibility for nurturing a neophyte.

A number of professional organizations of science supervisors have been formed at local, state, and national levels. Most of these have appeared since 1960, when a supervisors section of NSTA was formed. It later became the National Science Supervisors Association. Therefore, despite the apathy of universities and certifying agencies toward qualifications for supervisors, it is heartening to see other limited evidence that many science supervisors are interested in improving their professional competence. *A Sourcebook for Science Supervisors,*[5] published by the National Science Supervisors Association and the National Science Teachers Association is a major beginning to professional literature in the field of science supervision.

The need for many more qualified science supervisors is apparent. The obligation for developing the latent abilities of appropriate candidates rests on three institutions: the professional organizations, the universities, and the public schools.

The future role of the science supervisor will include conduct of inservice programs, responsibility for teacher performance, and responsibility for evaluation in educational research.

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[5] *A Sourcebook for Science Supervisors.* Harbeck, Mary Blatt, Editor. National Science Supervisors Association and National Science Teachers Association, Washington, D.C. 1967.

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C. VICTOR BUNDERSON
Computer-Assisted Instruction Laboratory
and
DAVID P. BUTTS
Science Education Center
The University of Texas at Austin

DESIGNING AN INSTRUCTIONAL PROGRAM —A MODEL

IT HAS BEEN AN ARTICLE OF FAITH among many educators that instructional design is an art and can achieve its best form in the hands of an insightful teacher who designs materials with a critical perception of both the structure of his subject matter and the pitfalls and promise of individual students. While there is still validity to this point of view, it may serve as justification for fuzzy thinking and superficial workmanship. It further ignores the fact that a teacher with the present outrageous set of responsibilities characteristic of education cannot hope to invest the hundreds of hours necessary for the design, revisions, and validation of high-quality instructional materials.

Instructional design may also be considered an applied science, wherein elements of "art" are placed within a systematic framework. A model for designing instruction in such a framework is described in this chapter. This model is one result of the cross-fertilization now occurring between systems analysis, programing, and multi-media programed instruction. An insightful and capable teacher will find in such a model guidelines for instructional design. These can help him place a program in context, describe its structure, and develop, evaluate, and improve instructional sequences.[1]

PERSISTENT CHALLENGE

The challenge of instructional design lies both in content and strategy. While reassessing the goals of science teaching, we might also introduce a systematic model in our approach to instructional design. Experience at The University of Texas Computer-Assisted Instruction Laboratory provides a case study in which mathematics and science are systematically formulated and programed in sequences for presentation by computer. As Gagné [5] has pointed out, many of the techniques of "instructional technology," developed through the use of complex and expensive systems, are of general value independent of the systems in which they were first conceived. So it is with the principles and techniques for instructional design that are described and illustrated in this chapter. The procedures for instructional design employed in the development of *Science–A Process Approach,* sponsored by the Commission on Science Education of the American Association for the Advancement of Science, have much in common with a systematic model for curriculum design formalized originally to assist in the development of computer-assisted instruction programs.

The steps taken by a computer programer in designing programs are, indeed, quite similar to those that should be taken by an instructional designer. The "systems engineering" approach to instructional design (as it was developed in industry and government programed-instruction training programs and reinforced in psychological studies of programed learning in university laboratories) follows some of the same principles as effective computer programing. Thus, the union of computers and programed instruction techniques provides a basis for systematic curriculum development. The model in this chapter shows a systematic instructional design procedure and its applicability to noncomputer-based instruction and to the design of programs in computer-based instructional systems.

The systematic approach for the model is characterized by (1) consideration of the context into which an instructional sequence is to be

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[1] The authors are aware that this model is only one approach and that it reflects what might be called the "process" or "behavioral objectives" school of curriculum building. However, since few completed models are available in the area of science, this one is presented as an example of an operational program which does demonstrate the result of applying the systems analysis approach to curriculum design.

For other suggestions for curriculum design, see the publications of the National Science Teachers Association, particularly *Theory Into Action . . . in Science Curriculum Development* (1964). The NSTA curriculum committee maintains an interest in science curriculum development and issues publications from time to time. It is presently planning a monograph on curriculum construction.

introduced, (2) the "black box" model, and (3) the essential role of feedback.

By considering context, the designer takes into account the nature of the learners, their capabilities, and the instructional constraints under which instruction must occur. He may also take a long-range look into such areas as the expected performance level in certain skills that will be required in the students' later life, either on the job or in further education. The notion of context can even be extended to include whether the student's future performance of a learned task will fill an important need in society.

The "black box" model contains the elements:

For instructional design, *output* is stated as specific student-performance capabilities. *Input* includes student entering ability and situation constraints. Given *input* and *output*, the designer's task is to synthesize an instructional *process* that will transform input abilities into output behaviors.

A third, and crucial, aspect of this systematic approach is the role of feedback. In curriculum design, feedback is the basis for evaluation and revision cycles during materials development. A student's behavior and performance capability after completing instructional activities are considered as feedback, as are the individual responses he makes to instructional events. Such data are used to grade the performance of the instructional program itself. If performance objectives are not achieved at the end of an instructional sequence, then the sequence must be revised or must be applied to a set of students with different qualifications. Feedback from task performance to the instructional objectives can be used to modify expectations of the student's performance capabilities for the program or to alter the entrance requirements for students. If long-term evaluation reveals that graduates of the program are not performing in ways relevant to their scientific roles in society, further revision and re-evaluation of instruction objectives themselves will be necessary. Such use of feedback to stimulate and guide revision is a hallmark of systematic instructional design.

The instructional design model incorporates all of these systematic procedures. In addition, it stresses documentation of the various steps in instructional design in a *program manual* which is to be published along with the completed instructional materials. The potential user of a systematically designed instructional product must have a document by which he can evaluate the adequacy of the instructional design, the extent to which it is applicable to his situation, and the extent to which it achieves its goals. Evaluation should be built into any well-designed packaged instructional product, but the standards of documentation to be outlined below have seldom been achieved among published instructional products.

Figure 1. A Prescriptive Approach to the Design of Instructional Systems

Design Activities	Design Products (for program manual)
1. Needs and Justification	
a. Write societal need	Describe the social context requiring an educational program
b. Write program goals	
Describe "job" requirements	The situation in which graduates will find themselves and things they will need to do
Describe student population	
Describe institutional constraints	The available time, facilities, and other resources
c. Write justification of approach	Why are the media and general approaches appropriate to the program goals (in contrast to other ways)?
2. Instructional Design	
a. Goal synthesis	
Derive particular terminal objectives	Behavioral objectives
Set entering performance standards	Prerequisites
Effect of constraints on program design	Narrow choice of media and methods
b. Analysis of task and learner	
Derive intermediate objectives	What must learner be able to do to achieve higher-order objectives?
Construct learning hierarchy	What is the prerequisite relationship among objectives?
Specify relevant learner attributes	Which traits or background knowledge differences interact with possible instructional methods?
c. Synthesize instructional system	
Specify display requirements	
Specify response detection requirements	Further justification of media and methods
Construct flow chart if individualized	How are learners entered into different levels of the hierarchy, and what alternate routes are possible?
Construct steps and step format	Describe conditions of stimulus display, response requirements, and branching for each program frame.
d. Produce and "debug" media and materials	Describe in manual but produce separately
3. Evaluation and Revision	
a. Editorial evaluation	The product is changes in the program
b. Internal empirical evaluation	Item analyses and revision
c. External empirical evaluation	
Do learners meet terminal objectives?	
Longitudinal validation—do graduates meet "job" requirements?	Revision and validation data
4. Use of Feedback: Return to any previous step as indicated by evaluation; revise and recycle.	Revision data if appropriate

Figure 1 presents a prescriptive model for the design of instructional systems. The model is prescriptive in the sense that it prescribes (1) the activity which the instructional designer must perform, (2) the appropriate sequence of these activities, and (3) the nature of the product which results from each activity. Except for the output of Steps 2d and 3a, which are the instructional materials themselves, all products prescribed by this model are documented (that is, described in specific terms) in the program manual.

To place the program objectives in context, it is often useful to write the needs which motivate the development of some systematically designed instructional product. Most of these needs are institutional, that is, they result from situations existing in typical school settings–high school, junior colleges, etc. More generally, these institutions, and programs within them were initially established and should continue to be responsive to the needs of society and culture which sponsors them. It is most useful to list societal needs when support for curriculum development is being sought from national agencies and when the potential utility of the planned instructional materials are being communicated to a lay audience. To these same audiences a justification for the media and methods selected should also be written insofar as it can be derived from the needs.

The first step in systematic instructional design per se, as indicated in Step 2 of Figure 1, is to specify program objectives. The design activities in Step 1 are necessary to assure that important rather than trivial objectives will be stated. If an instructional designer thinks of the goals of an educational activity in relation to the things that the student will be doing after graduation from the course or program and considers the goals in terms of the needs, he is less apt to write objectives so narrow as to lack relevance. At this point the description of goals need not be in behavioral or operational language. Later, however, the designer must specify the performance he wants to result from any particular sequence of instruction in a measurable way.

A statement of overall needs and goals provides the proper context for the instruction designer. In science, educators would have introduced instruction in "finding problems" as well as in testing hypotheses much earlier if they had defined and clearly stated the job requirements of scientists before designing instructional sequences.

The use of expensive digital computers has highlighted the problem of justifying the media and approach (Step 1c of Figure 1). Computers are splendid devices to augment certain aspects of instruction. It is also easy to put programs on a computer which can be adequately performed through other media (e.g., textbook). Therefore, it is important to be sure that a program will utilize characteristics which are partially advantageous or unique to a computer or any other medium chosen, and that are cost-justified within the given institutional setting for which the program is designed.

Steps under the second heading--Instructional Design--begin by clearly specifying behavioral objectives, taking care, as discussed above, that the objectives derived do indeed represent the vital aspects of activities graduates will perform "on the job." The terminal performance objectives are the operational definitions of a program's "output." Input must also be stated as the minimum prerequisites for the program. The institutional constraints considered in the first step, such as available time and equipment may limit the design of the program and should be considered here also.

In Step 2b, the instructional designer must build a staircase between input and output. He must build this staircase subject to the constraints on program design. One usually successful method is to analyze the behavioral objective, separating it into a hierarchy of intermediate objectives, by successively asking the question "what must the learner be able to do to perform the higher order objective, given only instructions?" Gagné [3, 4], Briggs, Gagné, Champeau, and May [2] have described this procedure in some detail. As Glaser [6] and others have pointed out, it is also important to analyze learner attributes that may interact with instruction at any level of the learning hierarchy. At present, behavioral scientists have given us too little evidence about which traits interact with which instructional methods. However, with sweeping individual differences such as sensory handicaps or cultural differences, alternate sequences of instruction might be apparent and thus required in the synthesis step.

