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FLANNING FOR EXCELLENCE IN HIGH SCHOOL SCIENCE.
BY- STOLLBERG, ROBERT AND OTHERS
NATIONAL SCIENCE TEACHERS ASSN., WASHINGTON, D.C.

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THIS REPORT TAKES THE POSITION THAT SCIENCE SHOULD BE TAUGHT TO DEVELOP STUDENTS WITH BEHAVIORS WHICH INDICATE (1) AN ABILITY TO ENGAGE IN SCIENTIFIC THOUGHT, (2) AN UNDERSTANDING OF THE RELATIONS BETWEEN SCIENCE, SOCIETY, AND TECHNOLOGY, (3) THE DEVELOPMENT OF PERSONAL SCIENCE INTERESTS AND APPRECIATIONS, AND (4) AN UNDERSTANDING OF THE MAJOR PRINCIPLES AND CONCEPTUAL SCHEMES OF SCIENCE. MOST HIGH SCHOOL STUDENTS SHOULD TAKE A BALANCED PROGRAM OF BIOLOGY AND PHYSICAL SCIENCE IN WHICH THE PROCESS OF SCIENCE AND THE NATURE OF THE SCIENTIFIC ENTERPRISE ARE STRESSED. CURRENT SHORTCOMINGS OF SECONDARY SCIENCE PROGRAMS INCLUDE (1) A LACK OF CONTINUITY, (2) THE COVERAGE OF TOO MUCH MATERIAL AND TOO MANY AREAS WITHIN DISCIPLINES, (3) THE PRESENTATION OF A DISTORTED PICTURE OF HOW SCIENCE IS PRACTICED, (4) AN OVEREMPHASIS ON CONTENT AND TECHNOLOGY, (5) THE USE OF LABORATORY EXPERIENCES THAT ARE NOT DISCOVERY-ORIENTED, AND (6) A FAILURE TO CHALLENGE THE INTELLECTUAL RESOURCES OF STUDENTS. SUGGESTIONS FOR THE IMPROVEMENT OF SCIENCE SUPERVISION, TEACHER COMPETENCE, AND TEACHER PREPARATION ARE INCLUDED. THIS DOCUMENT IS ALSO AVAILABLE FROM THE NATIONAL SCIENCE TEACHERS ASSOCIATION, 1201 SIXTEENTH STREET, N.W., WASHINGTON, D.C. 20036, FOR $1.00. (AG)

Planning for EXCELLENCE in High School SCIENCE

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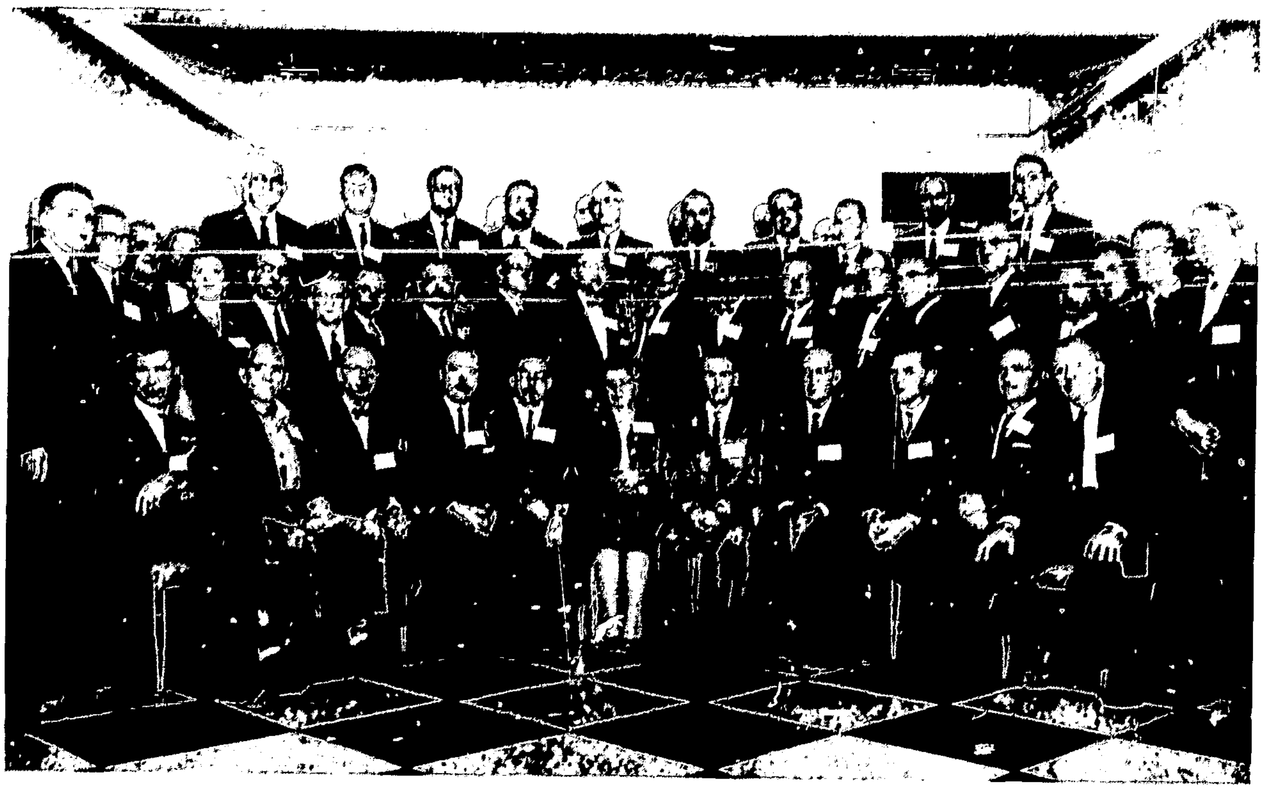


CAMERAMEN INC., WASHINGTON, D.C.

Front row (l. to r.): Friedman, Tomer, Lisonbee, Harlow, Stotler, Stidham, Miller, Hurd, Roller, Blanc, and Fitzpatrick.

Middle row: Renner, Schulz, Seyfert, Whitney, Hale, Stollberg, Keirstead, Taylor, Phillips, Mustard, Henze, Varner, Lacey, Van Hooft, Johnson, Shannon, Spalding, Zaiman, Subarsky, Carleton, and Decker.

Back row: Obourn, Smith, Woodburn, Williamson, Richardson, Ayars, Auffenberg, Mandell, Benjamin, and Silber.

FOREWORD

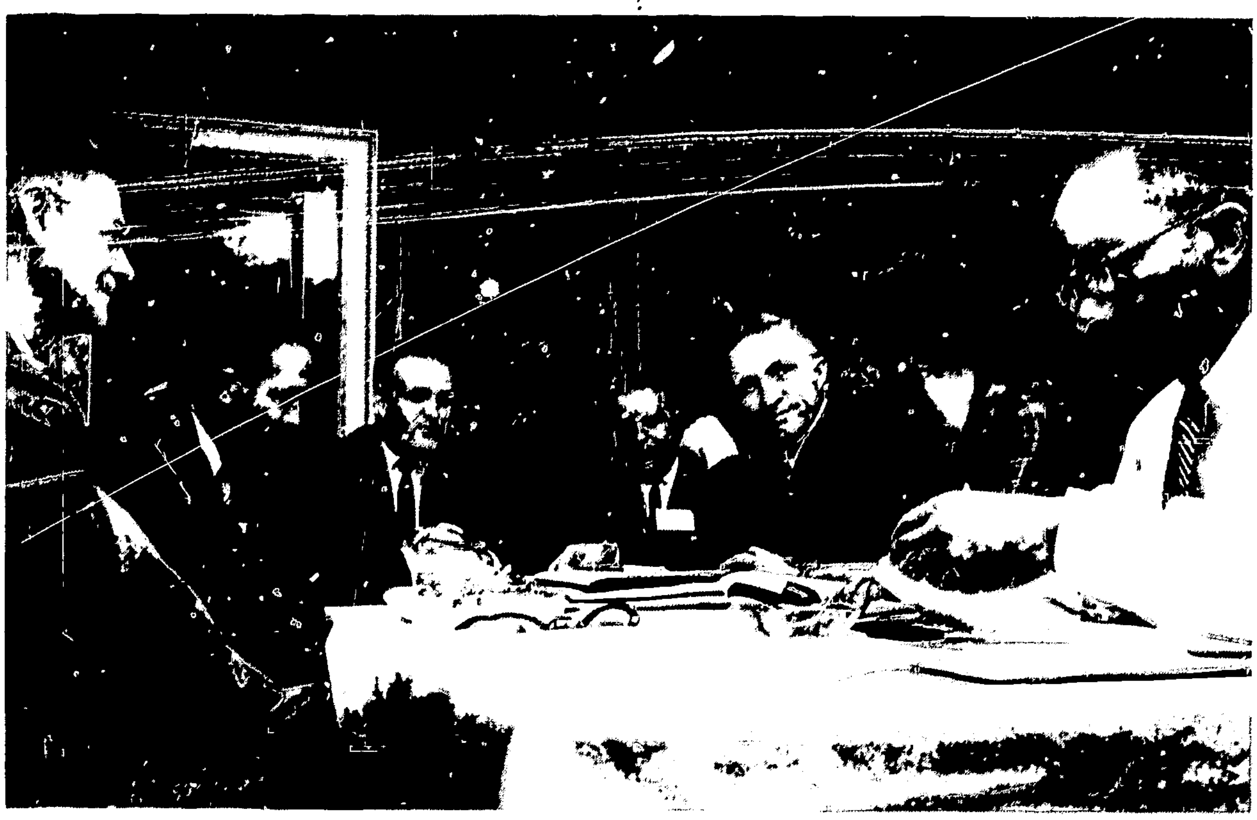
Planning for Excellence in High School Science is a report from the National Science Teachers Association which expresses the beliefs and hopes of the Association as it aims to assist teachers in analyzing and projecting for science education at the secondary school level. It is heartening to witness current, critical re-examinations of the scientific and educational enterprises. All science teachers have the responsibility to re-examine their own field of endeavor just as critically and to take appropriate action.

Through the encouragement and support of the National Science Foundation, NSTA was enabled to bring together fifty specialists in education, science, and science teaching for a work conference at Washington, D. C. in November 1959. The goal was to develop guidance for the reshaping of science courses and curricula and to study ways which might assure that classrooms will have suitable personnel, facilities, and materials for use in future programs.

The initial conference was followed by extensive consultation among the conferees and with members of the Conference Executive Committee. From these exchanges and "conferences by mail" emerged the final report. The extent to which the conference and follow-up procedures succeeded can best be determined by you, the reader.

Appreciation is expressed to the Conference Executive Committee and to the conference participants for their efforts, and particularly to the chairman, Robert Stollberg, and to Theodore Benjamin who together were responsible for the final collation and editing of the report.

National Science Teachers Association
Donald G. Decker, *President*
Robert H. Carleton, *Executive Secretary*



Conference participants debate issues. (l. to r.) Mustard, Silber, Renner, Harlow, Smith, Hale, and Blanc.

INTRODUCTION

Historically, the educational system of our country has been designed to serve societal and national needs through maximum development of the potential of each and every individual child and youth. As the needs of society change, new goals must be established and the appropriate action taken. The educational system must also re-examine its goals and make the changes necessary to keep them valid in terms of new cultures and contemporary thought.

Cognizant of the responsibility placed on the educational enterprise and in recognition of the demands from society for solutions of problems within this framework, the National Science Teachers Association received support from the National Science Foundation to conduct a conference to evaluate and assess current needs in secondary school science programs. This four-day conference was held in November 1959 and was attended by some fifty science teachers, research scientists, science educators, and administrators. This report is the result of the deliberations of that group.

In setting a frame of reference for the conference, the participants were reminded that the science teacher is actively involved in two distinct enterprises, *i.e.*, the enterprise of science and the enterprise of education. Moreover, teachers practice this dual-directed profession in a dynamic society.

At present, society is becoming concerned by the increasingly dominant influence that the scientific enterprise is having upon it. Furthermore, many people and many different kinds of people—military leaders, scientists, journalists, as well as research scientists—are questioning whether our culture is ready for the type of life that our exploding scientific enterprise can provide.

Readying the citizenry for life in our society is the function of the educational enterprise. Within the last decade, the educational enterprise has come under close scrutiny in terms of its adequacy to prepare scientifically literate citizens. The question has been repeatedly asked whether science is being properly taught in our schools.

