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TEACHING HIGH-SCHOOL SCIENCE.
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THIS DOCUMENT WAS DEVELOPED TO HELP THE SECONDARY SCHOOL SCIENCE TEACHER KEEP PACE WITH THE CONTINUALLY ADVANCING FIELD OF EDUCATIONAL RESEARCH. IT IS ONE IN A SERIES OF PAMPHLETS ON "WHAT RESEARCH SAYS TO THE TEACHER," PRODUCED JOINTLY BY THE NATIONAL EDUCATION ASSOCIATION (NEA) DEPARTMENT OF CLASSROOM TEACHERS AND THE AMERICAN EDUCATIONAL RESEARCH ASSOCIATION. A COMPLETE SUMMARY OF RESEARCH IN THE AREA IS NOT INTENDED. RATHER, THE AUTHOR HAS ATTEMPTED TO DRAW FROM RESEARCH MATERIAL ON HIGH SCHOOL SCIENCE EDUCATION THOSE IDEAS WHICH PROMISE TO BE MOST HELPFUL TO CLASSROOM TEACHERS. DISCUSSED ARE (1) REASONS FOR EDUCATION IN THE SCIENCES, (2) THE OBJECTIVES OF SCIENCE EDUCATION, (3) THE INSTRUCTIONAL METHODS WHICH SHOULD BE USED, (4) THE UTILIZATION OF MATERIALS AND FACILITIES, (5) STUDENT EVALUATION, AND (6) TEACHER EDUCATION. THIS DOCUMENT IS ALSO AVAILABLE FROM THE NATIONAL EDUCATION ASSOCIATION, PUBLICATIONS SALES, 1201 SIXTEENTH STREET, N.W., WASHINGTON, D.C. 20036. (DS)

WHAT RESEARCH SAYS TO THE TEACHER

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Teaching High-School Science

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of the National Education Association

SCHOOLING is what happens to children and youth under the guidance of classroom teachers. If the teachers are well prepared, the teaching is likely to be effective in helping pupils attain the goals of the school program. But the most effective teacher is one who keeps his planning and instruction in tune with the useful and constructive findings of educational research.

Research may be useful to the classroom teacher in at least three ways: (1) by helping him develop an alert, sensitive attitude to the advancing edge of human knowledge, (2) by supplying him with facts whereby he can improve his own work, and (3) by stimulating him to go on beyond existing research findings to discover additional facts for himself.

The problem of the typical classroom teacher is to keep pace with the continually advancing field of educational research. He must know where and how to find research and then he must be able to read with understanding what he finds. The problem is further complicated by the varying degrees of reliability among research studies. These complications are so serious that many classroom teachers do not have the benefits of research and many research studies have little effect on everyday practice.

The bridging of this gap seems to be one of the most important problems in today's education. For this reason the NEA Department of Classroom Teachers and the American Educational Research Association have joined together to produce a series of pamphlets on "what research says to the teacher." The cost of printing these publications has been met by the Department of Classroom Teachers of the National Education Association. The authors are well-known research leaders from among the membership of the AERA. The layout and editing of the series have been done by the NEA Research Division.

The Department of Classroom Teachers and the AERA are indebted to the individual authors of this series. All of them have made personal sacrifices to prepare their manuscripts; none has received an honorarium. Their contributions are unselfish gifts to the progress of education.

First Edition, April 1956

Single copy, 25 cents. Quantity orders at the following discounts: 2-9 copies, 10 percent; 10 or more copies, 20 percent. Address communications and make checks payable to the National Education Association, 1201 Sixteenth Street, N. W., Washington 6, D. C. Transportation charges will be made on all orders not accompanied by funds in payment.

Teaching High-School Science

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EXPLANATION

The author has attempted to draw from research material on high-school science education the items which promise to be of most help to classroom teachers. It is not a complete summary of research. In some instances opinion has been given which is believed to represent the views of most experts. The interpretation and recommendations are those which the author, J. Darrell Barnard of New York University, believes to be soundly supported by research. His original manuscript was reviewed by William Reiner, Board of Education of the City of New York; and Robert H. Carleton, executive secretary, National Science Teachers Association. Changes were made by the author on the basis of the suggestions of the reviewers and of the staff of the NEA Research Division.

TEACHING HIGH-SCHOOL SCIENCE

WHY TEACH SCIENCE?

KEEPING America secure among the nations of the world is an objective toward which many believe we should concentrate our efforts. As a nation, we have achieved a comparatively high standard of living and desire to maintain it. The health of Americans is good and is improving every year. Our national security, our standard of living, our health status, all have been achieved in large measure thru science. We have used science to develop fearful weapons of destruction, to build machines and processes that improve goods and services, and to understand the nature of diseases and ways of controlling them. Thus, science has played a dynamic role in building a country that is physically a strong power and materially a prosperous nation.

It is imperative, however, that the scientific conquest of the unknown and the technical application of what is learned be continuous if the goals we have achieved are to be maintained. During the past 20 years, progress has been so rapid that the new process or technic which was a revolutionary technical discovery yesterday, may have questionable value today, and tomorrow may even become obsolete. A new weapon promises security in our hands; but, when in the hands of an enemy, it confronts us with the more perplexing problems of defense. The magnitude and variety of machines, that permit us to use our energy resources at astronomical rates, also make the discovery of new energy resources a high-priority problem if we are to survive. The wonder drug which insures protection from one killer microbe may induce a more virulent mutant microbe from which there are presently no wonder drugs to protect us.