Step 2c, course synthesis, is much easier to complete properly if the analysis is adequate. The hierarchy of behavioral objectives makes it easy to specify the display requirement and response detention requirements, because good behavioral objectives include a statement both of what the student is given (display) and what he must do in relation to this material (response). The hierarchical organization of the objectives also provides a basis for deciding on the sequence of steps in the program, since the student must achieve the lower-order objectives before he can tackle the more complex levels.

Computer-assisted instruction has made the possibility of individualization at the tutorial level of interaction a reality. A flow chart showing how individuals may be introduced into different levels of the hierarchy and how they might pass through different levels of the heirarchy and how they might pass through different versions at different levels, becomes a necessity for describing a highly individualized course. A filmstrip, videotape, or teacher-presented set of instructional steps is linear and does not require a flow chart.

Instructional theory does not provide us with too many prescriptive statements that are generally acceptable for the actual construction of steps and step format. A great deal of creativity is required by the instructional designer to make the program steps clever, interesting, and yet efficient in bringing about the behavioral objectives at any level. Guidance is available from the programed instruction literature which can be of great value in writing good programs. Perhaps the most useful procedure is to try out early drafts with students who will quickly tell whether information is missing or ambiguous. Regardless of how the designer invents steps, it is important that the steps be documented in a program manual so that the program can follow these steps if it is to be presented by a human being.

The production of media and materials differs greatly, depending upon what medium is used. The design of computer programs requires a translation into the language of the computer and a debugging step to clean up the inaccuracies which have been entered into the computer's memory during production. Generally, there are proofreading and subsequent alteration of the media and materials, regardless of whether they are computer based or not. Implicit in Step 2d, then, is rewriting, revision, and more revision.

Two kinds of evaluation are identified under Step 3. Editorial evaluation may be accomplished by someone who studies the program manual and the program materials. He attempts to evaluate the adequacy of the instructional design. He seeks to define whether all of the products described in column 2 of Figure 1 are present, and the adequacy of these intermediate products of instructional design. He also evaluates the scope, the taste, the effect, and in general, the kinds of things for which a good reviewer of a book would look.

Perhaps the most useful evaluation is derived from trying the program on students and getting their comments. This step of program development usually opens the door for massive revision and rewriting. The axiom "a good program is not written; it is rewritten and rewritten" is certainly true in good instructional design, regardless of media. Computer-assisted instruction offers the advantage that changes in the program may be entered directly into the computer memory, thus changing the program for all users of the system. Textbooks and filmstrips are more difficult to revise once they have been distributed for students' general use. This aspect of computer-assisted instruction may be important to publishers as well as to teachers who have access to CAI systems. These users may use the rapid feedback from CAI systems during a developmental phase leading to the later publication of well-designed and validated materials in non-computer form.

External validation requires that a meaningful number of students be involved in the completed program and that measurements be taken of the level of attainment of the terminal objectives. To discover and confirm evidence of long-term effects of a program requires a study that follows graduates into later settings. Long-range data, along with validation data from earlier studies, should be included in up-dates of the program manual as the data become available. While the recycling which is so characteristic of a systems approach is not readily apparent in the tabular display in Figure 1, it should not be forgotten.

The details which the instructional designer may include in his manual or program vary with the type of media used. For a computer-assisted instruction program, the expense involved makes it important that great detail be provided in the program manual. For a module prepared by a teacher for presentation in his class, much less effort need be expended. Indeed, the magnitude envisioned here will only be possible if teachers are given released time or reclassified as instructional designers and relieved of many responsibilities. If the teacher does not intend to disseminate the product, the documentation may not be necessary. Whenever dissemination is involved, a program manual should be available which includes a brief description of the student population, a justification of the media under Activity 1, and the behavioral objectives and intermediate objectives, under Activity 2. It should certainly include revision and validation data. [1]

TEACHER-ADMINISTERED INSTRUCTIONAL PACKAGES

One set of science curriculum materials has been selected to illustrate incorporation of the steps described in the instructional design model. It is relevant to note that these materials were developed before the specific description was made of this model. Hence, the purpose here will be to illustrate the comparison and contrast, rather than to demonstrate the model. These materials, *Science–A Process Approach,* have been developed by the Commission on Science Education of the American Association for the Advancement of Science.

Needs and Justifications Identified

First, the societal need for these instructional materials was identified by an interdisciplinary group of scientists and teachers. This need was specified as:

> There is joy in the search for knowledge; there is excitement in seeing, however limited, into the workings of the physical and biological worlds; there is intellectual power to be gained in learning the scientist's approach to the solution of human problems. The first task and central purpose of science education is to awaken in the child, whether or not he will become a professional scientist, a sense of the joy, the excitement, and the intellectual power of science. Education in science, like

> education in letters and the arts, will enlarge the child's appreciation of his world; it will also lead him to a better understanding of the range and limits of man's control over nature.[2]

AAAS was designed to apply to any institution, hence the instructional needs which are often part of the instructional design were not outlined here.

Second, the needs and justifications for the program were made explicit, the results of a series of exploratory conferences. Gagné summarizes the needs for the program:

> There are a number of ways of conceiving of the meaning of "process" as exemplified in *Science–A Process Approach.* First, an emphasis on process implies a corresponding de-emphasis on specific science "content." The children . . . are expected to learn such things as how to observe solid objects and their motions, ... how to infer mechanisms in plants, how to make and verify hypotheses about animal behavior . . . including the control and manipulation of relevant variables . . .
>
> A second meaning of process, referred to by Gagné (1966), centers upon the idea that what is taught to children should resemble what scientists do–the "processes" that they carry out in their own scientific activities.
>
> The third and perhaps most widely important meaning of process introduces the consideration of human intellectual development. From this point of view, processes are in a broad sense "ways of processing information." Such processing grows more complex as the individual develops from early childhood onward. The individual capabilities that are developed may reasonably be called "intellectual skills," a phrase which many would prefer to the term "processes."[3]

Description of the Program Goals

Agreement on a need for more emphasis on a program that has "process" as a focal point is not enough, however. Translating the emphasis into descriptions of terminal behaviors which, when combined, provide a frame of reference for the program becomes an essential task before the work in developing the instructional materials can begin. This analysis was mostly done by small groups of knowledgeable individuals who identified and described what they considered to be significant behaviors (and their general sequence) of scientists at work. Gagné delineates these terminal behaviors and their rationale as:

> There is, then, a progressive intellectual development within each process category. As this development proceeds, it comes to be increasingly interrelated with corresponding development of other processes; inferring, for example, partakes of prior development of skills in observing, classifying, and measuring. The interrelated nature of the development is explicitly recognized in the kinds of activities undertaken in grades four through six, sometimes referred to as "integrated

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[2] *Commentary for Teachers.* Third Experimental Edition. Miscellaneous Publication 68-7. American Association for the Advancement of Science, Washington, D. C. 1968. P.1.

[3] *Science–A Process Approach, Purposes-Accomplishments-Expectations.* AAAS Miscellaneous Publication 67-12. Commission on Science Education, American Association for the Advancement of Science, Washington, D.C. September 1967. Pp. 3-4.

processes," including controlling variables, defining operationally, formulating hypotheses, interpreting data, and as an ultimate form of integration, experimenting.[4]

Institutional Constraints

Before goals can be translated into an instructional step sequence, careful consideration must be given to the institutional constraints.

Some of the institutional constraints on teaching science to children were: the time available for science instruction, the organizational climate of the school, and the teacher's competence in science. Time for science instruction in the elementary school was limited. There seemed to be no accepted pattern for scheduling of science instruction, if it was even included in the schedule. Teacher competence and confidence varied widely. Thus, the course to be developed had to include many opportunities for flexible time periods. By necessity, it had to include relevant background information for the teacher.

Preparation of Instructional Materials

Task 1: Identification of Specific Behaviors or Learning Tasks

To prepare instructional materials, the first task was an explicit description of the behaviors expected to result from the terminal behavior. For example, the four behaviors shown in Figure 2 are included at the beginning of the learning hierarchy leading to the terminal behavior of inferring.

Task 2: Selection of Content for the Learning Task

With the general goal specified, the need described, the terminal behavior of the general goal identified, and the instructional constraints made explicit, small groups initiated the design of instructional materials.

Many considerations went into the selection of specific content, such as student interest, and appropriateness to students' physical and mental development.

For the learning task designed in Figure 2 a variety of content areas were thus considered. From these specific areas, the team agreement resulted in the selection of experiences with packaged articles and containers of substances as the potential content area to be developed.

Task 3: Specification of Instructional Steps

Armed with a specific learning behavior and the content area in which the student could acquire this behavior, the teams then generated the instructional steps. These included: an origination of the problem; a way in which to capture the students' interest and also identify his initial performance levels of the objectives; a series of activities in which the

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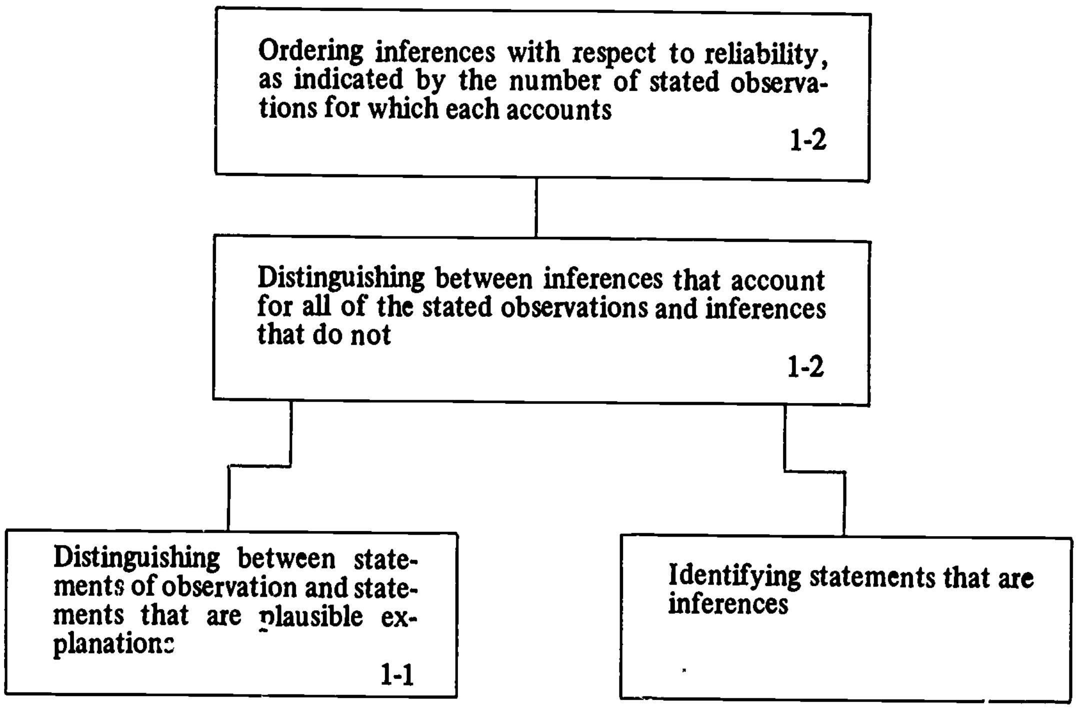
[4] *Ibid.* P. 5.

teacher could guide students toward the desired behavior. An appraisal activity was created to be used either to display students' behavior or for rediagnosis of the learning situation.