When approached from an analysis of the nature of the educational and scientific enterprises, past science teaching has been primarily concerned with teaching what scientists know (the product), but has failed to yield proper understanding of the ways in which scientists obtain this knowledge (the process). The latter is extremely important, not only for the training of future scientists, but also for the production of a scientifically literate citizenry capable of applying broadly the modes of scientific thought and sympathetic to the scientific endeavor. Consequently, there is a need for a re-examination of the aims, content, and methodology which form the larger part of the complex that is science education.

This report is a beginning in that direction. By no means has it rendered an exhaustive enumeration and treatment of the problems and potential involved. It attempts, however, to give teachers, supervisors, and administrators a working directive and to indicate some of the issues and possible guidelines for action that arise as a result of this approach.

The ultimate design of the science teaching program that will emerge lies in the hands of properly trained and competent teachers and supervisors, aided by sympathetic administrators who provide the atmosphere, facilities, and time through which the student may obtain a feeling for the excitement, satisfactions, and values inherent in the pursuit of scientific knowledge.

PART ONE

I

THE NATURE OF THE EDUCATIONAL ENTERPRISE

Education Defined

Every experience to which an individual is exposed makes him different from what he was. It changes his behavior. In a very real sense it educates him. Such education may be conscious or unconscious, temporary or permanent, desirable or undesirable. It may pertain to the intellect, to bodily skills, to emotions, or to attitudes. In this sense, the totality of every man's experience is his education.

For the purposes of this report, however, it is useful to confine attention to the formal, deliberate, planned program of experiences sometimes called schooling. This departure sidesteps the potent educational influences of mass media, of religious experience, and of play and entertainment activities, among others; rather, it focuses attention on that deliberate and indispensable aspect of any society which attempts to prepare young people for their place in the culture. Since the nature of this societal operation depends on the nature of the culture which it serves, any considerations proposed must be specific as to time and place.

The American educational enterprise, as we know it today, contains many elements by which it may be characterized and identified. As an integral function of American society, it is directly or indirectly controlled by that society. American education serves society and, in particular, does much to mold

the next generation. To the extent that American society is democratic and is in a state of dynamic change, so is the American educational enterprise.

Because American democracy is predicated on the dignity of the individual human being, the enterprise strives to promote this dignity and to enrich human living. It further strives to inculcate worthy moral and ethical standards in young people and to develop individuals who will live responsible and fruitful lives within the framework of American culture. At the same time, it promotes the value foundations of American culture which permit and encourage responsible living.

Purposes of Education

There are numerous approaches to an analysis of the purposes of the American educational enterprise. From the seven "Cardinal Principles of Education" through and beyond comprehensive statements by such groups as the Educational Policies Commission, dedicated and thoughtful persons have sought to formulate statements of the objectives of education. Individuals and groups—some from within and some from without the ranks of professional educators—have formulated these statements which vary widely in approach and format, length and detail, and sometimes in underlying philosophy. Significantly, however, many of them refer to such goals as responsible citizenship, competent consumership, and effective relations with other persons and with the community. Many place strong emphasis on the optimum development of the individual. With few exceptions, these statements focus attention on the development of effective thinking, the ability to make value judgments, and general intellectual resourcefulness. Sometimes the development of the mind is seen as an essential ingredient of other objectives; sometimes it is represented as a dominant objective in its own right.

In working toward any of these achievements, American educators assume that young people are educable in the same related dimensions and that desirable behavior patterns can be fostered. To develop them, the educational enterprise

seeks to provide experiences through which youth can acquire the patterns of knowledge, the skills, and the attitudes which lead to the desired behavior. It is important to recognize that the patterns of behavior are objectives of education. The requisite knowledge, skills, and attitudes are not only objectives in their own right, but are also means toward the ultimate end of responsible, satisfying behavior.

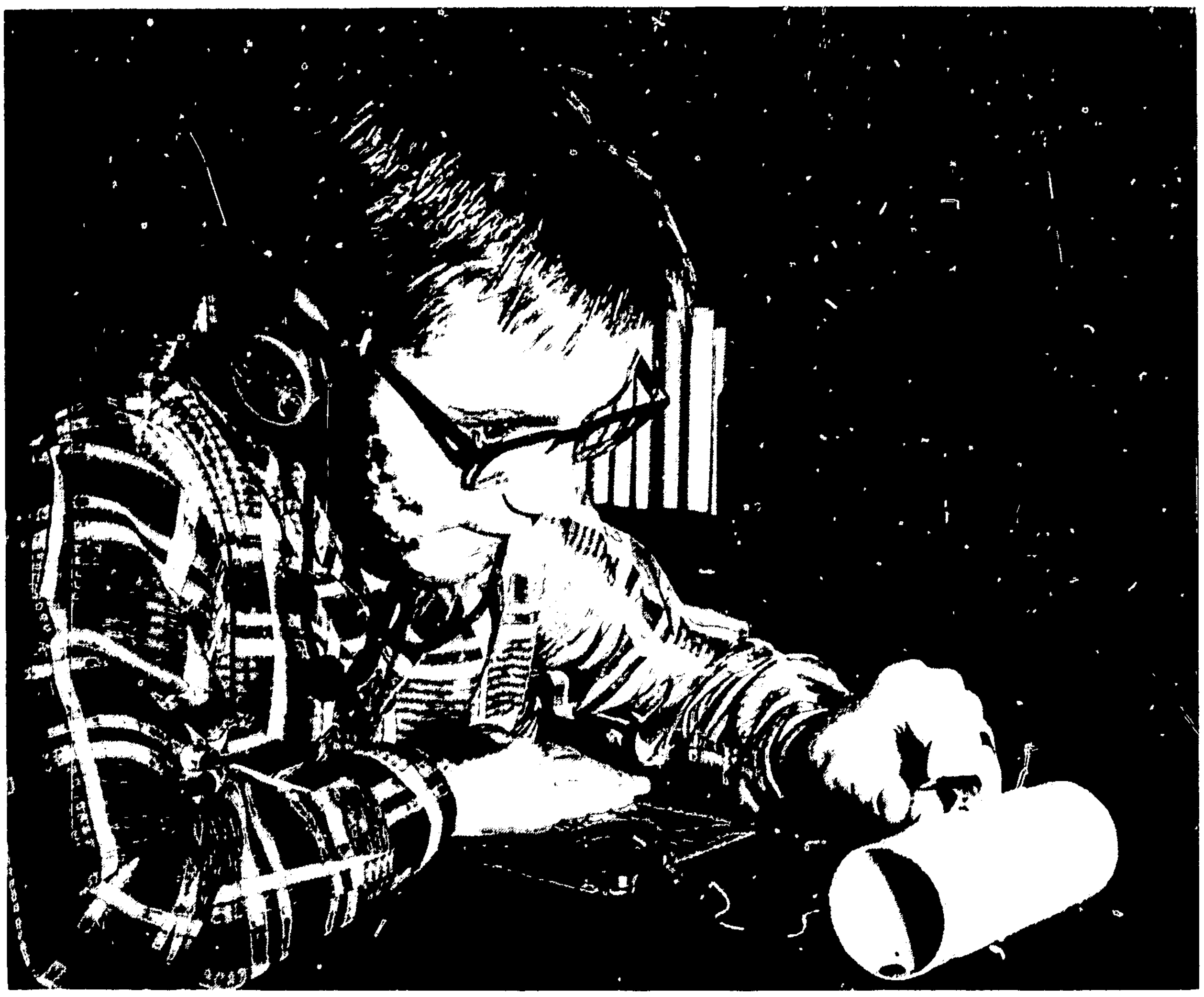
Thus the purposes of the American educational enterprise are to provide experiences through which young people can acquire the knowledge, the skills, and the attitudes that in themselves have value, and thus lead to patterns of human behavior which are desirable within the framework of American society.

The Learning Process

The character of the educational enterprise is derived from the nature of today's American culture and from the nature of the learning process. What is known and what can yet be learned about the way the human mind operates and the way the human organism learns can have a profound effect on the enterprise. Thus, modern education draws heavily on human experience in general, and in particular, on the youthful but growing science of the psychology of learning.

One of the most important lessons of educational psychology is that behavior can be modified; that is, *behavior is learned.* In addition, the more subtle traits known as attitudes and emotions are also "learned" traits. Recognizing that physical and intellectual capacities—and sometimes predispositions—are inherited, modern psychology emphasizes the role of the environment, controlled and otherwise, in shaping the behavior patterns of the human organism. Not only does this place a severe responsibility on the educational environment, but it also establishes a tremendous potential for the effectiveness of the total educational enterprise.

Research in psychology has clearly shown that physical, emotional, and intellectual involvement in the learning process enhances its effectiveness. Granting that people can learn vicariously, it is increasingly clear that as a learning experience observation is inferior to more intense participation



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The learning experience must include participation rather than mere observation.

on the part of the learner. Thus, it appears that active participation in the learning process is of particular importance with young children and with students of average and below average intelligence. Evidence shows also that learning for all people is enhanced to the extent that the learner considers the task important and/or interesting.

Educational psychology has demonstrated a wide variety in the makeup of individual learners. The desires, readiness, and potential for learning vary widely from person to person and from time to time. While there may be group learning experiences, *learning is primarily an individual activity.* The educational system, then, studies these individual differences because planned learning experiences, to be effective, must consider them.

Many variations are found also in school systems and in teachers. Some of these may be attributed to differences in community, student body, resources, or teaching procedures.

Education in Action

The educational enterprise—along with the process and the product—is firmly rooted in the nature of American society and in the nature of the learning process. Among the outstanding determinants of education in action are these:

The structure of a democratic society demands that citizens be responsible, competent, and ethical. Hence, all citizens are required to have an education. Accordingly, all youth capable of profiting from an education are required to undergo a minimum pattern of learning experiences. It is considered also that there is less expense and more pleasure in educating youth than in supporting, supervising, and reforming uneducated persons. Because the education of youth benefits all of society, the cost is spread over a wide tax base. As a result, a minimum education is not only required of all youth, but is largely free of direct cost to individual learners or their families.

The educational enterprise has the potential for tremendous effects on all of society—it creates a climate for influencing or controlling the population, for better or for

worse. Partly to prevent any single group from seizing command of the nation, the control of the educational enterprise in America has been thoroughly decentralized. Constitutionally, education is the responsibility of the several states. In many states this control of education is exercised chiefly through such means as legislation for minimum standards and attendance, certification of teachers, equalization of state-provided funds, and general advisory functions. In typical American communities the establishment of basic policies is largely up to elected or appointed local lay boards of education, operating through their designated professional administrators. Ideally the administrators carry out broad policies and, at the same time, provide professional educational leadership for the lay board. But ultimate control resides with the board of education, and through it with the citizens whom its members represent.

The educational enterprise provides a controlled environment for education. For a fraction of each day during most of the early years of a person, the enterprise involves youth in a specific place under the guidance of specially prepared teachers. This controlled environment—the "school"—usually differs markedly from the total remaining environment or experience in the life of youth. The enterprise has a planned and continuous program for children and adolescents. There is a detailed sequence of learning activities which typically last from early childhood to late adolescence, and often far beyond. Although the enterprise per se differs markedly from other educational activities, such as television, summer camping, and adult education, it does seek cooperation with other related forces of behavior change.

Recognizing and respecting wide differences among individual learners, the American educational enterprise employs many techniques for identifying and providing suitable programs for each. Diverse patterns of grouping are in use, and programs of counseling and guidance are essentially standard parts of a modern school system. Various curricula permit different degrees of elective choice in learning. Many systems have well-developed programs of special education for

the handicapped, for the student with unusual objectives, for the gifted, as well as for the slow learner. In view of the diversity of educational control and the differences among students and among teachers, a variety of educational patterns throughout the nation is inevitable.

As the process of learning becomes a more mature area of specialty, the results of instruction are being treated quantitatively with ever-increasing effectiveness. Intellectual ability and achievement are well within the scope of measurement, as is the learner's acquisition of skills and attitudes. Although typical educational measurements have more validity for groups than for individuals, progress is being made toward quantification of the results of learning. To the much less tangible question, "How well is the educational enterprise serving society," valid answers are much more difficult to find. Most attempts to measure the product of the educational process against its avowed purposes are highly subjective—and needless to say, the variety of results of such evaluations is fantastic. The predicament in itself contributes one of the outstanding characteristics of education in action. The American public is not positive as to how effective the educational enterprise is, or whether and how it should be restructured.