Schools Educate Our Scientific Manpower

Science has been developed by man. The great discoveries of science have evolved out of man's efforts to interpret the findings of his investigations. The technical applications of these discoveries to the improvement of human welfare have, in turn, been made by man. Science is a creation of man, and its future, in the realms of both theoretical and technical advancement, will depend upon the quality and number of our future scientists.

Our need for scientifically trained manpower is greater today than in any previous period of history. But today proportionately fewer college students are preparing themselves for careers in science. Many citizens consider this situation one of America's most critical problems. Some believe that the secondary-school science program can play an important part in solving it.

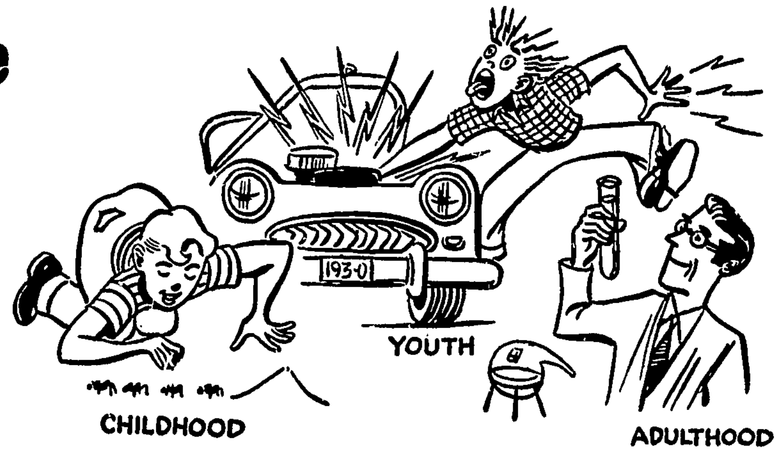
Schools Educate for Citizenship in a Technological Society

In a democracy, such as ours, many decisions must be made by citizens. Decisions on the financial support of scientific research, whether by private corporations, by publicly supported foundations, or by government-sponsored agencies, ultimately rest with people. How our natural resources will be managed is decided by people. Citizens determine what our national and local health programs will be like. They say how much they are willing to pay and thus determine how well the programs will be maintained. A scientifically literate citizenry is greatly needed if intelligent decisions in these and in many other matters are to be made. This is a responsibility of the schools and primarily a function of science programs in the schools. Since the public schools belong to the people, the people are the final authority on what shall be taught and the types of facilities that will be provided to teach it.

Schools Educate for Adjustment

From conception, thru infancy, childhood, adolescence, adulthood, and old age, human beings change. They change as functioning biological organisms. The ways they feel about themselves and other people change. The manner in which society deals with them also changes. At each developmental stage there are certain needs the individual must meet if he is to work out satisfying adjustments to himself, other people, and his environment. Identification of these needs and an examination of the roles which education should play in meeting them help define the goals, content, and method for the educational program. Selected content of science and the methods of science can contribute to meeting these needs for adolescents.

Every age has its science problems



Young people have a variety of interests that can be developed and extended within properly planned science programs. By the time they enter the secondary school, a number of them have developed special talents which, if carefully guided thru an enriched and challenging science program, will lead to careers in science. For all secondary-school youth, science programs that relate to personal and social problems will help them grow in their concept of the unique role of science in the modern technological world. Young people can have experiences in science that develop attitudes and abilities of critical thinking that motivate them to face problems and seek reliable solutions. These attributes are basic to the intelligent solution of personal and social problems and thus to an effective program of citizenship education. Altho the development of these attitudes and abilities may be emphasized in a social studies program, science has unique contributions to make.

Enrolments Lag

In the secondary school, science has not kept pace with the growing importance of science in our lives. For many reasons—the education of critically needed scientific manpower, education for effective citizenship in a scientific age, and education to meet the needs and interests of the adolescent—science should hold a position of eminence in the secondary-school curriculum.

Since science can play such a vital role in the education of young people, one would expect to find increasing enrolments in secondary-school science courses. But this has not generally happened. In fact, there has been a decrease in the proportion of youth enrolled in science courses. It would seem, therefore, that the present science programs in the secondary schools should be critically re-examined in the light of the research in science teaching. The evidence thus obtained should provide bases for revising or designing programs which will more nearly meet the needs of youth and society. It is hoped that this pamphlet will aid in promoting such a forward undertaking.

WHAT SCIENCE SHOULD BE TAUGHT?

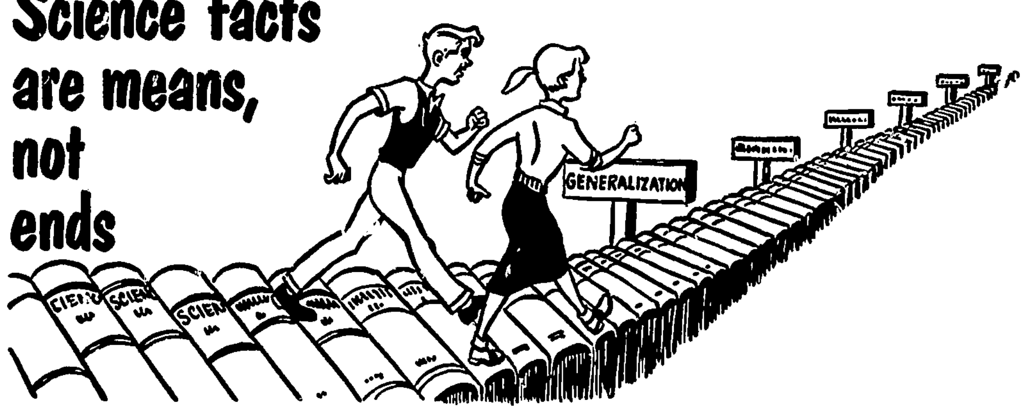
Altho the specific objectives of science, as they are listed in authoritative reports and courses of study for the public schools of America, are varied and extensive, they generally relate to three major types of objectives. Furthermore, these objectives are viewed as directional goals toward which the growth of young people should be guided thruout their science experiences in the schools.