Figure 2[5]



For example, the objectives in Figure 2 were given a specific content (inferring the contents of wrapped packages), and the summary of the sequence of instructional steps is described. The original material constitutes the main part of the program manual for the AAAS instructional package.

Task 4: Prerequisite Task Identification

With the learning task identified and the content selected for development, it became appropriate next to identify the constraints or prerequisite skills needed by the students if they are to achieve the objectives of the instructional experience. Any previous experiences relevant to the student's completion of the task were considered as prerequisite skills. Although the model in Figure 2 suggests that the inferring behaviors were identified before the hierarchical analysis is completed, these prerequisite skills were often described in the quite general and unspecific terms and only became functional for a teacher as they became more closely related to the structure of the instructional task. The analysis of the instructional task thus led to a clear description of what previous student experiences were desirable.

For example, in the set of experiences "Inferring the Characteristics of

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[5] Based on Part C, *Science–A Process Approach: Description of Program.* American Association for the Advancement of Science, Washington, D.C. 1967. Published by Xerox Corporation.

Packaged Articles" the primary focus of instructional activities for the student is to distinguish between statements of observation and statements that are plausible explanations. The instructional experiences here assume that the student has acquired abilities to (1) describe characteristics of living objects as they develop and change and to describe the changes observed from one stage to another; (2) order objects according to weight for making comparisons using the equal arm balance; (3) distinguish between objects that are magnets and those that are not magnets; and (4) identify common, environmental, three-dimensional objects by describing their two-dimensional projections.

The likelihood that a student will successfully acquire the desired performance capabilities in this specific set of instructional activities is thus related directly to his previous experiences.

Task 5: Feedback and Revision

The final step of the instructional design model depicts the need for feedback reflecting both the accuracy of the goals and the adequacy of the original materials. In the example taken from *Science–A Process Approach*, two types of feedback were included: The first was a group appraisal in which the teacher could obtain feedback regarding the general performance of the group. This provided him with the opportunity to rediagnose the students' behavior performance and make decisions about what to do next with the class. The second was an individual performance test, the competency measure. Figure 3 illustrates both the appraisal activity and the competency measure for one performance objective.

A COMPUTER-ADMINISTERED PACKAGE

Using the design model of Figure 1, the most extensive CAI program developed to date is in the area of mathematics basic to science concepts. This diagnostic and remedial course, called "Preskills,"[6] is designed, first, to measure the student's achievement in those mathematical skills prerequisite to freshman science, especially chemistry; second to inform him of his deficiencies; and third, to instruct him individually until he has corrected these deficiencies.

The "job" of graduates of the Preskills program involves using scientific notation, logarithms, and unit conversions in the solution of problems in physical science, primarily chemistry. There can be no claim that successful achievement of the objectives of Preskills is sufficient for the solution of problems in freshman chemistry, for there are scientific concepts introduced in any problem which also must be known. It is known that these objects skills are necessary for such performance.

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[6] Preskills (Authelia Smith, author) was developed under contract to Science Research Associates. It is implemented on the IBM 1500 instructional system.

Figure 3[7]

HIERARCHY	APPRAISAL	COMPETENCY TASKS
Distinguishing between statements of observation and statements that are plausible explanations.	Have several children in the class bring packaged articles to school. Tell them to choose some common object that the other children probably have seen. Label each package with the child's name or with a number, and collect them all in front of the room. (It is a good idea to have a few packages ready in case some of the children forget to bring them from home.) Have the class members examine and familiarize themselves with the packages in their free time. Exchanging guesses and observations among themselves will prepare them for expressing their observations and making inferences.	Give the child a cloth sack containing a half-used tube of toothpaste (or glue or cold cream). The tube should be partially filled and flattened at one end. The sack should be tied securely at the open end so that the tube is not visible. Task 1(Objective A): Say, "Tell me all the possible observations you can make about the object in this sack without actually looking in the sack." Put one check in the acceptable column if he notes at least three of these observations: a. how it feels as to shape and flexibility; b. whether it has an odor; c. how heavy or light it is; and d. that the object has edges.

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[7] Based on Part C, *Science–A Process Approach: Description of Program.* American Association for the Advancement of Science, Washington, D.C. 1967. Published by Xerox Corporation.

The institutional constraints for this CAI program are primarily related to time. Thus, Preskills runs from 1½ to 30 or 40 hours, with a total for the average freshman of less than 10 hours. Another constraint is the student's tightly blocked-out schedule, requiring a course which can be taken in variable length segments at the student's convenience.

As entering skills, it was assumed that the student had been exposed to at least one year of elementary algebra in high school, and that he could add, subtract, multiply, and divide.

The heart of instructional design is truly the separation of the program objectives into a hierarchy of subobjectives. In the case of Preskills, the objectives all require that mathematical behavior of various types be displayed. Since this is impossible on most teletype-like devices, a cathode-ray tube device was used to display the formulas and equations, augmented by color slides which illustrated various mathematical principles and could be held on the screen for study while the students worked a series of problems presented by means of the cathode-ray tube.

Since most of the course objectives and intermediate objectives require the student to give a constructed solution of some mathematical problem, keyboard response rather than multiple choice or light-pen response was selected as appropriate. It is important in mathematics that the student not be restricted to narrow response formats since problem solving and not notation is the objective of the Preskills course.

The first step in course synthesis for an effective CAI is the construction of a flow chart which at a gross level shows the individualization provided by the course. Since Preskills is such a long and complex course, it is inadvisable to present a flow chart of the entire course. Separate flow charts showing the different routes a student might take depending on his performance on diagnostic tests and during instruction are provided in the manual. In general, the major individualization occurs by means of the diagnostic pretest given at the beginning of each segment. When the student's status on the intermediate learning objectives is determined for each segment, he is branched into the highest level of the course consistent with his background and proceeds from there. As he proceeds, however, his responses may indicate that he is missing one of the lower order of objectives. This may happen because students do not necessarily begin with Segment 1; i.e., each student may choose which segment(s) he wishes to take or has been assigned to take. Once this diagnosis has been made, he is branched to the appropriate subroutine or introductory subprogram, goes through it and then refers to the high level at the appropriate point. A given subroutine may be a prerequisite and thus callable from many different parts of the course. At the end of the chapter in the manual describing each segment of Preskills, a table is presented which shows the subroutines callable from that segment, and the labels from which those subroutines can be called. This modular use of subroutines that represent lower levels of the hierarchical task provides a level of individualization and an economy of storage not possible with other instructional media.

Other individualization occurs in the drill problems throughout Segment 5, the first segment on logarithms. Logarithms were a new concept for some students. Hence, this became an ideal place to individualize not only the topic but also the length of the exercise sets. If logarithmatic notation and definition are new to a student, practice is essential. The computer retains all responses, and exercises are lengthened or shortened according to each student's frequency of error. The flexibility provided by this type of programing is a major justification for use of the computer rather than programed texts or other media.

Item 2b in Figure 1 asks the instruction designer to specify relevant attributes of the learner. This specification is different from the consideration of background knowledge mentioned above. It implies that because of persistent cognitive abilities or styles, or personality variations, different learners may require different presentations. There is mounting evidence that this is, indeed, the case. Because of lack of information about styles in mathematics learning, no individualization dependent on trait measures was designed into Preskills.

After the flow charts have been prepared, the author's working draft is written. This draft shows the actual steps of the program and their format in the form of the displays anticipated, student response entries and tutorial hints contingent on anticipated answers. Because few guidelines for preparing CAI programs were available, the first draft of Segment 1 was written by intuition. Early versions of the materials were tested with secondary-school students. These students were graduating seniors who had been accepted to college and whose records showed they were deficient in mathematics. The author "simulated a computer" in presenting displays and feedback, to see how the students would react. From this experience, the lowest order subroutines and many common errors for which instruction was required were identified.

In a complex course such as Preskills, effective dissemination will require a knowledgeable programer at any installation to maintain the course and enter revisions as they are sent from the publisher. The bulk of the Preskills manual consists of information about each frame, including the correct answers for that frame and the branches possible from the frame, and the responses which may alter the conditions under which that frame may be displayed. The subroutines which may be called from any frame are also documented.

As the 12 diagnostic and instructional segments of Preskills were programed, each one was made available to a number of students from the university population. These students proceeded through the course, and the responses were recorded by the computer and listed later for the course author to examine. Each response was examined individually and modifications were made in the course where appropriate. These modifications were primarily the addition of more extensive response alternatives, enabling students to input various types of correct responses. Many other additions were made to the course, however, to provide for anticipated wrong answers. Remedial tutorial branches were installed to provide for those error factors which caused difficulty for a sizable number of students. Ambiguities in many of the items were also weeded out by this procedure.

Media preparation and "debugging" proceeded simultaneously. Problems were encountered in communicating with artists whose ideas of artistic value were sometimes incompatible with correct mathematical notation. Teachers need to be vitally concerned with the accuracy of any media and must not succumb to the attractive appearance alone.

Because of its modular and diagnostic nature, one cannot specify how long a student will take to go throug [illegible]eskills. If he is thoroughly familiar with the materials, he can pass all diagnostic tests in about two hours. If he has extensive difficulties he may fall through to the very lowest subroutines of the course on a number of occasions and take more than thirty hours.