II

THE NATURE OF THE SCIENTIFIC ENTERPRISE

Science Defined

Existing in our culture is a distinctive area of human knowledge which some people believe is synonymous with science. This knowledge is largely related to the physical and biological phenomena of the universe. It constitutes a complicated structure of fact and theory, principle and hypothesis, law, generalization, and conceptual scheme. Much of the knowledge is too voluminous and detailed to be remembered; when needed it is culled from books, tables—even computers. People who define science as this *body of knowledge* often think of scientists as those whose special background has enabled them to possess and understand much of this knowledge.

Common though this percept of science is, it is a limited one indeed. While there is truth in this definition, it falls so far short of the total truth as to be dangerously misleading to citizens in general and to educators in particular.

The description above is a somewhat superficial statement of the *content* of science, or to use another term its *subject matter*. Except for the fact that this storehouse of knowledge acquires constant additions and modifications and that people use this knowledge, the *content* or *subject-matter* percept of science is a static one. For a more useful interpretation of science, one must turn to the human activity involved.

Science may be thought of as an ongoing process through which man strives to explain natural phenomena. Man observes all manner of physical and biological situations, measures and classifies them, seeks to relate them to other phenomena. He attempts to formulate simple explanations for what he perceives; he seeks to contrive a set of rational postulates consistent with his array of empirical observations. Rational explanations are acceptable and satisfying if they are in accord with observations and if they predict new observations which are consistent with existing knowledge. This percept of science is far from a static one; indeed, *it places science in the position of being permanently open-ended.* Far from accepting science as *content* alone, this interpretation represents science also as an *activity* of mankind.

In a very real sense, these two descriptions of science are not simply antithetical; they represent one enterprise seen from two different perspectives. For science can be thought of as *activity* and as *content*, as *process* and as *product*. Indeed, these two are inseparable and interdependent. The product owes its existence to the process; on the other hand, the process is impossible and also pointless without the product, the knowledge of science.

Science, then, is a human enterprise including the ongoing process of seeking explanations and understanding of the natural world, and also including that which the process produces—man's storehouse of knowledge. Science is process and product.

Science as Product

Regrettably, the product of science is often confused with material achievements—miracle drugs and synthetic fibers—increased farm production and abundantly available power—color television and space travel, that is, *science is often confused with technology.* There is no doubt that science and technology are related, although they have not always been so, and they are both deeply rooted in the culture of today. But science is an intellectual quest for explanations and understanding of natural phenomena, and technology is a practical effort to use and control natural phenomena. Modern

technology is thus extremely dependent on science, and much of modern science is properly directed at improved technology. The confusion of the product of technology with the product of science does an injustice to both.

Strictly speaking, the product of the scientific enterprise is knowledge, a dynamic heritage accumulated on printed pages and in human minds. It ranges from innumerable specific data to the broad conceptual schemes of man's most sophisticated thinking.

Science as Process

The process of scientific inquiry involves many kinds of activities. Observation and measurement are included, of course; so are codification and interpretation of data. Hypotheses must be developed, experimental procedures to check them designed, and assumptions must be identified and stated. The scientific process sometimes requires the development of a meaningful conceptual model, of a functional mathematical expression, or of a precise laboratory instrument. It involves communication of ideas to others engaged in the scientific enterprise. Communication must also exist between teacher and learner, whether it be from master-scholar to student, or from writer-publisher to the reading public.

Analysts of the scientific process do not always agree on its anatomy. There are those who hold that there is "a scientific method" more or less expressable as a series of specific operations. It is contended that these steps with appropriate modifications are followed by any and all persons involved in scientific activity. An increasing number of scholars, however, appear to regard the scientific process as a different kind of procedure. These analysts point to the tremendous spread in patterns of operation among the great scientists of history. They refer to Copernicus and to Lavoisier, who clung to their rational postulates—ideas which are assumed "correct" in the modern view—in spite of overwhelming evidence to the contrary. They refer to Gilbert and Tycho Brahe, who conscientiously used valid empirical observations in an attempt to develop "invalid" postulates. They even refer to Galileo, who

sometimes displayed a haughty disdain for experimentation. These analysts suggest that factors such as stubbornness, intuition, and chance have had a great deal to do with major breakthroughs in science.

The often alleged fact that the activity of science takes place in the field and laboratory is only partially true. The process of science takes place mostly in the human mind. Of course the processes of science involve a multitude of skills and also involve a pattern of attitudes such as open-mindedness, thoroughness, and intellectual integrity. Except for its adherence to truth, science is amoral. Value judgments reside in individuals. In seeking explanations of phenomena, science is surely a distinctively creative process. Somewhere along the bridge which links science with philosophy, man also seeks to interpret his own place in the universe of time and space, to develop a satisfying philosophy of life, satisfying because it is consistent with the universe as man observes it.

A scientist is a person who participates in the scientific process, that is, he seeks to extend man's understanding of natural phenomena. He may labor in laboratories or libraries or in the field; he may work with test tubes or telescopes, paper or people. To the degree that he seeks to extend man's knowledge about the natural world, he is engaged in the creative scientific process. This creativity is somewhat akin to that of the painter and the writer and the explorer, except that the scientist's creativity is less in the dimensions of expression of ideas or extension of maps and more in the dimension of explanation of natural phenomena.

Those involved in the scientific enterprise are not inherently different from the rest of mankind. Their backgrounds are specialized along different lines; they have developed skill in and enjoy the activity of intellectual inquiry and often the activities of observation and experiment. But in general, those involved in science are neither more nor less intelligent, dependable, religious, or worthwhile than active people in other walks of life. *There is no stereotype of a scientist;* he is a human being, with all the firmness and the frailty connoted by that term.

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The scientific process involves activity with observation and measurement.

Science and People

Science is a human enterprise. It directly involves multitudes of extremely worthwhile people, from mathematical scientist through physicist, the engineer, the teacher, and the writer, to name a few. But no less directly are *all* people involved in science. They eat, travel in, and communicate through the products of science (and technology). Their judgments and beliefs are conditioned by what they learn of science and the scientific process. There is scarcely an issue, whether it be a political, social, or economic one, that does not in some way involve science.

The behavior of people is marked by the process of science. It influences the extent to which they are self-directing and self-reliant, and the extent to which they seek and arrive at rational decisions to issues and effective solutions to problems. This science-influenced behavior applies to society and also to individuals. While not necessarily being creative in the more profound sense, all individuals can profit by using the methods and attitudes of science in finding needed information and in seeking solutions to life's multitude of problems. In this sense, every man could be his own scientist, his own problem-solver. He could use the process and the product of the scientific enterprise to be a more competent individual and a more responsible citizen, to live life more abundantly, and to understand better his own place in time and in space, in life, and in thought.

A scientifically literate citizen is essential to safeguard the national security, to assure advances in basic science, and to maintain our standard of living. Because of the place of science in the culture of our times and its impact on the personal lives of people, it becomes imperative that science have a prominent place in the educational enterprise at every level of teaching.

Modes of Scientific Thought

The product of science and its application in technology has been the major, and sometimes the exclusive concern of secondary school science. What is taught of the process is referred to variously as "the method of science," "problem

solving," "reflective thinking," etc. In general, these terms refer to some aspect of the process of science, an aspect which is alleged to be characteristic of, sometimes peculiar to, practicing scientists. In many discussions, student growth in this aspect of science is considered to be an important objective of science teaching; in some it is held to be the most important of all objectives.

Since many terms tend to become limited and stereotyped through usage, it is sometimes fruitful to abandon such terms and in their stead, suggest a new term which stimulates more imaginative thinking. In place of the terms above, let us apply the term "modes of scientific thought" to this important objective of science teaching. The selection of this term evolves from the following convictions.

Generally, patterns of thinking or modes of thought which are characteristic of, although not exclusive with, science and scientists are evident.

Although there are several patterns or modes of scientific thought, there does not appear to be a fixed "scientific method," sometimes described as a series of specific steps. Different scientists attacking different problems use various patterns; sometimes there seems to be a distinct lack of pattern. Yet, there are characteristic modes of thought which are used by many persons engaged in the scientific enterprise.

These modes of scientific thought so common in the process of science are useful to thinking persons in all walks of life. Often they are of great value in thinking about problems which have no apparent relation to the product of science.

These modes of scientific thought can be learned; and the extent to which students practice scientific modes of thought is capable of educational evaluation. Although some progress has been made along the lines of instruction and evaluation in modes of scientific thought, the work yet to be done is very great, and it is very important.

Much of the difficulty and the effort in science education in secondary schools today is centered around such problem areas as the identification of scientific modes of thought and problems related to instruction and evaluation of scientific thinking. It is around

these two clusters of issues that we must now address ourselves if we are to identify the behavioral elements which make our goals and enable us to ascertain the degree of achievement.

Identification of Modes of Scientific Thought

If there are modes of thought which are characteristic of the scientific enterprise, and if secondary school science programs are to undertake to help students grow in these modes of thought, then it is essential that they be carefully identified. Analysts of scientists' procedures find considerable variety in the thought patterns which biologists, chemists, anthropologists, oceanographers, and other scientists use. Variations and special designs depend on the nature of their work, as well as on the backgrounds of the scientists. However, there are certain modes of thought which seem to be used by many scientists. The major ones of these are listed below. These are in no particular order, and specifically, *they do not* constitute "steps in a scientific method."

Wanting explanations for phenomena and being predisposed to be "bothered" by inconsistencies. This is a fundamental and primary characteristic of the "scientific" mind and one that leads the scientist to seek further knowledge through books, journals, laboratory investigations, field investigations, or personal communications with other observers.

Observing with discrimination. "Observing" is here used in a generic sense to include the use of other senses, the use of instruments that extend or translate sense impressions, and even the invention and improvement of such instruments. Moreover, it includes the judgment of what is relevant to observe and what is irrelevant; it includes also an awareness of the limitations of one's ability to obtain that which one expects as a result of observing.

Classifying observations and other information. This mode of scientific thought is closely related to the previous one. Scientists are predisposed to become aware of similarities and differences. The juxtaposition of similar phenomena is often the germ of an explanatory idea or the spark of a new challenge for investigation. Good examples of this are the

evolving classification that eventuated in the Periodic Table of Chemical Elements, and the many branches of biological science which were meaningfully integrated to make up biological systems of taxonomy.

Putting observations into quantitative terms. To progress in an investigation, scientists often devise ways of measuring what, at first, are qualitative properties. Thus acidity became controllable within narrower and narrower limits when methods for measuring acidity in terms of hydrogen ion concentration were devised. Understanding of heredity leaped ahead when Mendel went beyond mere observation of the *kinds* of offspring from experimental plants and *counted* the different kinds and noted their ratios. Even a child begins to quantify when he learns to ask "How much," "How far."

Pursuing hunches and flashes of insight. The pursuit may take the form of search through literature, further observation, and/or experimentation. The design of an experiment which answers questions, suggests explanations, or confirms them, involves a special phase of creativity associated with the scientific enterprise. The simplicity and elegance of some experiments can best be described as artistic.

Synthesizing and modifying explanations. The extent to which scientists are satisfied with explanations depends on the degree to which the explanations are consistent with observed phenomena and with other explanations. The creative ability to "synthesize" theoretical but limited explanations into even more inclusive theory is a mode of scientific thought. It is one of the prime hallmarks of scientists. There is, for example, tremendous insight and power in the now famous formula of Einstein, $E = mc^2$.

Making and testing predictions based on theory. The "strength" of a theory is reflected in the ability it often gives the scientist to predict the action of forces, the reactions of chemicals, and behavior of living organisms. Into this category fall the postulation of the existence of an unseen planet, the prediction of the properties of a specific chemical element, and the planning of the outcomes of genetic crossbreeding.

The verification of predictions provides some of the most exciting moments of scientists' lives.

Communicating. Free communication is a basic characteristic of the scientific enterprise. Through formal and informal meetings and conferences, scientists exchange experiences and thought; through journals and books, they publicize their organized information and the sources and procedures which lead to the information. Mutual stimulation helps keep the scientific enterprise alive; from it often come deep and enduring friendships between people who live far apart geographically and culturally. To many scientists, these friendships are among their most satisfying rewards.