Science Facts Are Means, Not Ends

One of the three general types of objectives deals with the content or subjectmatter of science. From the beginning of science instruction in the schools the so-called facts of science have been accepted objectives. Too often, however, they have been considered the only objectives—if not in theory, in actual practice. They have frequently been taught as specific and discrete items of information or as definitions. Science has thus become characterized as a factual course. For this, and other reasons, science courses have not generally been popular courses in high school. To counteract this situation, some have condemned facts as tho they should have no place in science teaching; but facts are indispensable. They are basic to an understanding of science and to the use of science in problem-solving.

In and of themselves, however, facts should not be considered the ultimate objectives. The ultimate objective is an understanding of the generalization which makes clear the relationship of a number of facts to the interpretation of a natural phenomenon. For example, there are many incidents in which one animal may be observed eating some form of plant. There are many incidents in which one specific animal may be observed eating or otherwise using another animal to maintain itself. One may read that green plants use carbon dioxide in manufacturing food. Furthermore, one may read, or observe thru indirect means, that human beings give off carbon dioxide as a waste product. Each of these may be considered a fact of science and possibly an interesting fact. But these facts individually have little meaning or significance in understanding the environment, or in solving problems related to use of our biotic resources. On the other hand they can have meaning when, thru guided learning experiences, they are related to an important generalization of biology: Living things are interdependent. This generalization in turn has significance when it is applied with understanding in making decisions regarding such questions as: Should we kill off the hawks in our community?

Science facts are means, not ends



Altho the reasoning above would seem to make a pretty good case for "understanding science generalization," there is other evidence even more convincing. It has been found that up to 70 percent of the specific facts learned in a science course are forgotten within one year after the completion of the course. The loss in understanding of generalizations and in ability to apply generalizations is very much less. In light of this evidence one research worker has pointed out that, since most final grades in science courses are assigned on the basis of scores made on factual examinations, the A's are given to the student who is going to forget the most.

A Basis for Selecting Generalizations

In terms of the subjectmatter objectives of science it is quite obvious that science teachers should be teaching for growth in understanding generalizations of science. There are numerous and extensive published lists of selected science generalizations. Many of the generalizations are further defined as science principles. All lists have been prepared by research workers who followed carefully controlled technics. There are lists of generalizations or principles for biological science, physical science, general science, geology, entomology, earth science, conservation, and many others. No science teacher could teach even a small fraction of them. The lists have value, however, as authoritative sources from which the generalizations to be taught may be selected. Science teachers, therefore, must have some bases for selecting those generalizations or principles which would be suitable as learning goals in their courses.

There are at least two methods by which generalizations may be selected and used in science teaching. Each is based upon a rather clearly defined educational point of view. By one method the science teacher selects those generalizations which, in his judgment or in the judgment of experts, are most important for his students to understand. He then organizes his course to teach for an understanding of the selected generalizations. By the other method the science teacher considers first the personal and social problems which would form the organizational foci of the course or curriculum. He then uses those generalizations which have direct utility in solving the problems. Learning, as it relates to generalizations, may be as effective by the latter approach as by the former.

Competence in Science Requires Understanding

The second of the three general types of objectives in science teaching has to do with growth in abilities involved in using the methods of science. Objectives, such as critical thinking and scientific method, are related to this general type. These objectives are easily validated in terms of the general purpose of education in a democracy. They have long been found among those listed for courses of study in science. General practice in science classrooms, however, appears to be given little or no direction by a mere published commitment to these objectives in courses of study. Contrary to what the research shows, some teachers believe that the study of science by any method will concomitantly result in growth toward this objective, or that infrequent periodic lessons on scientific methods are adequate. Altho trained in science, other teachers have frankly admitted that they do not understand the objectives nor how they may be realized in science teaching.

Numerous attempts have been made to analyze and to formulate clear statements of the steps, elements, or aspects of the methods. Criticism from some educators has been leveled at these investigations. They would question the existence of a scientific method, contending as one scientist did, that "science is doing your best to get the answer, no holds barred." Others contend that there are identifiable behaviors which distinguish the methods by which scientists approach problems toward attainment of demonstrable, reliable solutions. These educators believe that such analyses provide meaningful clues to the abilities which one would have to possess in order to be an effective problem-solver in science. One investigator synthesized out of a number of lists 51 specific abilities involved in perceiving a problem, relating problems to previous experience, formulating hypotheses, testing hypotheses, deriving a conclusion, and applying generalizations. He found that one who possessed these abilities would be able to recognize conflicts with previous experience; state problems in his own words; define the problem; infer; select the most logical guess; differentiate among hypothesis, fact, superstition, and theory; clarify; organize data; devise experiments; establish experimental controls; generalize from specific data; and use generalizations in interpreting new situations.