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STANLEY E. WILLIAMSON
Oregon State University
Corvallis

CHANGING THE EDUCATION OF SCIENCE TEACHERS

AS WE ENTER THE DECADE of the 1970's, realistic answers are still being sought to questions which have confronted American society since the founding of its first schools. Two questions of major concern have been: What is the primary function of education in a democratic society? What priority should a democratic society place on providing maximum educational opportunity for all? Such questions have now been joined by those of greater immediacy and threat: Can *all* really share? Can we ever convince those who have been deprived for so long that they are not still being cheated? Can parents be involved—or reinvolved— in the education of their children? To these may be added a question for this chapter: What kind of teaching personnel is needed to provide effective educational programs for the remainder of the twentieth century? Only through careful analysis of present social situations and of the current educational scene can we develop plans that provide alternate goals and programs of action for the education of citizens in the future. Each generation must add its own solutions as new problems arise.

SOCIETAL FORCES

As we develop a design for progress in the education of science teachers, we must make certain inherent assumptions about society and education.

Such assumptions must be considered as background for understanding the problems and for planning. In a publication of the "Designing Education for the Future" project, Morphet and Jesser suggest the following as the assumptions that must be made for planning education programs:

Assumptions Relating to Society

1. Man, himself, is not likely to change significantly in basic respects.... Man's attributes and attitudes will depend increasingly on the kind and quality of his socio-economic environment and of his educational experiences...
2. While world tensions will continue and many crises will develop as a result of ideological struggles and the cold war, the gravest problems are likely to arise from the increasing differences in economic level and social progress between the educationally and technologically more advanced nations and the underdeveloped (and generally poorly educated) countries and peoples....
3. Information—potentially available to all—will increase somewhat in geometric progression—will probably double every ten to fifteen years. But so will our ability to store and retrieve information. One of our problems in educational institutions and in society will be to select and utilize effectively the most pertinent and significant information in arriving at decisions, and to learn how to avoid being confused by the irrelevant or inconsequential.
4. In this country... our technological and economic superiority is likely to continue for some time; however, the extent of this superiority should gradually decrease. In the meantime, increasing urbanization, crime, air and water pollution, transportation congestion and other similar developments will continue to bring more complicated and troublesome problems that could result in retrogression or chaos in many respects...[1]

Basic Assumptions Pertaining to Education [selected as they apply to science education]:

1. During coming years provision will need to be made in every society to assure that, in so far as practicable, everyone is educated to the maximum of his potential as an individual and as a contributing member of society. This means that better provisions will need to be made to help each individual to recognize his potential and to continue his education formally or informally as long as society can benefit.
2. The formal and informal education programs and influences will need to be much better coordinated than at present. The environmental influences (home, peer groups, subcultures, other organizations that are concerned) should receive much more consideration in planning and conducting the formal educational program.
3. Much of the relatively unutilized information currently available about the learning process will need to be brought to bear to facilitate learning... Thus, we should be able to do an increasingly better job of facilitating learning for all students.
4. Many prospective changes in society will require changes or adjustments in the educational program.
5. If education is to become more effective, as seems essential, goals will need to be stated more clearly and meaningfully, means (often cooperative) of achieving them must be carefully developed, and realistic measures of progress toward achieving each goal devised and utilized.
6. The emphasis will be on learning—not on "teaching" in the traditional sense. Much of the learning will probably be self learning, with appropriate counseling, involving much more extensive use of technology.

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[1] *Cooperative Planning for Education in 1980—Designing Education for the Future, No. 4.* Morphet, Edgar L. and Jesser, David L., Editors. Citation Press, New York, 1968. P. 4.

7. Major aspects of the curriculum will probably be much more oriented to occupations and professions–in contrast with the traditional college or academic orientation–as a means of helping to meet the needs of a substantial portion of the students that are not now being met realistically . . . .
8. Programs for the preparation of teachers, administrators and other school personnel will need to be significantly reoriented to enable them to provide effective leadership, participate constructively in planning for the future, learn how to help students prepare for change and to utilize the best information available to help motivate students and to facilitate learning.[2]

If we accept these basic assumptions about society and education as possible guidelines, current practices in the preparation of science teachers obviously are inadequate and outmoded. A new teacher preparation model must be designed and developed. This new model should consider the dynamic changes inherent in a society and the implications these changes must have on science education. The model must also identify those basic concepts, procedures, and strategies needed to prepare science teachers to assume a leadership role in a period of change.

The conventional concept of the preservice education of science teachers in the areas of general education, basic science, and professional education must be examined in light of the basic assumptions made. Steps in this direction have been made by the Cooperative Committee on the Teaching of Science and Mathematics of the American Association for the Advancement of Science, the Association for the Education of Teachers in Science (a section of the National Science Teachers Association), and other interested groups through reports during the past decade. Just how effective the guidelines proposed by these groups have been in changing science teacher education is most difficult to determine. However, it is reasonable to assume that growing out of their recommendations, in some institutions preparing science teachers, certain procedures and strategies are emerging, or have emerged, which may serve as models for further improvement of science teacher preparation programs.

Preparation in three basic areas–general education, basic science, and professional (teaching methods, etc.) education–have traditionally been considered essential in the preparation of prospective science teachers. During the past decade, evidence has shown that the time devoted to each area is not of greatest importance. What does matter is the breadth and depth to which each area is studied, the quality of the experiences, the implications, and the interrelationships among the science and the global viewpoint.

There is mounting evidence that the proper preparation of science teachers cannot be accomplished in the traditional four-year baccalaureate degree program. Such time does not permit the study in breadth and depth in the basic sciences, nor in general and professional education, to cope

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[2] *Ibid.* Pp. 5-6.

with the multitude of problems confronting education. Five years should be considered as the minimum in the immediate future, with six years required for standard certification by the end of this century. Within this additional time, it will be possible for the public schools to assume their rightful position as partners in teacher preparation. For convenience, the preparation period will be discussed under preservice and inservice science teacher education programs.

COMPETENCIES NEEDED

The many problems in preparing science teachers for the future may be resolved in part, by studying and coming to some general agreement about the competencies needed to be effective teachers in the science classroom. In the past, major emphasis has been placed on the development of competency in science content and in methods of teaching. Changes in societal structure, in educational technology, and in the complex interrelationship between the school and the community demand the development of new competencies if science teachers are to achieve maximum effectiveness. Just what these competencies must be is yet to be determined, and will vary from community to community and from school to school. Specific competencies that have been identified for the present by Richardson and others are as follows:

The Education of Science Teachers

1. Science teachers must create and provide an environment in which students can learn. Situations involving the association of new scientific information with the old and familiar should be included. Those situations promote the ability of the students to evaluate their own growth, and they help students to develop their personal goals and plans.
2. Science teachers must learn how to stimulate students to develop attitudes and methods of scientific inquiry. In this way they help students to become interested in their environment and to learn how to use the products of science. The students are stimulated to consider potential careers in science, science teaching, and engineering.
3. The science teacher should share with other teachers the responsibility for the development of intelligent self-direction.
4. The science teacher should counsel with students in planning their work, developing their goals, and solving their problems.
5. The science teacher must be able to relate the science curriculum to the total school curriculum.
6. The science teacher can and does contribute to the development of creativity and habits of inquiry, and the fostering of the scientific attitudes through his own activity in the science classroom-laboratory.
7. The science teacher should be able to transmit man's cultural heritage. In itself, this ability involves a breadth of preparation in science and in related fields. It requires that the science teacher be able to develop the relationship of science in the schools to the community of which the school is a part.[3]

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[3] Richardson, John S.; Williamson, Stanley E.; and Stotler, Donald W. *The Education of Science Teachers*. Charles E. Merrill Publishing Co., Columbus, Ohio. 1968. Pp. 20-21.

PRESERVICE EDUCATION

General Education

Prospective science teachers must be aware of the societal implications of the times—the social forces and conditions influencing the educational endeavor. They should study the characteristics or projected changes in society and be able to identify the societal ingredients that have implications for education. The increase in population by an estimated 45 to 50 million in the next 15 years, combined with an ever-increasing life span, and the tendency toward urban living, present many problems related to environmental pollution, maintenance of physical and mental health, and the depletion of natural resources. These concerns must be kept in their proper perspectives by science teachers.

Scientists and science teachers have a responsibility to understand the problems involved in the development of a more humanistic culture and must be able to assist in developing effective strategies to bring it about. To accomplish this goal demands quite a different program for the preparation of all teachers—especially those responsible for teaching science. The common core of courses included in the general education phase of teacher education needs to be thoroughly overhauled. Traditional content must be replaced with high-priority content designed to prepare teachers and students to solve societal problems, or at least to recognize the consequences of certain lines of action.

The general educational experiences for future science teachers must include work in the social sciences, humanities, and the fine and practical arts. There is some evidence that the field of anthropology may well serve, in the future, as the core in general education through the study of man, his origin, distribution, environmental and social relations, and his culture. Study in depth in this area would provide (1) a better understanding of man and why he is not likely to make significant changes in behavior in the near future unless his socioeconomic environment and his educational experiences are directed toward his basic attributes and attitudes, and (2) a knowledge of the cause of world tensions and crises that are related to differences in social progress and economic conditions between the well-developed and underdeveloped nations from the standpoint of education and technology. Science teachers should recognize the serious problem areas of the contemporary society, recognize new ones as they emerge, and should see the implications for science and science teaching.

Such concepts and attitudes are not likely to be developed among prospective teachers through experiences in highly departmentalized courses in social science, humanities, and the arts. Interdepartmental planning will be necessary if societal problems are to be identified, studied, and brought into sharp focus. Then, and only then, can the science teacher—in fact, all teachers—see the real role of education in modern society. With anthropology as the central core, other courses in the social sciences, humanities, sciences, and arts would be selected to provide greater breadth and depth in understanding man and his culture.

In preservice science teacher preparation programs, from 40 to 50 percent of the undergraduate degree work should be in general education. The major area of interest, science, may be pursued in greater breadth and depth in the inservice or fifth and sixth years of preparation.

Basic Science Preparation

Emerging curriculum materials for the elementary and secondary schools have presented a real challenge to institutions charged with the responsibility of preparing science teachers. New objectives, content, and methodology in the K-12 curriculum programs have revealed glaring weaknesses in undergraduate teacher preparation courses. Prospective science teachers who are expected to use inquiry and investigations, direct research on problems of interest, and make full utilization of the processes of science will too frequently find little in their undergraduate courses to prepare them for such an assignment. Some science organizations—Commission on Undergraduate Education in Biological Sciences (CUEBS), Advisory Council on College Chemistry (AC₃C), Commission on College Physics (CCP), and others—have made encouraging efforts to improve undergraduate education in their respective disciplines. Whether their efforts will be a case of "too little, too late" remains to be seen. Attempts by foward-looking institutions to integrate the biological and physical sciences into broad core areas reveal a real concern on the part of scientists to improve the situation.