Instruction and Evaluation of Scientific Thinking

To the extent that science teachers accept student growth in modes of scientific thought as a worthwhile objective, they will introduce changes in typical classroom procedure. Current practice places large stress on the learning of facts and principles of science, and the development of certain skills, including manual skills, as well as those related to observation of facts and verification of hypotheses. If the newer view outlined above is valid, there should be increased attention given to the processes by which scientists develop knowledge. In accordance with the principle of student involvement in the learning process, young people should have experiences of participating in each of the modes of scientific thought so that they will understand them better and become more inclined and able to use them effectively. However, as science teachers explore this educational frontier, several key issues become apparent:

> *How can schools under present circumstances of schedules, methods, facilities and equipment, teacher preparation, supervision, and class size develop student ability to use modes of scientific thought?*

The modes of scientific thought given, as applied to the science classroom, in general represent individual student thinking. Ideally, this thinking should grow out of firsthand experiences and observations. Although the pursuit of

explanations may begin with individuals, a student team may eventually become involved. Seeking explanations requires a variety of reference works, some of which resemble the reports of scientists. Also required may be equipment and materials to provide further firsthand observations. Time limitation constitutes a severe hazard; curtailing the pursuit of explanations often dampens student enthusiasm for scientific inquiry. An attempt to provide students with these kinds of experiences poses many difficult questions:

How much time is needed by students with various levels of ability and interest?

How can teachers be most effectively helped to develop modes of scientific thought within themselves?

How can techniques of evaluating student status and growth in use of modes of scientific thought be improved?

How can teachers determine the proper emphasis to give to modes of scientific thought in comparison with other objectives of science teaching?

Science encompasses a vast array of fairly well-established explanations. These are the *products* of the work of scientists. This body of knowledge is part of man's heritage, and youth should not be denied this aspect of culture. Explanations of the past are subject to constant re-examination and modification, while at the same time, new knowledge is being accumulated. Attempts to help students understand a useful selection of scientific knowledge could easily consume all the time available for science instruction. It is also a worthwhile experience for students individually to develop a real understanding of the interrelationship existing between science and society, and to grow in their personal interests and in appreciations of science process and product. Because these other objectives of science instruction are also important, the problem of time allocation for students to have personal experiences in the *process* of science becomes a very acute one.

What part should out-of-class opportunities play for the students who have been motivated to seek observations and explanations?

Instruction should include the same processes by which scientists develop knowledge and acquire skill.

Out-of-class activities can include extended work of a laboratory type and can develop skills in communicating with other youthful scientists. These represent modes of scientific thought which should be a part of the science experiences for all students. Can the classroom provide sufficient experience for the students who show high curiosity and other attributes of a developing scientist? Should such students be encouraged to write to and interview active scientists? Should teachers work with such students or should the students work with teachers on research-like projects? What kinds of reports should be encouraged for the budding scientist? How much should be done in class, in laboratory, after school, or at other times? What modifications, if any, should be made in science fairs and other exhibits in order to encourage and promote the development of scientific thought? What responsibilities should the organized teaching profession assume in providing out-of-school opportunities for science-motivated young people to experience scientific processes?

PART TWO

III

IMPLICATIONS FOR SECONDARY SCHOOL SCIENCE

The Role of Science in the Secondary School

In consonance with the foregoing analysis of the educational and scientific enterprises, statements concerning the role of science in secondary schools should conform to the following criteria:

Statements should be consistent with the nature of the scientific enterprise. In view of the opening pages of this report, particular attention should be given to the process and product aspects of science, and to the relationships of contemporary science with the society in which it exists.

Statements should be consistent with the nature of the educational enterprise. In the perspective of the previous section of this report, they should reflect education's obligations to American society and to individuals, and should be consistent with modern interpretations of the learning process.

Statements should suggest course content and teaching procedures. General statements cannot be expected to define courses of study or to outline lesson plans; they should, however, provide a basis for challenging and productive discussion among teachers, administrators, and others interested in science education. While general statements cannot delineate all the knowledge, skills,

and attitudes which should be learned through science, they should provide guidelines for the development of such specifics at the local level.

Statements should be practical in terms of achievement and evaluation. The role of science in secondary schools should be sufficiently realistic that progress can be made toward the goals, and that achievement can be evaluated. One effective way to achieve this is to couch the statements in terms of student behavior—not in terms of what students know or think or feel, but rather, in terms of what they *do*.

Outcomes of Science Education

There are numerous ways in which the outcomes of science education can be organized and phrased. The statements on these pages are phrased with an eye to simplicity and clarity. They are intended to be provocative, certainly not exhaustive, suggestive rather than definitive. The order is not intended to be indicative of their relative importance. The statements are certainly not mutually exclusive.

Personal Use of Scientific Thought

As a result of science education, students should habitually and skillfully employ sound thinking habits in meeting problem situations in the daily walks of life. They should exhibit reasonably mature attitudes related to tolerance, curiosity, honest doubt, and the like. To do this, young people must have an understanding of, faith in, and direct practice with sound methods and attitudes of thought.

There are many learnings in the form of knowledge, skill, and attitudes involved in this outcome of science education. For example:

Students must have knowledge and skill in modes of scientific thinking, such as discriminating observation, formulation of hypotheses, organization of facts and ideas, quantification of observations, analysis and synthesis of facts, and development of conceptual models.

Students must grow in acceptance of the attitudes

characteristic of science, as intellectual curiosity, respect for differences of opinion, thoroughness, intellectual honesty, and reliance on facts.

Students must understand the use of techniques and tools of science, such as mathematical representation, experimental procedures, communication of ideas, nature of evidence and of proof, and instrumentation.

Students must understand the characteristics of scientific achievement, such as recognition and statement of problems, tentativeness of conclusions, predictive value of laws, continuous and cumulative productivity of knowledge, reliability of inference, and interdependence of scientific disciplines.

Relations Between Science, Society, Technology, and Philosophy

As a result of science education, students should recognize and accept their place in a society which is largely scientific in character. They should be in the process of developing a personal philosophy based on truth, understanding, and logic, rather than one based on superstition, intuition, or wishful thinking. To do this, students must acquire a working concept of the relations between science and society, science and individuals, and science and technology.

Among the knowledge, skills, and attitudes needed for the realization of this outcome are:

Students must recognize that science is the process and product of human endeavor, that it is cooperative, international, intercultural, personally satisfying and that it flourishes in a climate of intellectual freedom.

Students must understand the impact of science and technology on the culture of this and other societies and its relation to mores, family living, leisure time, standards of living, health, and safety.

Students must recognize the influence of scientific explanations on patterns of thought, including intergroup relations, religion, the status of mankind, and social responsibility.

Personal Interests and Appreciations Related to Science

As a result of science education, students should develop and enjoy personal interests, some of which are related to science. They should recognize and enjoy some scientific aspects of their natural and man-made environment, and should appreciate and respect the efforts of those who have made the latter possible. To do this, students must have varied and pleasant experiences in activities related to science, and should know something of the development of science and of the people who have contributed toward it.

Knowledge and skills and attitudes play an important part in the realization of this outcome. For example:

Students must be made aware of occupational possibilities related to science, including the nature of the occupation, preparations required, need for personnel, financial and other rewards, and their own suitability for such occupations.

Students must know of the avocational possibilities related to science, including their variety and availability, the satisfactions to be derived therefrom, and their potentials and limitations.

Students must know enough of the basic principles of science to recognize and appreciate the science involved in their natural and man-made environment, such as weather, geological phenomena, flora and fauna, astronomy, agriculture, chemical synthetics, electric appliances, and modern means of communication and travel.

Personal Command of Scientific Product

As a result of science education, students should base their opinions, decisions, and actions on a reasonable background of principles and conceptual schemes in science. They should not only carry on sound thinking, they should have a fund of reliable knowledge with which to think. They should also be able to locate needed science information which is beyond the limits of personal memory. To do this, students must have adequate understanding of the broad generalizations and conceptual schemes of science, as well as

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Personal command in experiments contributes to early development and understanding of principles.

some command of the more important factual knowledge involved in science.

This type of knowledge itself is the heaviest contributor toward the achievement of this outcome. Except for the prospective specialist in science, skills usually play a relatively minor role here. The knowledge may be thought of as ranging from specific facts through principles, concepts, and generalizations, up through the broad and sweeping conceptual schemes which ramify throughout human experience and which clarify the underlying nature of the universe. In terms of content, scientific knowledge may be thought of in many patterns. The major criterion for the selection of a given pattern is that it shall make a properly balanced contribution to the recognized goals of science education and that it shall afford ample opportunity to demonstrate the interrelationships of process and product as described.

There is a vast array of assumptions underlying the outcome of science education as outlined above, as well as a variety of inferences which may be drawn from them.

The foregoing statements represent the role of science education in American high schools, phrased in terms of the kinds of behavior students should exhibit as a result of instruction in science. These goals can be achieved by students who acquire a suitable pattern of knowledge, skills, and attitudes, which are thus means to the ends. The appropriate knowledge, skills, and attitudes are only suggested on these pages. The development of these in detail at the local level constitutes a useful and educational activity for all involved.

The outcomes here outlined are in terms of the science education for all students—that is, "general education" in science. Students who plan to specialize in science to some degree need this kind of education plus perhaps more specific background selected in terms of depth rather than breadth.

Science education does have an obligation to serve not only individuals, as outlined above, but also society as a whole. It is assumed that society is served by providing it with a scientifically literate citizenry and with technically prepared scientific

manpower in sufficient quantity and quality to serve whatever needs and demands a society seeks.

Science education's responsibility to provide technically prepared scientific manpower is implicit in the purposes as outlined above. The greatest single step toward this goal is the preparation of a broad base of generally educated young people from which the pool of specially prepared manpower can be drawn.

The fourth purpose, that related to knowledge, is both an end in itself and an indispensable means toward achieving the other three kinds of purposes.

While there are many educational procedures which can contribute toward the realization of these outcomes, one key technique is that of getting students physically, emotionally, and intellectually involved in the learning process.

Curriculum in Science

In the broad sense of the word, the curriculum in science consists of all the learning experiences in science for which the school is responsible. This includes not only the required and optional courses in science, but also science clubs, science fairs, and any school, campus, bulletin board, or other such out-of-class activities as are related to science. It is evident that all such aspects of the curriculum help determine the effectiveness of the science program, and that the underlying perspective of science education helps determine the curriculum. In this section, attention is confined to that aspect of the curriculum made up of scheduled science classes, and to the way those classes might be influenced by the perspective developed in the preceding sections of the report.

Although the public school experience of young people is commonly subdivided into two (K–8 and 9–12) or three (K–6, 7–8, and 9–12 or K–6, 7–9, and 10–12) sections, the education of any individual is a single sequence of learning experiences. At its best, it is an organized sequence, planned for optimum results in terms of desired behavior patterns. *Applied to problems of school administration, this means that science curriculum planning should have longitudinal*

integrity—should be on a K–12 (or beyond) basis rather than fragmented into independent sections which correspond to the administrative structure of the school system. Accordingly, the over-all science curriculum should be planned on a K–12 basis, and the curriculum of the secondary school should be integrated with, articulated with, and dependent upon the elementary school curriculum. In this section, the secondary curriculum in science makes certain assumptions as to the character of the underlying elementary school program.

Elementary School Science

Within the past decade, tremendous strides have been made in elementary science education. The basic principles underlying this education have been crystallized and an eminently successful program of teacher orientation and training has been instituted. When viewed from the vantage point of the K–12 program, elementary science must make its contribution to the long-range, over-all goals set for science education. What might we expect from such an approach?

Desirable Outcomes that a Sixth Grader Should Achieve

Curiosity and enthusiasm. Youngsters come into elementary school teeming with curiosity and enthusiasm about science and nearly everything else. All too frequently in the past this has been dulled by ill-advised programs and ill-prepared teachers. It should instead be whetted by elementary school science experience to the point where youngsters enjoy participation in the scientific process at their own level.

Habits of systematic observation. This observation should be freewheeling. Instead of giving students categories and names for them, teachers should let them make the classification themselves, finding their own bases for inclusion or exclusion with little steering by the teacher. Thus collecting becomes the basis of classifying, and vocabulary is introduced to name what is already perceived. Rocks or plants, for example, may be used to provide the material.

A start on quantitative thinking and representation. This representation of data employs the arithmetic skills and

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The early development of habits of independent and investigative systematic observation strengthens skills.

elementary graphing. Counting may be introduced in quantitative measurements, for instance, of population in successive generations or of weight of objects balanced by different numbers of standard weights. Sequences in time and space can be graphed; for example, the number in population versus number of generations, weight versus age, etc. This procedure gives students samples of the idea that measurement is done by counting units—a big "idea that travels" in the sense that it has wide and continuing application.