The third general type of objective in science teaching is growth in the scientific attitudes. Altho on the practical level of classroom procedure it may be difficult to distinguish clearly between attitudes and methods, theoretically such distinction is made. These, too, have been explored thru research, and various lists have been developed. It has been demonstrated that guided experiences in science can lead to growth in attitudes which result in young people being more inclined to raise questions about things that are not understood, seek reliable explanations, suspend judgment until one has the best evidence available, weigh evidence, and consider and evaluate other points of view.

Development Should Be Continuous

Three general types of objectives are accepted for science teaching not only at the secondary-school level but also at the elementary-school and college levels as well. Children at the elementary-school level ask many questions related to science. They conduct scientific investigations at their level of development, generalize from observation in their science experiences, and evaluate evidence and conclusions. In the future, more and more young people will enter the secondary school with the formal development of their science learnings well under way. Classroom teachers at the secondary-school level must, therefore, obtain a better understanding of the nature of this development at the elementary-school level in order to insure its uninterrupted continuity.

Over the past 25 years a great deal of activity has been directed toward a clearer formulation of the purposes of general education at the college level and the function of science in helping to achieve them. A few colleges have moved into programs of general-education science with the expressed purpose of counteracting the specialized, compartmentalized nature of the science courses in the senior high school. College programs of general education, for the most part, accept the three general types of objectives discussed above as directional goals for their science programs. In light of this evidence and with the point of view of education as a continuous process of development, secondary-school science teachers hold a unique position between the elementary school and the college.

Secondary-School Programs Need Re-Examination

General science is now a standard offering from Grades VII thru IX. However, the amount of time allotted to it each week and the content of the courses vary from school to school. Results from standardized achievement tests reveal a significant gain in science learnings as pupils progress from Grade VII thru Grade IX. By the time most pupils have entered the tenth grade they have had some science instruction, but their backgrounds may be quite varied. Biology is the most commonly offered science course for tenth-graders, and about three-fourths of them take it. Chemistry and physics are generally offered in Grade XI and Grade XII respectively. About one-third of the eleventh-graders take chemistry and fewer of the twelfth-graders take physics.

A few high schools, mostly the larger ones, offer science courses other than general science, biology, chemistry, and physics. These have been designed to meet the assumed needs of certain students for generalized science courses beyond Grades VII thru IX and the interests of other students in prevocational science courses. Included among these courses are: applied chemistry, applied physics, applied science, aviation science, earth science, radio, photography, physical science, physiology, and plant science. Of these, the generalized or fused physical science course has probably been given attention in more senior high schools. The patterns of organization vary, but in most instances selected subjectmatter is drawn from both physics and chemistry and organized within contexts considered more functional for young people than the conventional chemistry and physics courses. In some schools the fused physical science is offered to the noncollege-bound student, even tho colleges often are willing to grant entrance credit for such courses.

It appears that secondary schools are moving toward a two-track pattern of science courses above the tenth grade: one pattern for general and special-interest education and another which includes chemistry and physics for college preparation. The following evidence, however, should cause teachers to question the validity of the trend. It has been shown that college students who have had chemistry and physics in high school will probably do no better in these courses than those who did not take them in high school. The pattern of courses studied in high school has been found less useful for advising college entrance than is the pattern of abilities of the high-school graduate.

WHAT METHODS SHOULD BE USED?

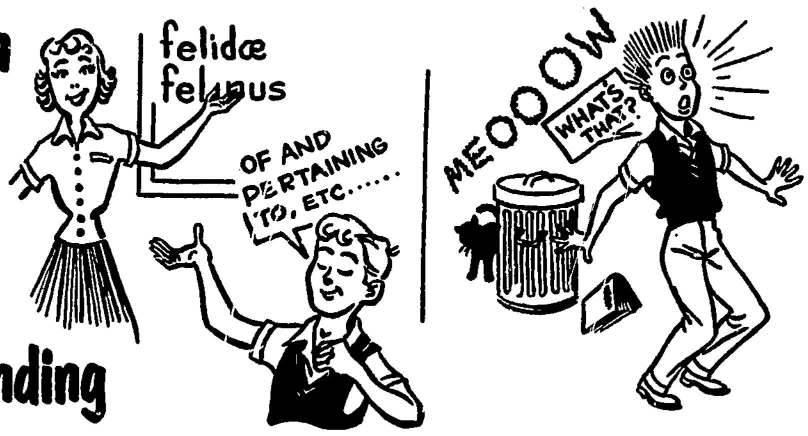
Comparative studies have been made to determine the relative effectiveness of numerous methods of teaching science. These studies have certain common features in their design and findings. One method, the so-called experimental method, is usually designed to incorporate technics which reflect currently accepted theory regarding learning. The other method, the so-called control method, is usually designed in terms of the investigator's concept of conventional classroom technics. Two or more classes of students with assumed or demonstrated equivalent abilities are used as the subjects. Tests, designed to measure achievement in one or more of the commonly accepted major objectives of science teaching, are usually administered to classes of students before and after the period of instruction by each of the methods. The relative effectiveness of the methods is judged in terms of gains from pretest to final test. In most comparisons the results are treated to determine the statistical significance of differences achieved by the methods.