Current curriculum developments in science, K-12, reveal the need for greater breadth of preparation in the basic sciences (biological, earth and space, mathematics, and physical) for all prospective science teachers. This breadth should be emphasized during the first two years of the teacher training program, with depth of preparation in one or two areas during the last two years of the undergraduate program and in the fifth and sixth years, during graduate study. Breadth of preparation in the first two years of the teacher preparation program is essential if the prospective teacher is to gain maximum benefits from study in depth in one area later. Regardless of the program followed by prospective teachers, three questions should be considered:

1. What is the relevance of the science content and teaching methods used in the science teacher preparation program to the day-by-day work of the classroom teacher?
2. How do the overall objectives and philosophy of science educators relate to the day-by-day work of the classroom teacher?

3. Has the prospective teacher caught the spirit of science, and with the knowledge acquired is he able to communicate this spirit to his pupils?

Review and analysis of current programs in science for prospective teachers reveal that a satisfactory answer to the first question has not been found. Much of the content and methodology utilized in teaching college courses has little relevance to the day-by-day activities of the elementary and secondary classroom teachers. The lecture method is widely used in disseminating knowledge, and this may or may not include laboratory activities related to the classroom activity. All too frequently little emphasis is placed on building, for the student, a structure of science using methods of inquiry and investigations or by applying other accepted processes of science. In many instances emphasis is placed on rote memorization of isolated factual minutia in a narrow field without concern for its place or importance in the total science picture.

Answering the third question: If the spirit of science is not caught by the prospective teachers in their preservice science courses, it is unlikely that the teacher will communicate this spirit to his pupils. To be effective in helping classroom teachers use current curriculum materials, "spirit-of-science" kinds of experiences must be included. In the teacher education program, such experiences can be more effectively developed in the basic science courses than in the methods courses, though attention to the spirit of science belongs in both parts of the teacher's preparation.

During the past 10 years, major emphasis in secondary school science has shifted away from the traditional, descriptive science to a more theoretical science. Science in the future may give greater attention to human affairs.

New curriculum materials are emerging that attempt to integrate all the basic sciences, K-12. This approach to the science curriculum has been supported by leading scientists and science educators for a number of years. The integrated approach is likely to gain popularity during the next 20 years, thereby influencing the background preparation, in the basic sciences, of prospective teachers.

There can be no doubt that the science teacher should have extensive and accurate knowledge in the basic sciences he professes to teach, but mere knowledge is not enough. There must be the ability to help young people translate this information, through the appropriate structure and process, to the solution of immediate and long-range problems of the individual and, in turn, society.

SCIENCE PREPARATION OF ELEMENTARY SCHOOL TEACHERS

A program in science for the elementary school teacher should be designed with full consideration given to the basic assumptions of society that have implications in science—the nature of man, the world situation, and the selection and use of knowledge that will enable a society to solve the problems of technological and economic development. Emphasis should be placed on content that will develop: (1) a degree of scientific literacy in all pupils, (2) a knowledge of the spirit and philosophy of science, and (3) knowledge of the processes used in the solution of environmental problems.

Elementary-school teachers should have broad preparation in the fundamental concepts of the biological sciences, earth sciences, physical sciences, and mathematics. Colleges and universities should explore and develop interdisciplinary courses that draw on the content of the various sciences. These should be laboratory-oriented with emphasis given to student involvement in the processing of information gathered in their investigations. The course should be taught to develop, on the part of the elementary teachers, the behavioral objectives they are expected to develop, in turn, in their own students.

It is not intended that elementary-school science teachers become specialists in a field of science, but rather, that they have the necessary competence and confidence to use science in working with their pupils and in interpreting problems in their own daily living. Research is needed to establish the science competencies needed by elementary teachers beyond the general education requirement in science and the methodologies necessary for effective classroom teaching. The partnership of the public school and college as an institution preparing elementary teachers should be encouraged to experiment with various approaches in preparing teachers.

The Unified Science—General Education Approach

Institutions desiring to follow this approach should choose, from the cognitive and affective domains of educational objectives,[4] those science-related competencies essential to elementary teachers. These should be organized into a three-year, laboratory-oriented, integrated, science program, including experiences in the biological, physical, and earth sciences. Cooperative planning between the program designers in general education (social sciences, humanities, and the arts) and in science would be essential for maximum effectiveness and efficiency for the learner. This would assist in bringing about an understanding, on the part of the

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[4] Bloom, Benjamin S., Editor. *Taxonomy of Educational Objectives, Handbook I: Cognitive Domain.* Longmans, Green and Company, New York. 1965.

Krathwohl, David R.; Bloom, Benjamin S.; and Masia, Bertram B. *Taxonomy of Educational Objectives. Handbook II: Affective Domain.* David McKay Company, Inc., New York. 1964.

student, of the interrelationship of science and society and the part each must play in the solution of the problems of man.

The prospective teacher would be involved in working with the processes of science, in inquiry, investigations, and in planning science experiences for children. He would become aware of the new programs in elementary science, as well as the old, and learn to identify the specific behavioral objectives essential in the study of science.

Inservice teacher education programs should be provided by the colleges and universities and/or local districts that provide continuous opportunity for elementary-school teachers to improve and update science content and methodology. The ever-changing competencies required for effective classroom teaching of science make the fifth and sixth year of preparation essential for high-quality instruction in the elementary school.

This approach would call for a sweeping overhaul of some of the basic science courses taken by prospective elementary teachers. Some work has already been done; but it is only a beginning–it must not be looked on as permanent, but must be continuously evaluated and redesigned. Planning at this level demands a higher degree of communication than has been in evidence in the past between academic disciplines. Such communication, it is hoped, will result in new concepts, new courses, and a more complete education of the prospective teacher in the sciences.

SCIENCE PREPARATION OF SECONDARY-SCHOOL TEACHERS

For the secondary-school science teacher, if instruction is to meet the challenge of the years ahead, breadth and depth of preparation in the sciences are mandatory, with significant changes in course content and methodology. The knowledge and understandings which we expect schools to transmit should be aimed at giving the student command of the nature of the world in which he lives or will live.

Two possible approaches may be used in the future to meet the educational needs of science teachers in a rapidly changing culture. (1) The unified science - general education approach and (2) the basic fields approach.

The Unified Science - General Education Approach

For the secondary-school science teacher the science program should be the same as for the elementary school science teachers for the first three years with the last two years devoted to areas of interest and specialization in the biological, or earth and space, or physical sciences. During the last two years, each prospective teacher should have the experience of working on a research problem and serving as an assistant in the science courses taken by prospective teachers during the first three years of the science teacher preparation program.

Major problems of society should be identified, their scientific implications determined and studied as a part of the science offerings. The interrelationship between the social sciences, humanities, arts, and sciences would be clearly established in the general education aspect of this approach.

The Basic Fields Approach

Progress in science teacher education at the secondary level may be stimulated by providing a common core of science courses for all prospective science teachers during the first two years. Experiences in the basic fields, biological science, earth and space science, mathematics, and physical sciences, with a minimum of one academic year in each would serve to provide breadth of preparation and a solid foundation for further study in science. Included within this should be a study of the historical and philosophical foundations of science.

Beginning with the junior year and continuing through the fifth and sixth year, specialized courses especially designed for teachers should be made available. Such courses should not emphasize narrow specialization in a given field; rather, they should bring together concepts from various areas, and they should be both liberalizing and professional. There is need for experimental research to seek more efficient and effective ways of organizing science courses to meet the needs of a modern science curriculum and to develop the needed scientific literacy on the part of teachers and students.

PROFESSIONAL PREPARATION OF SCIENCE TEACHERS

The role and importance of courses in professional education has been debated by various groups for many years. During the past ten years, for instance, the academicians and professional educators have, after being involved in curriculum programs of common interest in elementary and secondary school science, come to realize the importance of both areas—content and professional education—in the preparation of science teachers.

Many committees—including the Cooperative Committee on the Teaching of Science and Mathematics of the American Association for the Advancement of Science (1946), the Association for the Education of Teachers of Science (1960), and, more recently, a joint committee representing both groups (AAAS-AETS, 1967)—have studied and reported on professional preparation of science teachers. The reports of these committees have, in general, identified the following important areas of concern: (1) the role and importance of the school as a social institution, (2) characteristics of the learner and the learning process, (3) methods and techniques used in teaching science, (4) the internship or practicum-type experiences, and (5) the role of the science teacher in counseling students. These experiences are not unique to science teachers; indeed, they are needed by all teachers and will become of ever-increasing importance in the years ahead.

A prospective science teacher should be made aware of the current research on learning. He should enter the profession with a concept of learning that makes sense to him because he can use it in the classroom. Equipped with this concept, the teacher is more likely to select modern materials of instruction and to use them more efficiently, effectively, and intelligently. More emphasis should be placed on his becoming aware of how he is learning as a means of illuminating the very nature of the learning process.

Today and in the future teachers will need to be more concerned about individual differences in the classroom, about pupil behavior symptomatic of differing physical and mental maturity, about the impact of society and subculture on motivation, and about the many factors producing frustration which seriously affect the classroom situation.

Methods of Teaching Science

Traditional methods courses cannot help the teacher meet the challenges of the modern science classroom. The key to successful science teaching in the future must be *planning.* Today the science teacher still serves four major functions: (1) environment management, (2) interpersonal relationships, (3) information giving, and (4) clerical. In the past, major emphasis in teaching has been placed on dissemination of information and clerical procedures. In the future, science teachers must be more concerned about establishing a climate for learning and about developing desirable interpersonal relations.

Methods courses must familiarize prospective teachers with the method, techniques, and materials to use in handling environment management and interpersonal relationship problems. At the same time attention must be given to (1) self-learning devices, (2) the potential use of television and other electronic laboratory materials, and (3) other systems for instruction (filmed programs and instructional units or packages).

In addition, prospective teachers should develop a concept of measurement and evaluation according to the objectives sought that are consistent with research in the field. Experience in designing evaluation materials for a wide range of teaching purposes, pupil ability, and environmental conditions is essential to successful teaching. Evaluation techniques must change as objectives, content, and methods change to meet new conditions. This is not an easy concept to develop, even with experienced teachers.