Familiarity with modes of scientific thought. This can be obtained through experience with science as a method of inquiry and through varied and satisfying experiences in using these modes of thinking. Perhaps only the beginnings can be made by the sixth-grade level, as a rule, but the beginnings are indispensable foundations for further experiences along these lines. Certainly some additional research is indicated for the purpose of ascertaining children's ability to use abstract patterns of thought at a given grade level.

Knowledge of the development of science. This is not a matter of science history for its own sake, but rather a familiarity with some of the historical and biographical incidents from science which provide a basis for acquaintance with understanding of and respect for the strategy and tactics employed in the scientific enterprise.

Beginnings of a scientific vocabulary. When students have seen conceptual schemes through order and number and through learning about categories, the usual names are then appended to the concepts. No vocabulary term should be developed without this relation to demonstrable categories.

Desire for scientific explanation. This does not mean that students will have a deep understanding of science. What is involved is a beginning on the part of the students of generating explanations rather than repeating assertions. To obtain this goal, pat answers should be discouraged, and students should be rewarded when they search for regularities and for apparent casual connections. As they leave elementary school, they may already be coming to realize that certain techniques pay off in finding satisfying explanations. Evidence

of this realization, too, is to be sought in their actions rather than any verbal formulas about how to get an explanation.

Achievements such as these are not won by formulating general statements like "all measurement is counting units," unless the students happen to do it themselves. This kind of generalization can be emphasized later. Here the basis of such later verbalization is laid in experience. The choice of experience can be very free in detail; but it should emphasize the examples that will lead to "ideas that travel," ideas of wide later use, rather than the minutiae of any special field of inquiry.

Junior High School Science

Although all levels of science instruction are important, a reasonable argument can be made that in many respects junior high school science occupies what is truly a key position in the K–12 sequence. On a national basis, a larger fraction of enrolled students take junior high school science than any other science course. For some, it is terminal science, and this enhances its significance. The fact that junior high school science occurs during the highly formative years of early adolescence places it in an unusually strategic position. The scientific literacy of the average citizen of the future is determined largely during these years. It can well be said that at these levels, more than at any other, youngsters become oriented toward, or away from the product and process of science, either as prospective science specialists or lay citizens.

With the direction of elementary school science in mind, the junior high school must correlate and extend the knowledge, skills, and attitudes that youngsters have acquired through their experiences in the lower grades. Students must also be brought into more intimate contact with the way in which a scientist goes about his work. *This mandates a more formalized type of laboratory experimentation on the part of individuals and small groups under teacher supervision.* While this may or may not involve a special purpose laboratory separate from the science classroom, it does require classrooms which are specially laid out and equipped with

the space, facilities, equipment, and materials necessary for such activity.

The subject matter of junior high school science should cover all phases of physical and biological science and begin the identification of the special province of the areas of biology, chemistry, physics, earth science, astronomy, etc.

A further responsibility of the junior high school is to extend the provisions for individual differences among students and, where possible modify the basic course for students who on the one hand have unusual interest and talent in science and on the other are in the category of slow learners.

With elementary school science initiating progress toward the goals of an integrated K–12 program, what can the junior high school graduate be expected to possess?

Desirable Outcomes that a Ninth Grader Should Achieve

A basic knowledge of the nature of the scientific enterprise. He should begin to understand the tentative, cumulative nature of scientific knowledge. He should have a healthy respect for the role of honest doubting and begin to recognize, and himself use, the elements of scientific process. At this point, he should be convinced of the observation-experimentation approach. He should recognize that though intuition, imagination, and chance may play a part in the scientific process, it is the interaction of these on the prepared mind that is in reality operating. This implies that the student will have developed his reading ability so that he can carry on self-initiated work and has been motivated to begin study in depth. He should be able to analyze problem situations and use impersonal criteria for making judgments about the relevant and the irrelevant, the warranted and unwarranted claims. The student should also be aware of the international nature of science and the central importance of unrestricted communication among scientists. He should be familiar with the language by which this communication is made possible.

An increase in the mathematical, observational, and experimental skills. This necessitates a greater emphasis on laboratory work in the junior high school than has been true in

the past. It calls for a familiarization and coordination with the new directions of junior high school mathematics, so that optimum use is made of the knowledge and skills which are achieved by the students at that grade level.

Understandings related to the interrelations of science and society. Science is dependent on the social order and must have a large degree of autonomy to flourish. This indicates the need and desirability for public support of the scientific enterprise. In the other direction, society has become dependent on technological developments and scientific ways of thinking. Application can then be transferred to social problems and human values.

Increased understanding of the concepts and theories which describe and unify the fields of science. The junior high schools should continue to expand the dimensions of the pervasive ideas that were begun in the elementary school. These "ideas that travel" are a major criterion for the selection of subject matter. Such concepts and theories as those relating to the structure of matter, ionization, bonding, energy interchanges, and the periodicity of the elements are examples of these major ideas. Other criteria involve the selection of those areas which increase the students' understanding of the processes and products of science in keeping with his increasing maturity.

Career opportunities. For those for whom the junior high school is terminal, as well as for those who go further in science, it becomes desirable for the junior high school to begin to point out the career opportunities available in scientific and technical fields now and in the foreseeable future. Something about the nature of the training required for success and the ways and means for evaluating one's personal attributes against the known requirements might also be included as part of the guidance program.

Senior High School Science

Science in the senior high school is frequently elective in character. Sometimes a year of such science is required for graduation; or it may be added as general biology. Specific

requirements by many colleges and universities now upgrade this sharply for students who are bent on higher education. As a result, some localities have instituted two years of mandatory laboratory science at the senior high school level.

Neither science nor the student's ability to deepen his understanding of it stops at any time. Many students, however, do not take formal courses in science after high school. *The majority of students, therefore, should take a balanced program of physical and biological science courses as part of their high school education.* These courses, however, are not "general science" courses in the usual sense. They should be physics, chemistry, physical science or biological science courses, earth science, astronomy, etc. To this degree, they are more specific than "general science" in subject coverage. On the other hand, they are not specific preprofessional education. *The high school courses, therefore, in each of these disciplines should continue to stress the scientific process and the nature of the scientific enterprise.* The techniques used should still be chosen primarily because they are a necessary part of the process of understanding at this level and not the narrow tools of a possible later vocational specialty. This does not mean that techniques in general must be shunned; it means that they should be subservient to the paramount requirements of science education laid down in the sections on the scientific enterprise and the purpose of science teaching.

Most senior high school students should take at least two science courses. One should be in biology or the life sciences area, and one should be in the realm of the physical sciences. Some students should take more. The placement of students here should be based on counseling as well as on the student's interest. Earlier performance in science courses should not be used as though it were an infallible guide. Some students who have not shown earlier interest or aptitude "get started" in high school, and their rising interest may even lead them to make up deficiencies in allied subjects, especially in mathematics. For those students who have taken at least one senior high school course in science and who want to go into more

professional detail in science, there should be opportunities for further experience. Experiments are now going on concerning several different ways in which this may be done by seminars, college visits, and special advanced courses.

Capabilities, interest, and potentialities of students cover a wide range. This variability leads to a major problem in designing courses. Should there be several different courses in the same subject? Can courses be designed to provide for a common core of ideas and materials while leaving room for substantial differences in individual performance? Both directions should be explored. Each course should provide for individual variation, and it may be necessary or desirable to have two or more versions of a given course.

The slow learner is probably more interested in the direct utility of science to himself. A course for him should perhaps place emphasis on technology, but should still be science-oriented in that it stresses process as well as product. The gifted student should be handled in special courses or on an individual basis. Such ability grouping is one solution to problems of individual differences, but not the only one. There is considerable evidence indicating that a very wide variety of students can follow the same general course, especially when they can make some choices of their own as to how deep or how fast they can go. Also, the structure of a field of science is the same no matter who studies it; consequently, *the notion of teaching completely different sets of ideas to different groups of students is unrealistic.* Basic research work on the possibilities of pacing and of optional enrichment of the course should be undertaken for comparison with differentiated courses.

The problem of how many different courses should exist for the same subject is intensified by the rise in enrollment in high school science. Large classes sometimes make it difficult for the teacher to handle the individual needs of students. More separate classes must be scheduled to handle these numbers. The classes can then be differentiated if this seems desirable. At the present time there are numerous experiments being conducted which employ innovations in class size and

organization, and the techniques and potential of educational television are yet to be fully explored.

The character of senior high school science continues a logical development which begins with elementary school science. *Where elementary school science is more or less incidental and descriptive, junior high school treats science as a broad discipline. In the senior high school, science becomes increasingly specialized.* Here students can use more quantitative tools, both of measurement and representation. Large numbers of students can now use concepts from geometry and algebra and even the newer concepts of mathematics to get clear mathematical models. They can describe these ideas, these modes of scientific thought, as general concepts based on long exploration. Also with more extended work in a specific field, they see "the ideas that travel" unifying their explanations. Biological evolution and the conservation law of mass-energy have meaningful extent, and students can intellectualize them and their significance without just parroting words. They can even get a sense of the frontiers of what is known, where things are uncertain, and where knowledge approaches complete certainty.

In the high school course, real problems must be met outside of "the book," and students must design and carry out experiments. These experiments, however, need not be new original research. Otherwise the scientific process tends to lose its connection with the world of phenomena. Experience indicates that *students often face problems and wrestle with them more successfully in the laboratory than in the classroom.* In textbooks it is far too easy to find the answers rather than to search for them. The easy answers tend to be undervalued and quickly forgotten. Moreover, there are many subjects such as the behavior of waves and the laws of motion that can be taught effectively through laboratory experience but that are rarely, if ever, successfully taught by reading, discussion, and demonstration. The student must participate directly in the experiment. Consequently the effective teaching of physics, chemistry, and biology at the senior high school

level demands a laboratory, with adequate space, equipment, and related facilities. It may not be full of expensive modern apparatus, but it should give all students a real opportunity to work and learn through creative improvisation, observation, and experiment.

Many high school science laboratory programs are a sorry shadow of what they might be. In some cases, growth toward appreciation for, enthusiasm about, and understanding of the process of science is negative rather than positive. In general, *high school science laboratory learning needs great improvement*; moreover, intense research leading to such improvement is sorely needed.

An analysis of the present curriculum in science in the senior high school in the light of the content of this report indicates the following shortcomings:

1. It is not predicated on an enlarged, continuous, and coordinated science program starting in the elementary and ranging through junior high school.
2. It contains too much material in breadth and attempts to cover too many areas within any one discipline.
3. It is not up to date and fails to give the students an adequate picture of science as it is practiced today.
4. It lays undue stress on both content and technology at the neglect of the process goals.
5. The laboratory experiences are not truly indicative of the nature and techniques of scientific discovery.
6. There is considerable question as to whether present or "standard" courses realize optimum potential for increasing the level of sophistication of students and draw on the full extent of their intellectual resources.

It is to these criticisms that the syllabus-makers of the future must address themselves. They will be called upon to select and organize materials so that their syllabi illustrate and are in consonance with the goals of the over-all science program. They must include the methods and concepts of modern science, while not neglecting the older concepts upon which the sciences lean for growth and progress. They must

also include some of the newer concepts whose implications have had a far-reaching effect on the whole of modern science. Finally, the group must point out the direction of the subject.

They must recognize also that a given course should not be encyclopedic in scope; that skills (and here is included skill in application of scientific modes of thought) are retained longer than facts and are more likely to be employed in new situations. A judicious selection of content areas must be made so that a useful combination of facts and skills will eventuate.

Perhaps the most challenging problem is that of indicating suitable laboratory work. In implementing the goals of the program, laboratory experience assumes a most important role. Care must be exercised, however, to develop laboratory experiences that parallel, at the student level, the research and discovery aspects involved in the work of the practicing scientist. The laboratory should provide prime reinforcement of the skills and techniques developed in the course.

Responsibility for Curriculum Development

Many diverse groups, some of them well-organized and well-financed, have assumed a measure of responsibility for the development of the curriculum in secondary science. It is gratifying to see such a widespread base of interest and concern over such an important problem as the science curriculum. The basic research scientist, the technologist, and the science educator, each operating from a different viewpoint, can, through joint effort, establish clear-cut aims and objectives for an improved science program in schools. Such a group can also indicate the unanswered questions involved in a K-12 program, as well as point out paths of exploration.