Methods Are Related to Objectives

In most research studies where one method has been found to have an advantage over another, it was usually the experimental method. If the criterion for comparing the two methods is gain in factual knowledge, the method which puts the greater emphasis on this type of learning is usually found to be superior. If the criterion is understanding generalizations, the favored method is generally the one which provides more experiences in this type of learning. And so it goes with the other objectives. It would appear that the science teacher achieves the objectives for which he teaches. With the possible exception of rote learning of factual material, the superior method is usually the one by which the students are brought into more active participation.

The methods used by the science teacher are evaluated in terms of how well they achieve the objectives as conceived by the teacher. If the objectives are viewed as verbal competencies with the vocabulary, generalizations, methods, and attitudes of science so that definitions can be recited in class or correctly checked as true or false on an objective examination, a method characterized by much talk and drill would seem to be most appropriate.

Verbalism is not understanding



There is a distinction, however, between *verbalism* and *understanding* in science. Students may do very well on vocabulary tests covering factual information and fail miserably on tests designed to measure their understanding of generalizations and their ability to apply the attitudes and methods of science. As was pointed out earlier, the retention of factual information drops off rapidly after the period of instruction.

When, on the other hand, the objectives are viewed as behavior competencies and the generalizations, methods, and attitudes are used to change the way young people behave, quite different methods must be employed by the classroom teacher. If a science teacher believes that his students should grow in their ability to solve problems, he must design his course so that they will have guided conscious experiences in solving problems. If a science teacher believes that his students should grow in their use of scientific attitudes, they must have many experiences with choices of action where the attitudes are involved. If a science teacher believes that his students should grow in their understanding of selected generalizations of science and their ability to apply them, they must become actively involved in experiences out of which they "catch" the idea of the generalizations.

No One Method Can Be Universal

Among the various methods, which by controlled experiment have been found to be effective, no one can be proclaimed as unquestionably superior to the others. Because of differences among teachers, elements of one or several so-called methods may be highly effective when handled by one teacher but of questionable value in the hands of another. Differences in the ability levels of students must also be taken into account in deciding what technics will be used. It is more important that students of low-level abstract ability have a greater variety of direct, concrete experiences related to the objective to be achieved than those with higher abstract abilities. Yet this does not mean that the only experiences for even the superior student should be abstract intellectualizing. Teaching facilities and a variety of other factors enter into the teacher's decision regarding the technics he will use.

There is no *one* method of teaching science. Nor is there a method that will be equally effective for any one teacher in all teaching situations. The beginning teacher who assumes that during his first few years of teaching science he will develop an organization and a method which will serve him for the remainder of his professional career is doomed to disappointment. Science is dynamic. Students change from class to class and from year to year. The science teacher himself is undergoing change. It is inevitable that his technics of working with young people must frequently be evaluated and modified in ways to make his teaching more effective.

Understanding How Students Learn Science

In the past much value has been put upon the IQ as the basis for sectioning students into homogeneous groups for instruction in science. One might expect, therefore, to find a high relationship between IQ and achievement in science. This, however, does not always hold for individual students. Interest and purpose, coupled with a quality of neuro-muscular coordination appear to play a major role, along with high verbal and mathematical intelligence, in determining the potentially gifted in science. Home and school environments that provide enriched and challenging experiences interact with the individual to motivate and sustain personal interest in science and purpose to do something with it. The role of the classroom teacher and the technics which he uses in stimulating interest, and nurturing and guiding it are of supreme importance.

Furthermore, science teachers should not assume that students of any one age, grade, or intelligence level are similar in terms of other factors that affect learning. Their approach to learning experiences is as individualistic as their faces. The patterns they follow in solving problems are uniquely their own. A teacher may carefully set the stage for the presentation of a particular problem in science—even to stating the problem for his students. But he has no assurance that his, the teacher's problem, is the one which each student will accept as his own to solve. The teacher can also be reasonably sure that the student's intellectual effort will be directed toward the solution of his own accepted problem. Not until the student has satisfied himself about his own problem will he accept the teacher's problem. It may be that teachers, who are unaware of the individual's frame of reference as he cooperates in solving a class problem, will judge the quality of his contributions to be unsatisfactory, when in fact he may be doing a superior job of problem-solving within the context of his personal concept of the problem. It seems highly desirable, therefore, that group problem-solving (involving the cooperation of two or more people) in a science class should be preceded by give-and-take discussion in which each individual has opportunity to identify with the problem which is finally selected by the group to solve.

Not only the more formal experiences which youngsters have had in elementary science but also the many other experiences which they have had in a variety of home situations, in camps, in Scouting, and in various recreational activities, have affected in many ways the science concepts and misconceptions, as well as the problem-solving abilities which they possess when they enter the secondary school. In these respects, also, there are great individual differences, and these differences tend to broaden as students proceed thru the secondary school.

Importance of Student Participation

From the evidence it is clear that the teacher who ignores the myriad of individual differences that exist among students in his classes cannot do the most effective job of promoting their continuous development in science. If he assumes a norm and teaches to it alone, his work may be effective only for some hypothetical nonexistent learner. On the other hand, to make a thoro case study of each learner when he may have as many as 150 of them every day is expecting too much. He could, however, maintain permissiveness and flexibility in his methods of working with young people whereby the differences in background, in relative abilities, and in individualistic approaches to learning situations can be recognized and provided for in a variety of ways. It may well be that this interplay of variable individualistic factors related to learning accounts for teaching methods characterized by active student participation proving to be superior to teacher-dominated methods with respect to achieving growth in the behavior outcomes of science.