Internship and Practicum

Experienced teachers consistently report that the most valuable experience in their professional education lay in their interaction with students. A number of institutions which prepare science teachers are engaged in research activities designed to improve this experience. Promising results have been obtained from use of teacher-aide programs (one year duration) between the second and third year of the undergraduate program; extensive observation programs beginning with entry into the teacher education program; modification of the conventional student teaching program; and, the internship immediately following the completion of the undergraduate program. The importance of the active involvement of public schools as team members with universities in this search for more effective teacher preparation programs cannot be overemphasized.

There is evidence supporting the wisdom of opportunities for prospective science teachers to begin working in the classroom early in the program and to continue throughout the undergraduate program, culminating in the student teaching and intern experience.

Student Counseling

The science teacher must assume greater responsibility in the years ahead in the educational and vocational counseling of science students in a period of social, educational, and technological change. This responsibility will include cooperation with professional counselors. As the population grows, as societal problems become more complex, the need for scientists, engineers, and technologists will increase. The professional education of prospective science teachers should include experiences in guidance which would contribute to the teacher's awareness of career opportunities in all areas of science and engineering. Efforts should be made to alert science teachers to sources of information that would better enable them to understand the major areas of guidance and also assist them in obtaining up-to-date career information in related fields.

Inservice Programs for Science Teachers

The 59th (1960) yearbook of the National Society for the Study of Education, Part I, *Rethinking Science Education* concluded:

> Two great needs have become increasingly evident from the activities of these agencies [i.e., agencies interested in improving the preparation of science teachers]: (*a*) the development of instructional programs in science that serve effectively and uniquely the needs of prospective science teachers and (*b*) the development of a

professional program understood and appreciated by prospective science teachers and related to the academic components of preparation for teaching.[5]

As one reviews the progress made in science teacher education in the period of almost a decade since this report, one can see that some progress has been made; but the progress falls short of achieving the objective established in the report. Although special inservice institutes for science teachers, funded by national foundations, have had considerable effect on the subject-matter competence of participating teachers, the number reached is small compared to the number needing additional preparation. Many institutions have designed and developed fifth-year programs of preparation in the basic sciences. New masters degrees have appeared. Of greater importance, however, is the need for change in the very nature of these programs and institutes to provide experienced teachers with content and with the methods and techniques needed to work effectively with current curriculum materials.

THE FIFTH YEAR OR GRADUATE PROGRAM

A fifth year, based on the development of greater breadth and depth in the basic sciences of concern to science teachers, K-12, should be designed and developed by the major institutions preparing science teachers. The science courses taught in this program should be specifically designed for the science teacher, with emphasis not only on content but on the processes of science and the other tools scientists use to solve problems. The course should be taught using the same methods and techniques science teachers are expected to use in the classroom.

A sixth year of preparation for department chairmen and supervisors is recommended. Richardson[6] suggests the fifth and sixth year of preparation include the following minimum requirements:

1. Studies dealing with subject matter or content in the teaching field or fields and in related fields–50 quarter hours
2. Studies dealing with the nature of the learner and the psychology of learning–15 quarter hours
3. Studies dealing with the program of the school and the problems of the school–15 quarter hours

Professional courses in science education should be provided that would keep the experienced teacher abreast of developments in curriculum, methodology, measurement and evaluation, and with the more promising developments in educational technology. Provision should be made for

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[5] *Rethinking Science Education–The Fifty-ninth Yearbook of the National Society for the Study of Education. Part I.* The University of Chicago Press, Chicago, Illinois. 1960. P. 278.

[6] *Op. cit.* Pp. 127-128.

science teachers to read, study, and evaluate research in science education in order to discover the implications such research holds for their own classroom teaching.

The increasing complexity of society, and the problems growing out of society influencing education, and the continual growth in scientific knowledge will, in the years ahead, extend the preparation of science teachers to a sixth year or more. There must be in the minds of all good teachers the desire for continuous self-renewal, the need for intelligent self-learning, combined with an appetite for research not only in science but in the teaching-learning process.

RECRUITMENT OF FUTURE TEACHERS

As duties and responsibilities of classroom science teachers become more complex, there is need for a new approach to recruitment, selection, and admission to the science teaching profession. Personal characteristics and qualities essential for effective teaching must be identified. Assessments must be made about what makes a good teacher good. In selecting future teachers, more information is needed about the emotional makeup of good and poor teachers–of those who should or should not enter the profession.

Screening processes need to be developed to identify individuals who have the necessary mental ability, interest, dedication, emotional stability, and the qualities of leadership that make for success in the profession. One approach would be to develop a procedure whereby prospective science teachers receive psychological evaluations, using appropriate tests or other devices and/or in-depth interviews. Once selected, the prospective teacher should be counseled into the kind of individualized teacher education program that assists him to find a teaching style appropriate to his personal characteristics and which enables him to capitalize on his own special strengths.

To meet future demands for science teachers, ways must be found to reach prospective teachers before they enter institutions of higher education. Junior and senior high school science teachers are in a position to assist in recruiting and selecting future teachers. There is need for national groups (National Science Teachers Association, National Association of Biology Teachers, and others) to continue to produce information on science teaching as a career, to distribute it widely, and assist in all ways possible to see that those persons with good potential as teachers do, in fact, consider teaching as a career.

There is also a recruiting source in the role of junior colleges. Through the development of sub-baccalaureate degree programs for such roles as teacher-aides or educational technologists, it would be possible to develop interest on the part of individuals to enter science teaching as a profession. Not only would individuals in these junior college programs serve a most important need in the differentiated–staff school, such a program would help these students to develop an early commitment to teaching and thus serve as an important "recruiting" arena for the needed science teachers.

PERSISTENT PROBLEMS AND ISSUES

The problems and issues which have plagued those responsible for the preparation of science teachers in the past will continue in the future unless carefully planned research programs are developed. Institutions preparing science teachers must experiment with new forms of preservice and inservice programs of teacher education to meet new needs. Emphasis should be placed on the fact that teaching is an interaction, and that talking about teaching cannot be substituted for actually doing it. Bebell suggests four possible approaches to resolve some of the problems and issues in professional courses in teacher education:

1. Use of videotape recordings to bring field situations into the campus classroom for student analysis, or to provide the neophyte teacher with a chance to see himself in operation;
2. Establishment of additional kinds of field experiences for prospective teachers, including a student-teaching period of variable length, the use of students as teacher aides, tutors, or workers in community agencies, and such post-student-teaching experiences as part- or full-time internships;
3. Closer ties between education courses (including psychology and other supporting areas) and field experiences, in order to keep the practical implications of these courses foremost in the minds of both students and teachers; and
4. Development of new kinds of course experiences and sequences, including long-lasting seminars, team-taught courses involving two or more disciplines, and opportunities for greater independence in planning by the future teacher.[7]

Some of the listed schemes - are currently in various stages of development, but much research remains to be done in exploring new, creative ways to prepare science teachers.

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[7] Bebell, Clifford F. S. "The Educational Program: Part One." Chapter 1 in *Emerging Designs for Education.* Designing Education for the Future: An Eight-State Project, Denver, Colorado. May 1968. P. 42. (Republished by Citation Press, Scholastic Magazines, Inc., New York. 1968.)

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CHANGE

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RICHARD SCHULZ
Public Schools
Cedar Rapids, Iowa

THE SUPPORTING TEAM AS AN AGENT FOR CHANGE

AFTER MORE THAN A DECADE of expensive, arduous, and dedicated studies it may be surprising to discover that science education is still not the idealized discipline that many of us assumed it might be. One hypothesis is that in our attention to the development of curricula, we have overlooked the human factors required to bring about change. The role of these human factors must be understood and facilitated.

THE STRESS OF CHANGE

The forces of change bear incessantly not only on institutions but more particularly on the people within those institutions who must actually respond to the forces. Persistent change requires continual adaptation, not merely an occasional response or reaction. Introducing a course, building a guide, adopting a program of studies, selecting a text, authorizing teacher aides, remodeling a science facility, purchasing capital equipment and supplies—all are transition points, not end points, and innovation may arise from many sources.

Pellegrin[1] has identified 10 sources of educational innovation:

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[1] Pellegrin, Roland J. "An Analysis of Sources and Processes of Innovation in Education." Center for the Advanced Study of Educational Administration, University of Oregon, Eugene. 1966. Pp. 5-12.

1. Classroom teacher
2. Administrator (principal and superintendent)
3. School board
4. Lay public
5. State departments of education
6. Education faculties in colleges and universities
7. Professional associations
8. United States Office of Education and other federal government agencies
9. Textbook publishers
10. Scientists, technical specialists, and other experts

Each source brings different resources and biases to its confrontation with the learner. The stress of change is real. It must be respected in any design for progress.

NEED FOR LEADERSHIP

Adequate leadership is the most important prerequisite of managed change. Someone at a high administrative level must perceive that innovation and change are desirable. There is little incentive to struggling with the stress of change in the face of a department chairman, principal, curriculum coordinator, or superintendent who sees no advantage in change. Leadership is vital to all these roles, as well as to teachers. However, establishing executive support is only one of the leadership functions. It is also necessary to create and refine ideas, initiate and implement specific innovations, and appraise the effectiveness of the changes. Each of these activities requires leadership and is an integral part of the leadership function.

Rarely can the entire function be vested in a single individual or office, a fact which has led to the useful concept of a decision team.

THE DECISION TEAM

Regardless of the sources of innovation and leadership, what happens to the learner is ultimately a consequence of the decisions of many individuals. Independent, unsupported decision making is clearly deficient in the capacity to respond and adapt to a turbulent, dynamic, and uncertain environment. As a result, supporting, decision-making teams have emerged. As used here, the decision team is that group of individuals who, through active involvement and interaction, participate directly in the decision-making function at any level of school organization. Many superintendents have developed an "office of the superintendency." Some schools are administered by the "office of the principalship," and even the concept of an instructional office, a "teachership," is beginning to take form.

Without doubt, teachers are fully entitled to serve on various decision teams–administrative, curricular, instructional. On occasion, ill-prepared teachers may have unwittingly devastated some of the most imaginative and promising innovations, but elsewhere master classroom teachers have overcome overwhelming obstacles to create outstanding educational experiences for students. Fantini and Weinstein[2] have eloquently stated the case for the voice of the teacher in the decision team:

> Teachers must have a decision-making role in the transition (to a real overhaul of the entire process by which people are educated). Closest to the learner, the teacher is farthest from decisions on curriculum, grouping, and grading. Others develop the curriculum that the teacher is required to administer, whether it happens to be appropriate for his pupils or not.