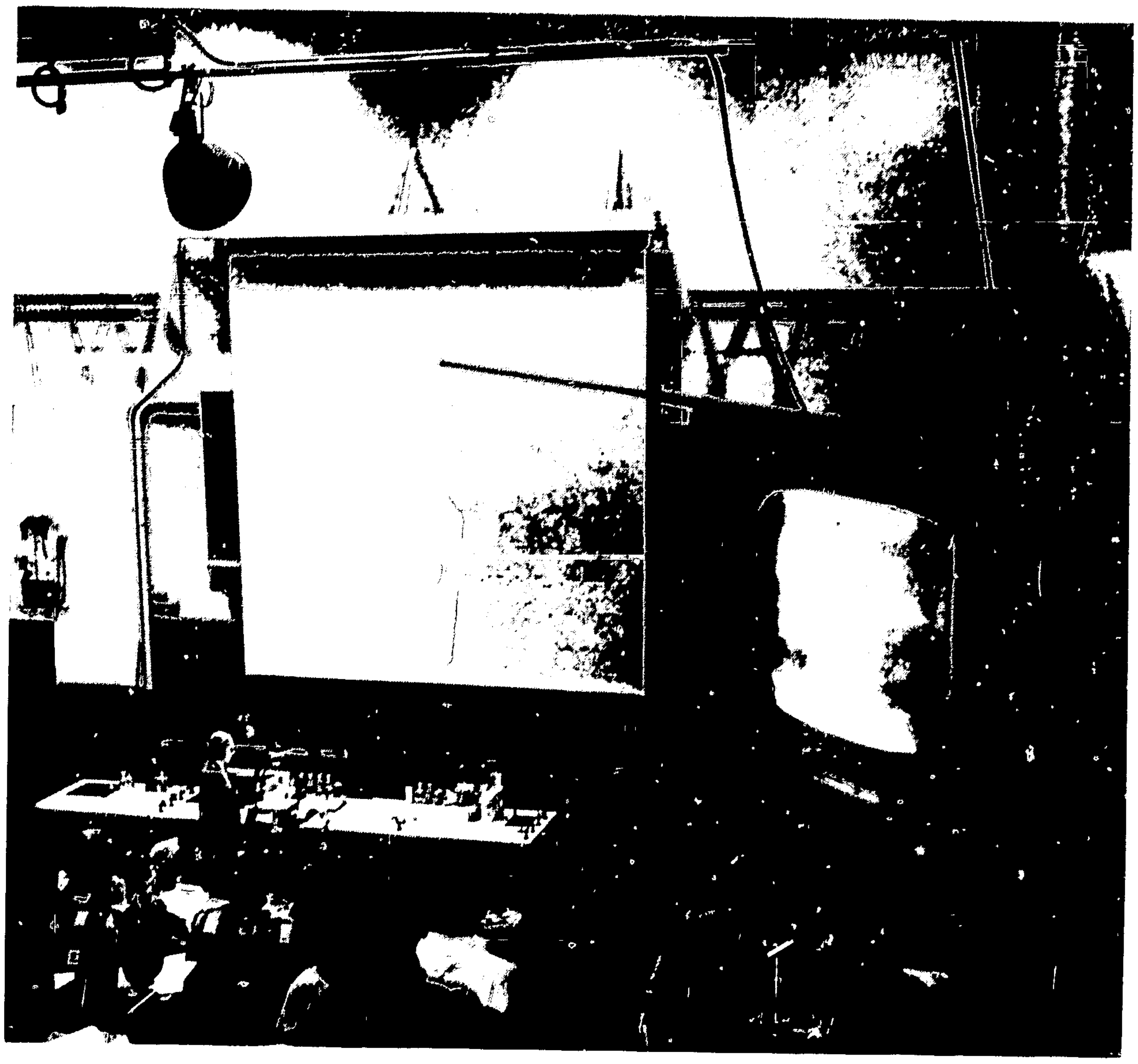
However, the task of translation of strong, but general guidelines into a science education program is not one primarily for professional scientists and technologists. Program development should be the responsibility of the science educator at local levels—state, county, district, and classroom. The wise use of advisory committees, concerned with local needs but aware of the national interest, can facilitate the

program of the science educator. Although science educators want and need all the help and advice they can get, the ultimate responsibility for the science curriculum is theirs. Curriculum development must involve those who ultimately have the responsibility for its implementation.

Particularly during the past few years, there has been increasing national concern over science education in public schools. Many suggestions have been made about it; and several courses, syllabi, and curricula have emerged at the national level. These provide an important basis for local curriculum construction.

The Physical Science Study Committee course in physics combines textual materials, laboratory, and films in a single modern course. The Biological Sciences Curriculum Study is at work on the materials for a sequence or thread of biology learning from kindergarten through high school. The Science Manpower Project of Teachers College, Columbia University, has published several booklets concerning secondary school science. Preliminary versions of several new chemistry courses are being tried out experimentally this year. A source book for geology and the related earth sciences has been prepared under the guidance of the American Geological Institute. Similar course and curriculum improvement work is going on in mathematics. Many new state and city syllabi are available covering the field of science and the related mathematics. The American Association for the Advancement of Science tries to keep an up-to-date list of the major projects.

No curriculum can relieve teachers and administrators of their basic responsibilities. In addition to determining the local curriculum, they must see that the facilities for instruction are adequate. Administrators, must also be responsible for a favorable environment. They must act as the liaison, and when necessary as the buffer between science teachers and the public. Teachers must be free to modify preconceived procedures to take advantage of special opportunities. This does not mean that teachers may ignore established goals. In any good course, however, they have latitude to stimulate apt students and time to help slower learners with their problems.



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Curriculum development should include techniques or media which would facilitate instruction.

Teachers must use judgment; no syllabus, no course, no curriculum can do that.

Finally, since curriculum development is a dynamic process and must never be static, the curriculum should always be in process of revision leading to modernization, refinement, and enrichment. Furthermore, since the science curriculum represents only one segment of the total education of young people, it should be developed in close relationship to other curriculum areas in the school.

Needed Research

The entire area of the science curriculum is one in which basic research is sorely needed. *Too little is known about the readiness of students for different concepts.* More must be learned about the dependence of readiness on age, on background, and on the type of presentation employed. Furthermore, there is need for a better basis for counseling students and for more knowledge about the possibility of handling a variety of students by appropriate course design. To what extent can individual differences be handled by letting students penetrate to different depths and take side excursions if they outrun a common core? Careful studies must point the way.

In designing a course or a sequence of courses, science educators must select concepts that explain much, concepts that make further learning easier. Science experiences should be developed to help students learn how to learn. But very little research (in comparison with the need) has been done to identify the methods and examples that promote this important kind of transfer.

A vital part of all these tasks is the problem of evaluation. To distinguish a better course from a less effective one, improved educational measurements must be developed. The identification of general objectives is necessary but not sufficient. The same thing applies to the total science program.

IV

IMPLICATIONS FOR ADMINISTRATION AND SUPERVISION AND TEACHER TRAINING

The Role of Administration and Supervision

The ultimate function of administration and supervision is to provide the best possible conditions for teaching and learning. Two important aspects of this function are the responsibility for assisting the teacher in directing the learning process for maximum benefit to the learner, and the responsibility for providing adequate classroom facilities and equipment. Many of the problems facing secondary school science education are rooted in part of the functions of school administration and supervision. Attention is now given to the responsibility of school administration in the area of science education, in the light of the nature of the scientific enterprise and the nature of the educational enterprise.

Just as it is the responsibility of the science teacher to keep abreast of the educational and scientific advances in his field, so it is the obligation of the alert administrator to be informed concerning the latest movements in the field of science education, for it is only by this means that he can make consistent and proper judgments. He can acquaint himself with these developments and demonstrate an active interest in them by attending conferences, reading current literature in

science education, and by discussing suggested innovations with supervisors and teachers. Such interest shown by the school administrator creates a stimulating atmosphere for all concerned and, curiously enough, the interplay of ideas involved in making judgments calls for the application of the self-same scientific ways of thinking that are featured so prominently in this report. When the administrator understands the problems and directions of science teaching, he can direct the works of those in his charge.

Inasmuch as effective science teachers are the core of an effective science program, principals and supervisors and others who share responsibilities for science programs should assist in making the selection and placement of science teachers. If they are cognizant of the needs of the program, they can make their selection with confidence, and if necessary, plan for the in-service growth and development of such teachers from the very beginning.

Administrators must make provision for the teacher to concentrate on his primary job—instruction. The teacher should be freed, to whatever extent is possible, from the quasi-educational duties which can be handled by clerks and assistants. Particularly is this true of the science teacher. In a science teaching program, the instructor spends considerable time and effort in preparing, storing, and stocking materials for use in laboratory experiments, and planning meaningful courses. Often, the science teacher is handicapped in giving full time to this work because of the demand from other non-science activities.

Science teachers need the sympathetic cooperation of both administrators and supervisors. They need encouragement in using effective modern methods in teaching; they need the freedom to experiment with new methods; they need acquaintance with the nationwide experimental programs related to content and method in the science teaching process; and finally, they need provisions for keeping up with science itself, as well as for association (on a national, state, regional, and local level) with the professional workers in their field.

Administrators and supervisors must thus keep themselves fully aware and well informed with respect to changes in the science education program.

Time for Science

Throughout the year, today's school administrator is called upon to exercise the wisdom of Solomon when he deals with the competition for curricular time. Each subject-matter area has its own reasons and justifications for seeking any additional time in the curriculum. There is rather wide divergence throughout the country in the matter of the time allotted to science. One fact, however, is certain. The time devoted to science is significantly increasing at all levels. Particularly is this true of the elementary and junior high school levels. In the secondary school, optimum results appear when the science time allotment enables the student to participate in an unhurried, extended period of laboratory work and five or more periods per week of demonstration, additional laboratory, discussion, and recitation. It is becoming increasingly apparent that to achieve the goals set for science education in the secondary school, five forty-minute periods per week are woefully inadequate.

Any attempt to promote optimum learning in science, as in teaching all other fields, runs into the problem of student grouping. The decision whether to group and the task of grouping and placing pupils should involve the cooperative effort of administrators, supervisors, guidance personnel, and teachers. Together they must evolve the criteria that are to be employed.

Providing for Ability Differences

Consideration should be given to all pupils who possess special talents or abilities. Study of this problem will involve all school personnel. While the goals suggested in this report apply to all levels of ability, those for the science-talented have different emphasis. The administrator and supervisor must accept the responsibility for formulating the course of study for the talented. This generally involves provision for additional

elective courses which themselves must contribute to the goals of secondary school science. Regardless of the action taken, however, a sincere attempt must be made to interest the student talented in science and to assure that this interest is not snuffed out by educational malpractice.

Facilities and Materials

Since this report places considerable stress on the processes of science as well as the product, the materials of science become a *sine qua non* of the teaching of science.[1] So important are the physical facilities and the instructional materials used by science teachers, and so frequently have they been poorly selected or inadequately provided that an extended discussion will be of considerable value to the administrator and supervisor whose responsibility encompasses these areas.

Planning for Facilities and Materials

To be most effective, science education facilities and materials must be planned at the local level, well in advance, and with such outside expert assistance as may be available. The planning should be a cooperative effort of the teachers who will use the facilities, the school administrators who administer the funds, and the competent architects and consultants with broad experience in school planning who also are familiar with the special needs of science education. Each science has special needs, such as proper ventilation for the chemistry laboratory and a growing area for biology. Nevertheless, there are some facilities and utilities which can be used in common by all of the sciences, such as tables and space for individual work by the students, storage and maintenance areas, teacher demonstration desks, and electricity and other supplementary services.

The matter of safety is of great importance in science workrooms. The layout should be such that the area can be quickly evacuated in the event of accident. This is especially

[1] NOTE: The National Science Teachers Association has undertaken a major national study of science facilities to determine the physical setting and tools needed for school science programs from kindergarten through junior college. Results of the study will be reported in the 1961–62 school year.

true of chemical laboratories. Provision should be made for providing first aid and on-the-spot control of small fires.