Teachers, however, may go overboard in their efforts to provide "freedom" in their classrooms; the result is confusion. Students become insecure, frustrated, and unhappy along with the teacher. In learning situations young people desire to see clearly the goals toward which they are working. In their activities students want the security that comes from the judicious guidance of a well-informed teacher. They seek the objective reactions of teachers in appraising their progress. The teacher plays the key role, altho a difficult one, in maintaining an effective balance among freedom, security, and control.

It should not be assumed that merely the will to work in such cooperative relationships with students insures success. When neither the students nor the teacher have had such experience, some elementary learning in group process must take place. As in all such learning, the first efforts may appear crude but become more refined with continued, meaningful practice. In some of the prerequisite skills involved in independent use of learning resources it may be necessary to take time for specific guided instruction. Where this has been done in such skills as locating reference material, reading for different purposes, note-taking and outlining, designing experiments, mathematical computations, and the like, the results have been highly satisfactory.

HOW SHOULD THE MATERIALS AND FACILITIES BE USED?

Few curriculums at the secondary level can provide as many opportunities for learning thru direct experience as science—the situations and the materials are on every hand. Altho a great many direct-learning experiences have been reported in the research, reading is common to most successful science programs.

Necessary Guidance in Using Textbooks

The science textbook provides basic reading experiences in most science classes at the secondary level. Altho these textbooks may differ in their manner of organization and treatment, there is greater standardization of content than in elementary science textbooks.

There is evidence that the different science texts published for any one grade vary in reading difficulty; furthermore, that the reading difficulty of any one text may vary from one section of the text to another. None of these studies has taken into consideration all the variables that determine reading difficulty—and the most important one of how the teacher will use the text. That young people be left "on their own" is questionable.

Textbooks contain a variety of materials and technics to aid the reader in getting meaning from what he reads. These aids include pictures, diagrams, cross references, glossaries, and the like. Comparatively few science pupils are ever taught how to use these aids. However, when science teachers take time to give their students organized instruction in how to use them, it pays high educational dividends. The slogan "every teacher, a teacher of reading" is a valid one when applied to secondary-school science. No longer should it be assumed that all students have learned to read to the maximum of their abilities by the time they complete the elementary school.

Reading is a complex ability, conditioned by many factors and continuous in its development. Nor should science teachers ignore the very poor readers in their classes and resort entirely to verbal communication supplemented with nonreading experiences in science. As has been demonstrated on the elementary level, interesting science activities can often be used to motivate the nonreader and supply meaningful content for his level.

Values of Supplementary Materials

Reading experiences in science should not be limited to the basic text. Demonstrations have shown that planned programs of extensive reading contribute to achievement in various outcomes of science teaching, even to growth in scientific attitudes. There is a wealth of nongraded material that can be used to provide extensive reading experiences in science. Popular books in science, for children and adults, provide for a wide range of reading experiences in terms of both reading difficulty and subjectmatter. When these materials are readily available for children to make a free choice, they tend to select those that supply information related to their specific interests. And it has been found that thru such a free reading program their interests tend to broaden.

Business- and agency-sponsored reading materials are numerous. A large majority of the science teachers who have used these materials have found them useful in broadening and deepening their own understanding of science and technology in modern living. These materials have been judged by most teachers to be useful to students in their science classes altho some materials were considered better than others on the basis of simplicity, attractiveness, and the ease with which they can be stored.

Study Guides Are Useful

As is true with science textbooks, study guides vary in organization and in the learning outcomes they emphasize. Most of them have been designed to provide learning activities which supplement the textbook. Altho workbooks have vigorously been condemned in many quarters, there is little research evidence to support this point of view. In fact, there is some evidence that the proper use of workbooks has favorable effects upon subjectmatter achievement in general science. When achievement in attitudes and in problem-solving abilities was the basis of comparison, a student-teacher developed study guide was found to be superior to a teacher-prepared study guide in teaching general science.

The Laboratory Serves for Problem-Solving

Many studies have been done and much has been written about the relative merits of lecture-demonstration and individual laboratory methods of teaching science. The accumulated evidence does not conclusively favor one method over the other. Whether one method were to be judged superior to the other would seem to depend upon the objectives sought and the conditions under which the course was taught.

It is doubtful that individual laboratory work that follows a cookbook procedure can do much more to achieve behavioral objectives of problem-solving and scientific attitudes than good lecture-demonstrations. On the other hand, if the laboratory is to serve a function for the student, similar to the one it serves for the scientist, it must become a place to solve problems. If this were to be the concept of the science laboratory in the secondary school, the laboratory would become just as important a facility for teaching science as the basketball court is for teaching young people how to play basketball.

The Classroom as a Work Center

For a long time science classrooms have been designed for recitation, discussion, demonstration, and other types of activities in which the entire class is handled as a unit engaged in the same activity under rather complete teacher domination. Research, however, indicates the desirability of the science classroom becoming a work center. In this work center, there would be occasions when the entire class would engage in one type of activity. On other occasions individual students or small groups of students would be working on different kinds of activities. Some might be working on experiments, others might be working with reference materials, still others might be writing reports or obtaining special instruction from the teacher. It is obvious that in such a classroom work center, a variety of facilities must be available, including those formerly reserved for use in a laboratory on a prearranged day schedule. The room would be equipped with furniture that could be arranged to serve the students best in different types of learning activities.