The unique range of professional competencies in a school or school district makes the decision team concept both reasonable and compelling. A highly trained staff cannot be discounted and ignored either by administrative officials, by fellow teachers, or by distant innovators. The new dynamism requires involvement and interaction, and it demands involvement for the purpose of advice rather than as a strategem to gain support. It pleads for increased faith in people, from the child in the classroom through Pellegrin's register of educational innovators.

PLANNING CHANGE

The absence of a clear, long-range plan invites disaster as curriculum adjusts to the forces of change. The answer to the question "Where do we want to be in the year 2000?" provides a model against which each potential innovation or alternative must be tested. There is no place for isolated innovations that only locally or temporarily relieve the current pressures. It would probably be incredible to learn how many schools have made post-Sputnik modifications in the science curriculum without a long-range plan. Such disregard for planning by teachers and administrators has made the schools excessively responsive to bandwagon swings and whimsical cycles. Only with an explicit, yet reasonably flexible long-range plan, acting as a guide but not a dogma, can educational decision making really be expected to be rational and effective.

From the large-scale, nation-wide curriculum projects as well as many smaller "funded" projects and many system-wide curriculum studies has come a certain set toward change. One needs only to review the summaries of the curriculum projects listed in the *International Clearinghouse Report*

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[2] Fantini, Mario D., and Weinstein, Gerald. "Taking Advantage of the Disadvantaged." A Ford Foundation reprint from *The Record* 69: No. 2, P. 5; November 1957. Teachers College, Columbia University, New York.

of Curriculum Projects in Science[3], review the materials issued by the projects themselves, or follow the journal discussions of the new science curriculums to know what a proliferation of materials are available. The problem may now be more one of selection and discrimination than merely developing an inclination toward change.

Within the last few years also, new dissemination centers have been established to provide access to reports and studies in many areas of education. These are the Educational Resources Information Centers (ERIC) supported by the U. S. Office of Education. The ERIC Center for Science Education is located at The Ohio State University. It regularly issues bibliographies and other informative materials, and in the January, March, and April 1969 issues of *The Science Teacher* and the January-February, and March 1969 issues of *Science and Children* published surveys of several hundred pieces of research in science education.[4]

Goal Selection

Too much can hardly be said about the importance of goal selection in the architecture of educational planning. What should students do and value as a result of having learned? How can goals be selected to anticipate the *next* quarter century, rather than to mirror the *past* quarter century? What are the forward-looking specifications for science education?

Should the specifications continue to focus on the discipline as they have in the '60's? Or, as Fox has suggested in Chapter 2, should they finally be addressed to the complete scientific enterprise—as an area of experience, a foundation for technology, an intellectual and moral influence, and a social enterprise as well as a body of organized knowledge and a way of knowing?

Should they provide for human individuality? Can the learner be moved still closer to the center of the stage? Many psychologists and educators are

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[3] A joint project of the National Science Foundation and the Science Education Center at the University of Maryland, College Park. J. David Lockard, Editor.

[4] The survey articles were as follows: Blosser, Patricia E., and Howe, Robert W. "An Analysis of Research on Elementary Teacher Education Related to the Teaching of Science." *Science and Children* 6: 50-60; January-February 1969. Blosser, Patricia E., and Howe, Robert W. "An Analysis of Research Related to the Education of Secondary School Science Teachers." *The Science Teacher* 36: 87-95; January 1969. Ramsey, Gregor A., and Howe, Robert W. "An Analysis of Research on Instructional Procedures in Secondary School Science—Part I—Outcomes of Research." *The Science Teacher* 36:62-66, 68-70; March 1969. Ramsey, Gregor A. and Howe, Robert W. "An Analysis of Research on Instructional Procedures in Secondary School Science—Part II—Instructional Procedures." *The Science Teacher* 36:72-81; April 1969. Ramsey, Gregor A., and Howe, Robert W. "An Analysis of Research Related to Instructional Procedures in Elementary School Science." *Science and Children* 6: 25-36; April 1969.

convinced that the best way to improve learning is to concentrate on individual differences in learning by adjusting the material which is presented to each student.

Should specifications accommodate human problems? What part should science education play in the human confrontation with burgeoning populations, leisure, poverty, racial tensions, and environmental pollution?

Should they exploit the role of science in a more general value system as presented so lucidly by the Educational Policies Commission in *Education and the Spirit of Science?* That report concludes:

> The profound changes men have wrought in the world by their uses of science and technology have been for better and for worse. But the spirit underlying science is a highly desirable spirit. It can enable entire peoples to use their minds with breadth and dignity and with striking benefit to their health and standard of living. It promotes individuality. It can strengthen man's efforts in behalf of world community, peace, and brotherhood. It develops a sense of one's power tempered by an awareness of the minute and tenuous nature of one's contributions. Insofar as an individual learns to live by the spirit of science, he shares in the liberation of mankind's intelligence and achieves an invigorating sense of participation in the spirit of the modern world. To communicate the spirit of science and to develop people's capacity to use its values should therefore be among the principal goals of education in our own and every other country.[5]

Decision teams which accept this view of science must bring science education into the mainstream of the schools—as a part of, rather than apart from, the total curriculum.

What then should the specifications be for the next quarter century of science education? Goal selection must be a primary concern of the decision team. Without goals, without a plan, decisions will be erratic and results unassessable. Furthermore, the decision team must establish priorities as it develops specifications.

PRIORITIES

No institution has sufficient resources to move in every direction at once. Priorities must be established, and available resources must be allocated wisely. Misguided efforts in education can be intolerably wasteful of time, personnel, and monies.

Preliminary study, assessment of degrees of freedom, assignment of leadership, wide involvement of personnel, goal selection, analysis of alternatives, provision of physical facilities, selection of a starting point, and quality control are among the design activities that consume valuable resources. Not surprisingly, many promising educational innovations have aborted in the classroom when the decision team failed to appraise its resources accurately.

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[5] National Education Association and American Association of School Administrators, Educational Policies Commission. *Education and the Spirit of Science.* The Commission, Washington, D.C. 1966. P. 27.

For example, the full implementation of a K-12 program is unrealistic in the absence of qualified teachers, supervisors, administrative and financial support, or adequate facilities. And it is futile to consider an inquiry-centered program without resources to purchase laboratory supplies or adequate time for students and teachers to reflect and interact.

What is desirable is seldom completely achievable within the limits of the available resources. All innovators must come to realize that in the conception of an idea, the sky may be the limit, but as a plan matures and moves toward implementation, the intellectual flight must eventually return to earth.

Designing for progress requires the identification or production of meaningful options and a careful projection of the probable consequences of each. This is ultimately that with which leadership, decision teams, long-range plans, and goal selection must be concerned. Alternatives must be patiently sought, regardless of the level at which the decisions are being made—department, school, district, city, state, or federal.

At times the span of options may be bewildering—for example, the proliferation of "ninth-grade courses" to which resources were committed by independent clusters of innovators during the past decade. A teacher, school, or district intending to change the ninth-grade science program does not lack alternatives but might wishfully question why the K-12 continuum and the recalcitrant or disenchanted science student could not have been of greater concern to the innovating teams. Nevertheless, the national curriculum project efforts have unquestionably helped to update knowledge and inquiry in the science curriculum. But it is unfortunate that in the hands of many decision teams the assumptions about learners and the use of new technology remain relatively sterile, or the student has been left behind.

SOME ALERTS

Designing for progress, then, involves committing leadership, developing a long-range plan, selecting goals, establishing priorities, identifying alternatives and studying their consequences, and finally moving to the point of implementation, where priorities, degrees of freedom, and general strategy must be re-examined. During implementation, the stress of change is particularly serious. It is again important to recall that people, not institutions, must make the changes. Furthermore, the relentless pressure of change can raise exaggerated fears of the severity of a problem. While avoiding the ultraconservative, it becomes vital to examine all avenues and approaches before plunging headlong into a hurried and harried project. Such action programs must be considered dispassionately and objectively, avoiding precipitous and frantic activity.

The following paragraphs call attention to several potential barriers to effective innovation and implementation. The list is not complete; and while some of the concerns are obvious, they are easily overlooked once the decision team begins to converge on a course of action.

1. Cost-Effectiveness Analysis

To some extent, critics are right in stating that the mores of education are not as much related to ethics as to a compulsion among educators to think that "more of everything" is the only credible means to every end. It may well be that education is underfinanced, but it is nevertheless time that cost-effectiveness analysis be applied to decision-making. The design team must examine the extent to which each resource allocated to a specific objective actually contributes to accomplishing that objective. Then, while costs will surely continue to rise, at least the wiser allocation of resources will be insured.

A major area to which cost-effectiveness analysis must be applied is the human-resources pool. There is nothing about lunchroom duty, playground supervision, equipment maintenance, mixing chemical solutions, ticket-taking, typing and duplicating supplementary materials, grading objective tests, and setting up demonstration experiments that requires personnel with a minimum four or five years of college education. Furthermore, there is little evidence that a teacher works best with a class of 25 students. It can even be argued that a work group of 25 could hardly be a poorer choice, for little can be done with a group of 25 that could not be done as well with a much larger group—at least with adequate paraprofessional support. On the other hand, small group and individualized activity is seldom manageable in groups as large as 25.

The problem is clearly to deploy resources more effectively than is commonly done. With a diverse range of activities already in hand, science teachers, consultants, and supervisors should take the lead in developing new kinds of professional work groups, school organizations, and instructional patterns attuned both to measured educational output and the hard reality of the economic input.

2. Evaluation

Cost-effectiveness analysis assumes that innovative quality can be measured. Actually, almost every member of the educational community has been guilty at times of soliciting support on faith alone. It is striking how much clamor accompanies the promotion or initiation of an innovation and how little publicity is accorded its subsequent evaluation—if indeed the project is sustained that long.

Furthermore, it is time the main purpose of evaluative activity be shifted from the learner to the education process. When a learner fails, who is sick: the learner or the system? Gideonse points out:

> The existing practice of grading students assumes at the bottom that the student is responsible for his learning and that his failure or success is a tribute to a

> consequence of factors intrinsic to him. The idea of grading a school on the basis of its outputs assumes that all students can learn and that the responsibility of the schools is to make that happen. (In medicine and law, for example, we judge success or failure and the system not so much by the patient's or client's end state as by the degree to which the doctors or lawyers skillfully utilized the most sophisticated practices in attempting to serve the client. We certainly do not "grade" the patient or client; quite the contrary, it is the professional services themselves which are assessed. An output orientation for school operations would cause the same reorientation of the direction of assessment in education.[6]

The usefulness of performance objectives, for example, may be largely a result of the attention they force on the relationship between goals, instructional procedures, and evaluation. It is time that educational evaluation be allocated a fair share of resources and that research efforts be expanded to include the affective as well as the cognitive portion of the output of learning in science.