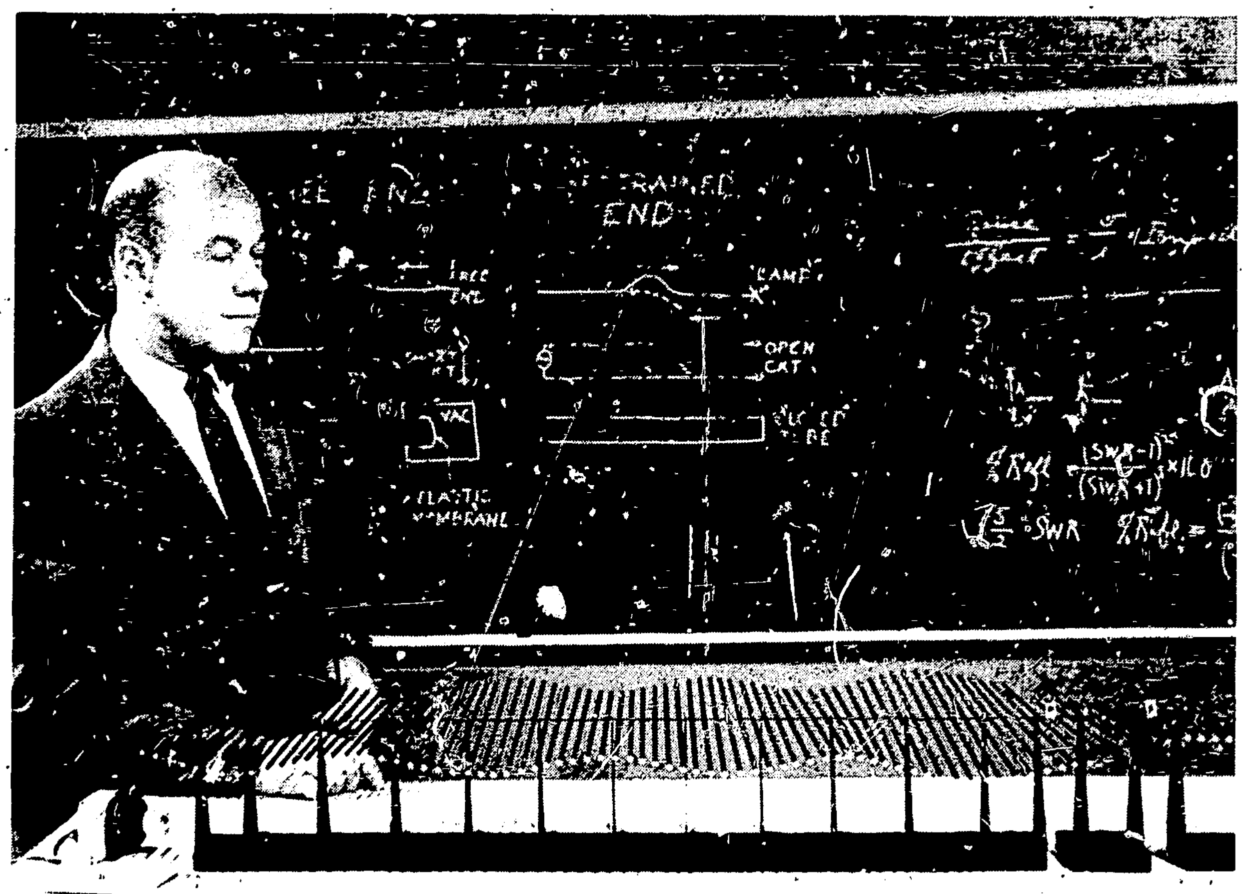
Proper planning should reflect the dynamic character of the sciences and their interrelationship with the total educational enterprise. For example, consideration should be given to space for individual student projects above the normal course requirements, areas for supplemental reading, study and writing of experiments, rooms for small group discussions and for the use of supplementary educational aids such as film projectors, and facilities for the storage and exhibition of special materials such as atomic and molecular models, biological specimens, mineral collections, maps, charts, and frequently used reference books.

Selection and Acquisition of Equipment and Materials

The selection of instructional equipment and materials is primarily the professional responsibility of the science teacher acting in conjunction with the supervisor and administrator. This responsibility demands competence on the part of the teacher in subject matter so that he knows what he needs and can evaluate descriptive literature and judge the quality and limitations of the products. Such competence is vital to insure that the best use is made of available funds and that the equipment and materials will be effectively used in the instructional program.

School administrators should make every effort to understand the science teachers' problems of needing special devices and of finding time to use them most effectively. Administrators have the responsibility of budgeting adequate funds for science teaching facilities and materials. Furthermore, they should see to it that science teachers have time for gathering information on prospective purchases and should give every possible assistance in handling clerical and similar details of selecting and ordering equipment and supplies.

Careful consideration should be given to the popular practice of having teachers and students improvise and construct instructional materials in science. When new devices are being developed, of course, this is a necessity. Furthermore,



AMERICAN TELEPHONE AND TELEGRAPH COMPANY

Information on new devices in teaching are coordinated through cooperative efforts of industry and education. John N. Shive, Director of Education and Training, Bell Telephone Laboratories, demonstrates and discusses aspects of wave behavior in the high school laboratory using specially built torsion wave machines.

there is much learning potential in properly guided improvisation, construction, and repair of materials for teaching. On the other hand, the economies in terms of funds and particularly in terms of teachers' time are seldom worthwhile. Teachers and students alike have more important things to do than to carry out an ineffective and time-consuming chore of making materials when much more effective instructional aids are commercially available.

Maintenance of Equipment and Materials

There should be a strong administrative policy stressing the importance of adequate storage rooms, convenient facilities for repair of apparatus, and in general the economical aspects of keeping equipment in good working condition. An up-to-date, or perpetual, inventory system ought to be employed. There is a mutual responsibility for teachers and administrators in the maintenance of equipment and materials and in insuring that the devices are in safe working condition. For example, safety hazards may arise from improperly functioning electrical equipment and from some chemicals that have deteriorated in storage. To provide time for the teacher to meet this responsibility, the use of properly trained laboratory assistants should be encouraged. Periodic check-ups by supervisors and other administrators should be scheduled.

Library Facilities

Library problems obviously refer to the "school library." Book purchase guides are available, but science teachers should be consulted before blanket purchases are undertaken by librarians. The school library should have a science section including encyclopedias and reference books, a range of resource books extending from early adolescent level through college level, books concerning the history of science, general scientific periodicals, hobby aids, handbooks, and the like.

Another important aspect of library services is the "local collection" placed within the science teaching area of the school. This locally available material has distinct advantages

in motivating students and teachers to look beyond the textbook, and in facilitating reference efforts for laboratory activities.

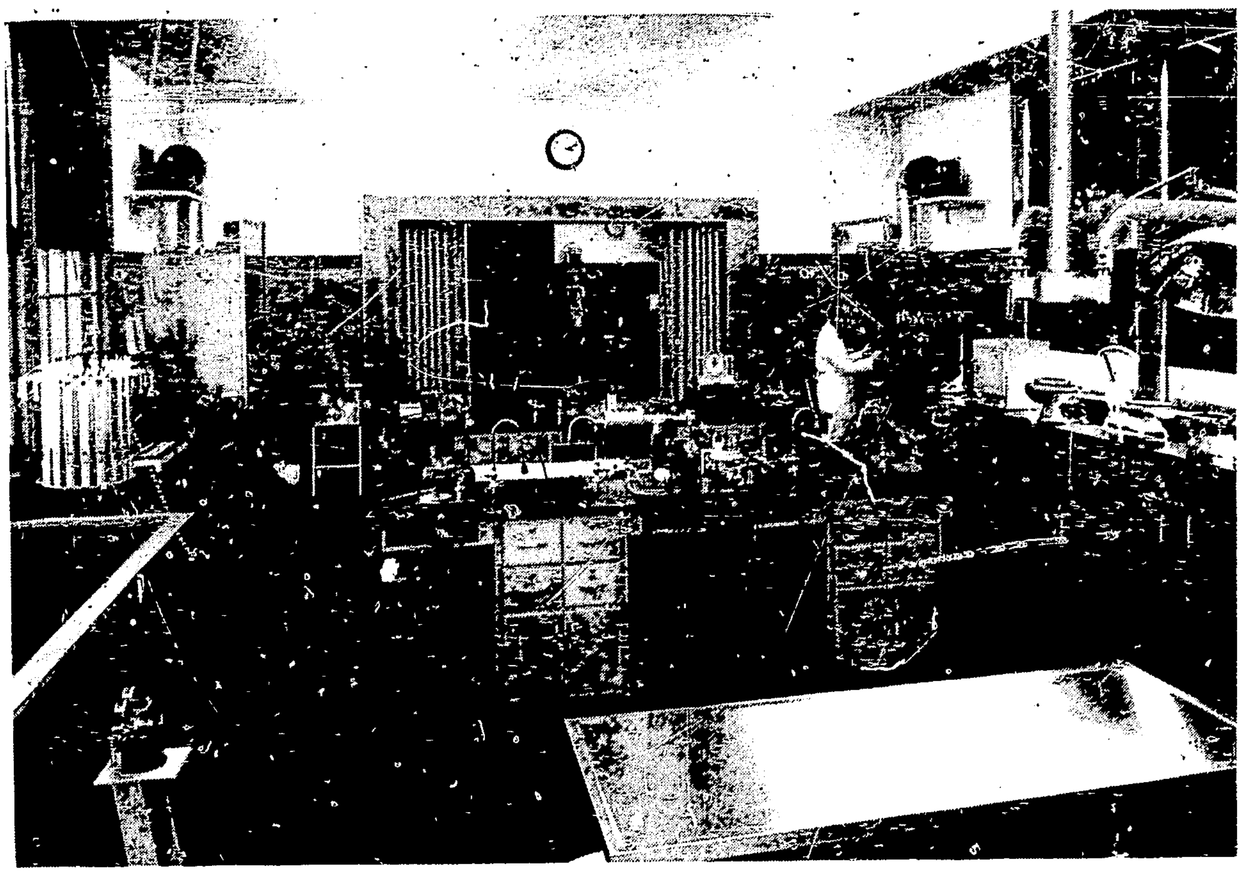
Supplementary Resources

The instructional program should determine the need and extent of use of science materials and equipment. To maintain consistency with the goals of science education implies availability and use of a wide range of supplementary resources such as reference books, periodicals, charts, models, tools, films and filmstrips, and similar instructional devices. Provision should be made for evaluation and efficient use of industry-sponsored materials.

Professional journals should continue, and perhaps expand, reviews of teaching aids, including equipment, books, and other materials for science instruction. Teaching guides, laboratory manuals, and similar text-type sources provide useful information and should be readily available for teacher use. Consultant assistance from educational organizations, local, regional, and national departments of education, scientific societies, industry, and institutions of higher education should be used to supplement local teacher and administrative planning for effective design and use of school buildings, facilities, equipment, and materials.

Improved use of materials and equipment depends on continuous development and application of new ideas. Such activity should continue to be encouraged through such programs as the Science Teacher Achievement Recognition (STAR) awards program of the National Science Teachers Association, the new equipment committee of the American Association of Physics Teachers, and the tested demonstrations of the Division of Chemical Education of the American Chemical Society. Research is needed to develop new equipment and evaluate the effectiveness of existing equipment.

Professional organizations should assume responsibility for keeping science teachers cognizant of new developments in materials, equipment, and facilities. Such publications as the



KORDAY STUDIO, FRAMINGHAM, MAS

Excellent facilities for classwork and research enhance student interest and efficiency. Science laboratories at St. Mark's School, Southborough, Mass.

NSTA *School Facilities for Science Instruction, Recommended Books for High School Libraries* by the American Association for the Advancement of Science, the Council of Chief State School Officers *Purchase Guide for Programs in Science, Mathematics and Modern Foreign Languages,* and others are valuable and should be periodically revised.

TEACHER COMPETENCE AND TEACHER PREPARATION

The development and maintenance of an effective program in science education requires highly qualified teachers. However, the statement becomes useful only when the word "qualified" is made meaningful and operational. Accordingly, one of the groups of problems confronting secondary school science today is concerned with three related areas:

- What are the patterns of behavior which are characteristic of highly qualified science teachers?
- What kinds of experience contribute toward the development of these highly qualified science teachers, and toward the maintenance of their competence?
- How can administrators identify, encourage, and reward excellent science teachers?

Some Characteristics of an Effective Science Teacher

The teaching patterns of good science teachers may vary considerably. There are, however, common characteristics which are identifiable in terms of what such teaching provides to the students, and they may be couched in terms of what an analysis of the scientific and educational enterprises implies.

Being aware of implications found in either enterprise, each individual may contribute. The effective science teacher:

Provides students with opportunities to identify and solve problems related to science learning (as contrasted to merely telling students how scientific information is acquired).

Provides his students some experiences with the unverified and hypothetical (as contrasted with only the relatively certain).

Gives his students opportunities to select and construct equipment, to develop experimental procedures, and to design (as distinguished from the "laboratory manual" method).

Devotes proper attention to limitations of measurement and observation and, hence, to the tentativeness of conclusions (as distinguished from presumed finalities).

Provides students opportunities in developing generalizations for themselves (as contrasted with handing them out or dictating them).