Science resources are found in many places

It has been demonstrated that, under the guidance of a creative resourceful classroom teacher, inexpensive materials from the junk yard and dime store can be used effectively to supplement the science equipment of the school. Well-equipped science rooms are highly desirable but, in or of themselves, do not give vitality to the science program.

Effective Use of Audio-Visual Materials

Motion pictures and filmstrips are the commonly used audio-visual aids in science classes. Science teachers have difficulty, however, in making effective use of the general run of teaching films made available to them. They have found many such films unsatisfactory because of subjectmatter content, quality of script, quality of production, obsolescence, vocabulary difficulty, and advertising. In an analysis of 24 films, previously selected as the best ones for use in science classes, 44 percent were found to serve no unique or specialized function and contributed to none of the three major objectives of science in the secondary school. In another study of a carefully selected group of filmstrips, less than half the frames made any contribution to scientific principles, methods, or attitudes. The major purpose of most filmstrips seemed to be that of a topical organization of subjectmatter. This evidence indicates that film should be carefully selected, and, when it is not possible for the teacher to be sure of the quality of a film, he should not gamble with class time which could be spent more profitably in other kinds of activity.

Carefully selected films, however, may have educational value in science classes. Selected sound motion pictures have been found to be as effective as teacher demonstrations in certain learning situations. Some films, if properly selected and used, can present facts and concepts not taught by other methods. In all instances, however, where selected films have yielded equivalent or better results than by other technics, the films have been used in accordance with a carefully prepared plan involving student preparation and follow-up.

The findings of research on use of radio programs as learning aids in science teaching parallel, in many ways, those for use of motion pictures. When radio programs are carefully selected with some definite purposes in mind; when students are properly prepared for listening; and, when there is some reliable follow-up, they do have educational value in science teaching.

Significance in Out-of-School Activities

Organized out-of-school activities of young people, such as camping, Boy Scout and Girl Scout activities, have been found to have close relationship to science activities in the secondary school. For example, when a composite list of general science activities was compared with the activities of a selected camp, it was found that 75 percent of the general science activities were treated at camp with parallel activities.

There are many instances where secondary-school science programs have been greatly enriched by using community resources. Field trips to agencies, industries, and natural environments of various types, if properly planned and conducted, develop interests, raise problems, supply information, and contribute to an understanding of the role of science in the welfare of the local community. Local communities also provide opportunity for young people to become involved in problems—real problems related to health, conservation, and safety—that will lead to action resulting in the improvement of the community. Where this has happened, it resulted in great satisfaction for students, teachers, and the community.

Enrichment thru Resource Units

Resource units are a type of facility many science teachers have found helpful in guiding the learning experiences of young people into an area of study which may be treated inadequately, if at all, in science textbooks. Resource units in health—or some special aspect of it such as polio, conservation, and atomic energy—have been reported. The unit may be prepared by one teacher or a group of cooperating teachers. It generally contains a clear definition of the area to be covered, specific aspects to be dealt with, a collection of pertinent materials, descriptions of activities, and a list of outcomes to be achieved along with suggestions for determining whether they were achieved.

WHAT DIFFERENCE DOES IT MAKE?

If the concept of learning as changed behavior is valid, instruction in science should modify the behavior of young people in ways defined by the general objectives. In other words, young people should grow in their ability to use science generalizations. They should grow in their ability to apply the methods of science in solving problems. Their development should be increasingly characterized by the predisposition to ask questions, to be open-minded, to suspend judgment, and to weigh evidence. If the science program is effective, young people will be different in these ways. If a science teacher is to know about the effectiveness of his teaching or the achievement of an individual in his course, he must use some means of determining the extent to which young people become different in these directions.

Factual Tests May Not Measure Behavioral Outcomes

Thruout the history of education, tests or examinations have been used to determine achievement. Tests of many types have been designed to measure the outcomes of science teaching; the most widely used are tests to measure the memorization of facts. Tests to measure understanding and ability to apply generalizations are less common, whereas those to measure abilities to use the attitudes and methods of science are used least frequently. As was pointed out previously, students soon forget factual science information when it is unrelated to broader and deeper understanding. Tests designed solely to measure this outcome could more properly be designated as tests to measure what students are going to forget. It might be argued, on the other hand, that facts are basic to understanding the generalizations of science and to using the attitudes and methods of science. Therefore, you teach facts, test for the facts, and the other learnings will concomitantly be realized. This argument has no support in research; there is a good deal of evidence to the contrary. For example, in one study of 300 physics students in 34 schools it was found that 70 percent memorized satisfactorily but only 17 percent really understood. Other studies have shown that traits associated with application of generalizations are not identical with those associated with recall. Nor do attitudes and abilities in using the methods of science develop automatically with increase in the factual knowledge of science.

Making Objectives Vital

A fundamental prerequisite for change in emphasis in science teaching is for science teachers conscientiously to seek to understand the implications of the objectives of science in terms of the behavior of young people. If a person understood a certain generalization of science, how would you expect him to behave in different situations where the generalization applied? In a problematic situation what would a person do who solves problems by using the methods of science? In situations where choices of action are involved, how would a person act who was guided in his behavior by scientific attitudes? In planning science experiences that will help young people develop in the direction of the accepted objectives of science teaching, it is necessary for teachers to ask themselves such questions as these. In designing tests and other means of measuring growth or achievement in science, these same types of questions must serve as guides.