3. Relevance

As has already been stated throughout this book, any design for progress must re-establish the relevance of science to the individual. The science experience must be such that every learner, at least occasionally, senses that something important has happened to him in the school science setting. Care must be taken that the beautiful, logical structure of the discipline and the perspective of the adult do not result in psychological chaos and irrelevance in the perspective of the learner.

Fantini and Weinstein raise the question of relevance for ghetto and middle-class child alike:

> The disadvantaged child has dared to call attention to the Emperor's clothes by asking, "What's really in education for me?" In a counterpoint of innocence and defiance, the ghetto student declares that the school is phony, that teachers don't talk like real people, that his reality and reality as painted by the language of the school are as night and day.
>
> In questioning whether the school has much intrinsic meaning, he has become the spokesman for the middle-class child as well. Middle-class students may drop out of college complaining of the irrelevancy of their classes, and middle-class America may betray its miseducation by its apathy toward social injustice. But even if they find the schools too distant from the reality of their lives they are little inclined to challenge the entire process because they have learned to play the game in order to make it to and through college.[7]

4. Fragmentation

Most of the impetus of the 60's was applied to the science curriculum through isolated courses. Despite some efforts toward unified science, there is little evidence that the resulting fragmentation is about to be relieved. For the most part, K-12 design remains wishful thinking. Within a school, vertical communication is often minimal.

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[6] Gideonse, Hendrick D. "Research, Development, and the Improvement of Education." *Science* 162: 544; November 1, 1968. Copyright 1968 by the American Association for the Advancement of Science.

[7] Fantini and Weinstein, *op. cit.*, P. 3.

Furthermore, the problem has been compounded by the rise of still another new force: the growing mobility of the American population. In theory, K-12 planning assumes that the experiences of a learner can build from grade to grade. In a stable population, this is probably a reasonable assumption. However, at present—and more so in the future—large numbers of learners and teachers move into several different educational climates during the K-12 years. Clearly, longitudinal growth and development will have to depend on more than the resiliency of youth. Population mobility has in fact fragmented learning in even the best-designed K-12 programs. Two alternatives appear to be realistic. Either schools will have to accept a nationally standardized curriculum, or they will have to allocate more resources to the individualization of instruction through various modifications of independent study. Science teachers and administrators may not have long to make their commitment. The thesis of the National Science Teachers Association maintains that no one curriculum will serve the entire nation. The objective of the Association, therefore, is to provide philosophical groundwork for the development of many different creative curricula throughout the country. Thus, the schools have an obligation to individualize instruction for each of their students.

5. *Individualized Instruction*

Whether or not the science curriculum is fragmented by design or by social forces, learning remains a personal matter.

> There is virtually a metabolism of learning which is as unique to the individual as the metabolism of digestion. Parents and teachers may create conditions for learning and may provide stimulating experiences with learning in mind, but the actual learning experience is intimate and subjective, for each human being reaches out to the world in his own idiosyncratic way.[8] Any policy which predetermines the total structure of a curriculum and attempts to impose it upon all, should be condemned. Such an approach is in complete antithesis to a learning program which seeks to develop the potential of every child.[9]

How then can individualized instruction be identified? A statement issued at the National Laboratory for the Advancement of Education suggests these criteria.

> An instructional system is individualized when:
> - The characteristics of each student play a major role in the selection of objectives, sequence of study, choice of materials and procedures.
> - The time spent by each student in a given subject area is determined by his performance, rather than by the clock.

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[8] The Report of the Provincial Committee on Aims and Objectives of Education in the Schools of Ontario, *Living and Learning*, Ontario Department of Education, Toronto, Canada. 1968. P. 49.

[9] *Ibid.* P. 60.

- The progress of each student is measured by comparing his performance with his specific objectives rather than with the performance of other students.[10]

With the range of resources already in hand, science teachers are in an excellent position to move into the last quarter of this century with their professional expertise focused on individual learners rather than on the faceless statistics of the annual crop of youngsters.

6. *Teacher Isolation*

Isolation has been the cause of many professional neuroses. As has been pointed out, it is partly responsible for the fragmentation of the curriculum. Whether it has resulted from institutionalization or from personal choice, it is highly improbable that the teacher of the next quarter century will continue to be characterized as an isolated dispenser of information. It will not be easy for some teachers to move from the podium, join colleagues in a decision team, and move the learner to "stage center." Nevertheless, teachers must learn to communicate as managers or organizers rather than in the posture of stars. Teachers must be encouraged to subject their value judgments to the penetrating examination of their colleagues–to give advice, seek advice, and accept advice. Interdependence rather than independence will mark the teacher of the late 20th century. Academic freedom at both the school and university level will be tempered by the consequences of mature interaction. Learners, too, will be increasingly involved in the changes in teacher philosophy.

7. *Latent Consequences*

No matter how carefully the options have been evaluated, incidental effects, the latent consequences of education, need to be kept in mind. Questions such as the following must be raised by the decision team as it selects alternatives in the design for progress.

a. Will students learn to value "finding out" or will they be further coerced to the point of merely tolerating school and science?

b. Will learners become self-starters, or will they grow increasingly dependent on cues from the teacher in the regimen of questions, assignments, cookbook details, and programed instruction?

c. Will students be given a chance to *interact* or merely be provided a setting in which to *respond*, or worse, *accept*?

The decision team must be alert to these and other latent consequences. Many will be totally inconsistent with the long-range plan and selected goals.

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[10] Identification Card for Individualized Instruction, issued at the National Laboratory for the Advancement of Education, Washington, D.C., November 18, 1968.

WIDENING RESPONSIBILITY OF THE SUPPORT TEAM

The purpose of this chapter has been to provoke rather than to prescribe. It has looked at the path ahead for changes such as those suggested in the previous chapters. Progress has been related to the stress of change, to the roles of leadership, to the decision team, to a long-range plan, to the selection of goals, to the designation of priorities, to the analysis of available alternatives, and to several potential barriers which often stand between the learner and his education in the classroom setting. In addition, this discussion, as well as the preceding ones, has strongly implied the following:

1. Science education must be humanized and must reflect greater faith in individuals—in learners as well as in teachers, administrators, and other members of the decision team.
2. Planning must be deliberate and future-oriented. The long-range plan is the only model against which the consequences of an alternative can be validly tested.
3. The impetus for change must be sensible—sensible in that it is both reasonable and felt.
4. Curriculum changes should never be considered as more than temporary. The science curriculum must be continually modified, responding to changes in social pressures, technology, available resources, sound educational research, and the nature of science itself.

The plan must be flexible, the decision team imperturbably responsive and responsible. Such is the profile of a design for progress in an era of widening responsibility.

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ELIZABETH A. SIMENDINGER
The Wheatley School
Old Westbury, New York

THE FUTURE

WE ARE CURRENTLY LIVING in an era of great excitment in both science and science education–an excitement which brings with it an awesome challenge to the scientific enterprise, to our educational systems, and to society. Through science, we are experiencing almost daily the thrill of new discoveries and splendid technological achievements and at the same time catastrophes and near-catastrophes affecting man and his environment. These successes and catastrophes are of two parts: on the one side, what we have learned through science; and, on the other, the man-made decisions for the application or the disregard of scientific knowledge. They can no longer be separated. It follows then that neither science nor science education can progress apart from society or from education. The preceding chapters suggest how science can be made more relevant to the student. It must also be more relevant to the entire educational program.

It is essential for the survival of our culture that all students have an understanding of the major conceptual schemes that constitute the basic structure of science. It is also fundamental to our existence that all citizens develop an appreciation for the work of the scientist. Such appreciation is required for intelligent political decisions with regard to the scientific enterprise. It also teaches the present and future citizens to look to science for a part of the "input" for making decisions in an increasing range of societal problems. Environmental pollution control, use of natural resources, changing concepts of certain disease states, genetic and biological manipulations, and uses of atomic energy are examples of areas that are now of life-and-death concern to human beings. In these areas it is no more possible to make an adequate plan without the knowledge provided by science than without taking into account economic, political, and ethical considerations.

It is evident that we must prepare our present students for life in a society the nature of which, to a large extent, we cannot predict. We must, therefore, enable our students to accept and adapt to constant change, to rely upon the broad conceptual schemes of science and upon the processes of science, and to form habits of interdisciplinary thinking, in order to make these adjustments.

The history and philosophy of science must take a greater share of the curriculum, as must the relationship of science to the humanities and to social problems which face us now and will persist into the future. The problems of urban living, pollution of our environment, and world food supply are constantly recurring areas of concern to society as well as to scientists and science educators. Such problems provide an opportunity for bridging the gap between science and the humanities. Our schools should be building these bridges carefully and consciously.

For many years—certainly throughout this century—the major concern in science education appears to have been the course content and the most efficacious means of teaching it. As the preceding chapters make clear, we now recognize the active role of the learner and his need to understand the relationship of the sciences to his own personal existence. This emphasis on the learner represents one facet of the widening responsibility in science education.

The scientific community and the science education profession must join hands with the psychologists and philosophers in our study of the learner, his learning problems, and his relationship to the scientific world.

We recognize that a youngster's mind is not composed of small compartments labeled "science," "social studies," "art," and so forth, but we persist in teaching him as if it were. Education must become a total experience for students and not the fragmented approach of the present. It is essential that educators from all levels and all disciplines join forces in providing this experience. Certainly the designs for progress in science education presented in this book will be far more viable if they have the nourishment of all other subject areas and of the entire climate of the school and school system.

With increased recognition of the learner, of the problems of society, of the many interdisciplinary areas of the curriculum, and of the possibilities of new ways of individualizing instruction, teachers become "directors of learning." Their primary function will be to create a climate for learning. Therefore, each will need to learn more and more about the learning process, to constantly nourish his subject-matter area, and to become one of the forces within the school that determines the learning climate throughout the educational system, whatever its size or location.

In science education, much has been achieved in the past 25 years, the period covered by the efforts of the National Science Teachers Association as an organized professional group. However, the persistent challenge lies before us. We are living in an epoch which holds ever greater prospects for advance in both science and science education and stronger ties to other areas of the curriculum. Our horizons are broadening, bringing with them ever-widening responsibilities. Let all of us in education assume those responsibilities boldly and cooperatively.