Emphasizes the development of generalizations (as distinguished from the mere memorization of discrete facts).

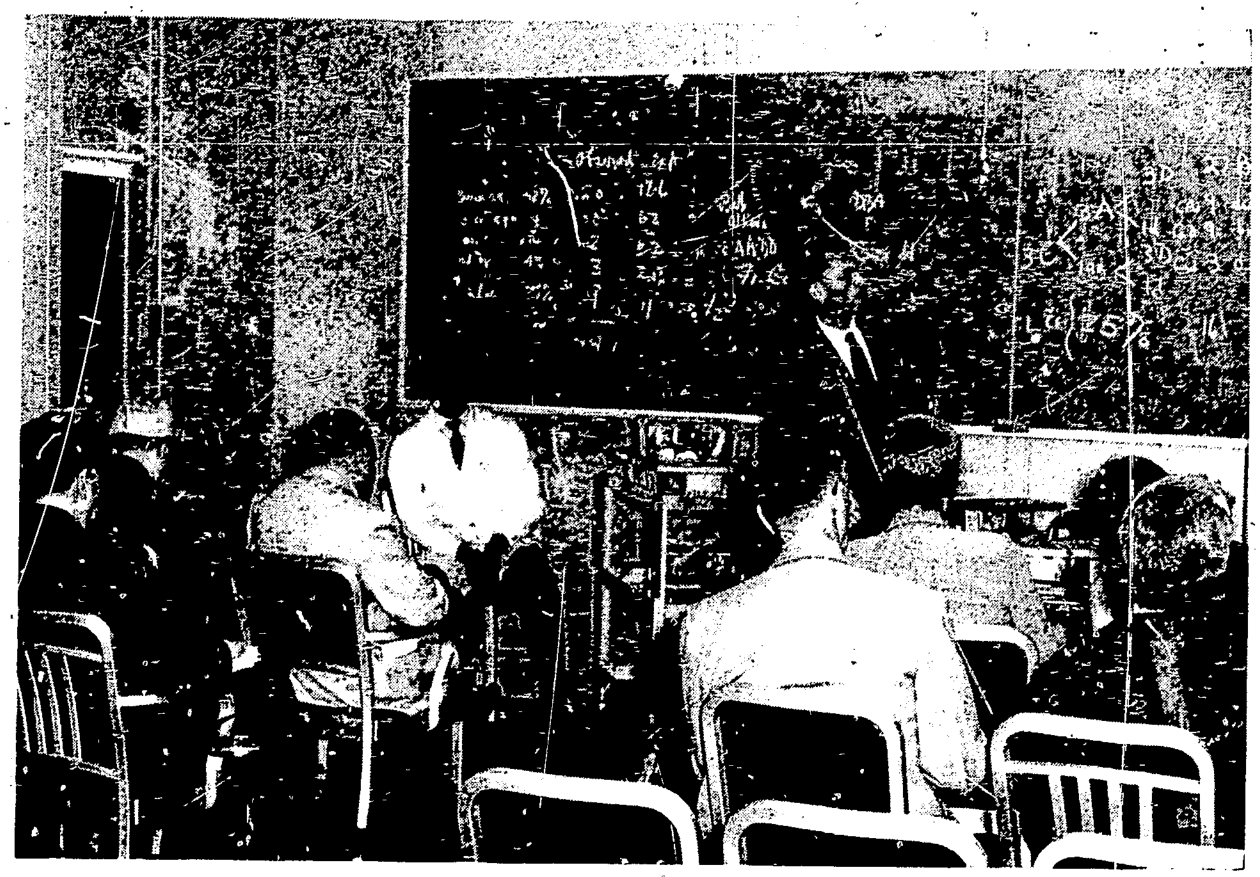
Helps students develop true understanding of generalizations by broad and numerous applications and illustrations (as contrasted to contentment with verbal facility).

Permits and encourages students seriously to explore questions of interest to them whether or not these questions are directly related to the logic of the course (as contrasted with confining everyone to the same learning sequence).

Is selective and creative in the learning experiences he employs in the light of the maturity and intellectual ability of his students (as distinguished from a formal or routine following of a text or course of study).

Insists on standards of performance at least slightly above those which evidence indicates his students are capable of (as contrasted with aiming his instruction at the average student).

Transfers the responsibility for the learning process from teacher to student by training the student in the



NATIONAL INSTITUTES OF HEALTH, BETHESDA, MD.

Secondary school science teachers learn basic principles of genetics from research scientist, Michael Potter.

processes and mechanics of self-initiated learning (as contrasted to continually leading the student by the hand).

Makes evident to his students his conviction that science, generally and in particular, is a matter of supreme importance and satisfaction to him (as distinguished from the appearance of being noncommittal or dutiful).

Consciously provides guidance for his students, helping them to identify and meet their own learning goals and their own occupational goals (as distinguished from merely helping them learn science and leaving guidance functions up to counseling specialists or to the students).

Preparation of Science Teachers

If effective science teachers are characterized by patterns of performance such as those above, what kinds of preparation, both pre-service and in-service, can insure these qualities? The type of teacher preparation that stems from the very nature of the scientific enterprise indicates the following:

Knowledge of Subject Matter. The verb "to learn" is transitive and as such must take an object. There must be something or things that the student learns. Unless that thing is worthwhile, relevant to the student's environment and to his future, and representative of no less than the best current thought, the entire process is of no value. *Teachers, therefore, must have good command of subject matter.* They must possess a broad background in science and mathematics with depth of specialization in at least one or two major fields. They must be expected to exhibit the high standards of scholarship and performance which contribute so much to the production of outstanding teachers.

With proper mastery of content and an understanding of the role that content plays in science education, the flexibility and value of the teacher thus is enhanced. A teacher can enjoy the confidence of being able to pursue whatever direction student interest or the dictates of the moment may lead him; and he can effectively participate in the dynamic process of curriculum building. If the science teacher is to teach with equal facility both

the process and product goals of science, he must himself experience these concepts in the science courses comprising his pre-service training.

History and Philosophy of Science. The teacher must have contact with the history and philosophy of science as a means of understanding how ideas and scientific explanations have developed. This will lead to an appreciation of the human element in scientific investigation and will enhance his understanding of the process goals, as well as the tactics and strategy of science.

Relation of Science to the Whole of Human Knowledge. Like any other teacher, *the science teacher needs a liberal education* with all this term implies. He should be afforded an opportunity for study in the arts and humanities, thereby enabling him to set science in proper perspective in relation to other areas of knowledge.

Work with Science in Action. Scientific horizons are expanding so rapidly that the "once qualified" does not mean the "forever qualified." As part of his continuing in-service growth, the science teacher owes it to himself as well as to his students to keep abreast of the happenings and discoveries in science—processes as well as products, understandings as well as facts, theories as well as technology. This can be accomplished through membership in scientific societies, visitation to research and field activities, enrollment in college or graduate level courses in advanced science, systematic study of books and journals, attendance at conferences, development of hobbies, and even through on-the-job research. He must also continue to develop in the area of manipulative skill.

By the very nature of the educational enterprise the preparation and in-service development of teachers indicates the following:

Continuing Development of Skills and Techniques in the Teaching Process. The pre-service training of teachers should provide opportunity to learn and practice, under suitable supervision, the skills and techniques which form the vehicle of the teaching process. At this stage, techniques of critical self-evaluation should be

built into the teacher's philosophy so that the development of these skills will continue through the in-service period and will be retained.

Knowledge of Psychology and the Learning Process. So that he can effectively assess and assure proper impact and efficiency of his method and content on the student, the teacher should have a working knowledge of the basic psychology operating within the youth with whom he deals. He must also be familiar with what psychology knows concerning the nature of the learning process and the reaching to examine the basic assumptions and rationale underlying the process.

Contact with Education in Action and the Results of Educational Research. Teachers should have an opportunity to observe outstanding co-workers in action and to practice and perfect their teaching skills. The neophyte should have an opportunity to examine critically the work of his superior teacher; while at the beginning stage, intervisitation should be encouraged.

Properly motivated, competent supervision is the birthright of every teacher. It is by such supervision that the improvement of instruction is most efficiently carried out and desired results obtained.

The process of in-service improvement can be effected by encouraging the teacher to become actively affiliated with professional organizations, attend conferences, read extensively in science education, and enroll in in-service training courses and summer institutes.

Although the activities of in-service preparation such as those listed above are primarily the responsibility of the teacher, there is much that school boards and administrators can do to encourage such effort. They can provide flexibility.

Identification and Recruiting of Science Teachers

It is not enough to be able to prepare good science teachers. It is also necessary to recognize them where they are and, in

these days of science teacher shortage, to encourage promising young people to prepare themselves for this profession.[2]

One of the tools for screening prospective science teachers is the system of certification which is, in one form or another, characteristic of each state's teacher selection pattern.

Because of the rapid changes in both the scientific and the educational enterprise during the past decade, the certification requirements for science teachers in the secondary school should be reviewed and evaluated. The background preparation of a science teacher must include sufficient general education to insure an understanding of and an appreciation for the culture of which he is a part and its interrelationship with the scientific enterprise.

It should involve breadth and depth in the science areas taught as well as the necessary methods to insure effectiveness in the classroom. Certification requirements for secondary school science teachers need not necessarily be stated in precise quantitative terms; more important are qualitative requirements which specify the minimum competency desired in both education and science areas. Recommendations for the preparation of high school teachers of science, such as the report of the Subcommittee on Teacher Certification of the American Association for the Advancement of Science and the Joint Commission of the American Association for the Advancement of Science and the American Association of Colleges for Teacher Education should be carefully studied by the departments of education in the several states and by teacher education institutions. Similar studies should be initiated in the professional education area to identify those courses which most effectively contribute to the development of capable science teachers. All courses contributing to the education of teachers should be re-evaluated in terms of their contribution to the production of qualified science teachers.

State certification requirements, college and university graduation standards, no matter how ideal, will not result in improved science teaching in secondary schools unless:

[2] *Encouraging Future Scientists: Keys to Careers.* Fifth Edition. National Science Teachers Association, Washington, D. C. 1959.

Administrators assign science teachers to areas in which they have necessary background preparation and other essential competence.

Teachers currently teaching science courses without adequate science training are compelled to obtain the necessary qualifications, or are replaced by qualified science teachers.

Adequately trained science teachers are given the opportunity and the incentive to maintain and increase their competence.

Faced with the powerful appeals the enterprise of science offers to any people, one way to attract and hold science teachers is to create a situation in which they can combine the satisfactions of teaching with actual participation in the enterprise of science. A wise investment of school funds would be the purchase of materials and equipment and the provision of the time necessary for the teacher to explore in his own field of special interest. Cannot these same forces which motivate the science teacher and scientist be used to arouse interests among science students?

Other factors which would contribute to the recruitment of science teachers and hold those already in the profession include:

Time for science teaching. Freedom from assignments which are unrelated to the science training.

Salaries that are competitive. Schools should be able to compete favorably with other positions in the science enterprise.

Adequate materials and equipment. Essential to actual utilization of the methods and processes of science in the classroom.

Community and professional respect and esteem. Reward for which science teachers will be willing to strive.

The total area of science teacher performance and preparation involves much uncertainty and often conflict of opinion. One of the reasons is that much of the knowledge of this area is uncertain; in some cases, the surface has barely been

scratched. Among the issues in which research is sorely needed are these:

Improved patterns of pre-service experience conducive to the preparation of good science teachers.

Means through which science-competent persons can be helped also to become competent science teachers.

Students' relation with and impressions of their teachers' adjustment, satisfactions, and enthusiasms for their subject.

The influence of the means of mass communication on the public picture of the science teacher.

Effective evaluation instruments for the identification of potentially good science teachers.

Conclusion

In sum, an attempt has been made to focus on the whole range of problems which relate to the secondary school science program. It is hoped through this effort to give embodiment to ideas or activities that may serve to inspire or initiate action for the recognition and successful solution of our dilemma.

If the dangers of passivity and complacence are to be overcome, we must constantly arouse ourselves to examine, evaluate, and nurture all segments of the scientific and educational enterprises and their effects on the individual and society. The task is one which belongs, not only to the teacher, the educator, and the scientist, but also to the individual who dares to examine the problems, overcome the obstacles, and sustain the burden of uncertainty and risk until new insights and remedies can be achieved.

CONFERENCE ON SELECTED PROBLEMS IN SECONDARY SCHOOL SCIENCE

Under the sponsorship of the National Science Teachers Association with the support of the National Science Foundation.
Washington, D. C.

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