Where teachers have turned their attention to the development of evaluative procedures by an analysis of the objectives of science to determine the behaviors which are implied by these objectives, the process has had great impact upon the way in which they subsequently worked with young people in their classes. Once teachers have a clearer understanding of the kinds of situations in which a generalization of science applies, they begin to use experiences in such situations as the avenues thru which the pupil may come to understand the generalization. Once teachers have a clearer idea of the behaviors which characterize a person who is using the methods of science, they begin to plan learning experiences in which young people practice the behaviors. Once teachers become alert to instances in the lives of young people where they should be exercising intellectual curiosity, where they should be asking searching questions, where they should be open-minded in situations that are charged with strong prejudices, where there is real need to weigh evidence, and where there may be tendencies to jump to conclusions rather than to suspend judgment until sufficient evidence is obtained, teachers will be more apt to use such instances in their teaching and to guide learning toward the development of these behaviors.

Appraisal thru Many Means

By the analytical processes described above, objective-type tests of reasonable validity and reliability have been prepared and used for evaluating achievement in the behavioral objectives of science teaching. In order to construct such tests, it has generally been necessary to describe in the test a number of situations to which the person taking the test will react by marking test items in accordance with a more or less elaborate pattern of instructions. For the person to understand clearly the test situation as well as the instructions for marking the test items he must be able to read. It may be that many of these tests are more nearly tests of reading ability than of achievement of the objective for which they were designed.

Efforts have been made to prepare behavioral tests by using pictures, filmstrips, and motion pictures to set test situations to which the student is to react. It is believed that these types of tests may more nearly simulate life situations and may be influenced less by reading ability.

Most tests have been prepared and most testing programs have been conducted to measure the end products of learning. It would seem, however, that an effective evaluation program should throw some light upon what happens to the individual in the processes by which he arrived at his end products. Some commendable efforts have been made in this direction. Technics have been developed for observing, and recording rather objectively on check sheets, the number and quality of reactions of individuals in a class as they engage, day by day, in science experiences. Tape recordings made periodically of classes have also been used. These have some advantages over direct observation and recording on checklists. The recordings can be played back many times for analysis and study.

Altho we have moved away from the old essay examination in which students wrote answers to specific questions, it has been found that considerable information about the behavior of individual students can be obtained from what they write. This is especially true when they are asked to write what they would do in different kinds of selected situations. Their writings represent their "free responses," unconditioned by a series of test items which they are to mark. There are technics for evaluating such responses which make it possible to assign reliable comparative quantitative scores.

Periodic individual diaries of out-of-class activities have also been used as a means of obtaining evidence on behavior changes resulting from science instruction. These have been especially useful in obtaining evidence on dietary changes resulting from a study of units on nutrition.

Just as there is no one method of teaching science, there is no one way of evaluating the development of young people in science. He who seeks the one magic formula is inviting disappointment. There are many technics, however, for obtaining insights into the effect of the science program on the behavior of young people. If any technic is to have the faintest semblance of validity, however, young people must be put into simulated or actual situations where they can demonstrate their behavior.

Student Participation in Evaluation

If evaluation is to serve an educational purpose other than mere rationalization for assigning a grade, the person being evaluated must become involved in a more real way than merely taking the test, writing statements, or being observed. He, too, must be made conscious of the objectives and of the behaviors which are implied by the objectives. He must have an opportunity to examine and discuss his performance on examinations. Generally it is by this process that he learns best what the behavioral goals are. By the questions he raises on items he marked "incorrectly" the teacher can obtain even greater insight into his thought and action patterns.

Checklists, upon which students evaluate their own progress and list the evidences upon which they based this evaluation, have been found to be effective. This technic is especially useful where the teacher also evaluates the student and they talk out their comparative evaluations. The effectiveness of such a cooperative evaluation procedure is minimized when the ultimate evaluation must be expressed in a single score or letter grade.

Integrating Evaluation with Learning

Evaluation is basic to the total educational experience in science. It is the procedure by which the progress of students and the effectiveness of the program are judged; it is not something that happens toward the end of the learning period. The basis for it is established in the planning of the course, unit, or specific learning experience. The identification of behaviors that will be involved interact with the teacher's selection of learning experiences in a sensible manner. The evaluative process itself is a part of the total activity of the teacher and of the student.

HOW DOES ONE BECOME A SUCCESSFUL SCIENCE TEACHER?

The distinctive role of the classroom teacher in developing and maintaining effective science programs at the secondary level is quite obvious. Little will be done with what research "says" about science teaching except as teachers feel predisposed and develop the essential competencies. These are critical times in science teaching.

Broad Backgrounds Are Necessary

One way in which far too many high-school teachers become science teachers is by having a science class assigned to them as a part of their major teaching load in some other field. Similarly many science teachers are also assigned to teach other courses in the high school. In fact, part-time science teachers in our schools actually outnumber the full-time science teachers. To be acceptable for a science teaching position in most schools, one should be qualified to teach in some other field—usually mathematics.

Most high-school science teachers will teach general science either as a full- or part-time responsibility. When the content of general science is compared with the preservice science which certified teachers have taken, there are some obvious blank spots in their subjectmatter preparation. The most common ones are astronomy, geology, meteorology, and bacteriology—areas from which 25 percent of the topics in general science are drawn. Altho a science teacher may have his major training in biology, or chemistry, or physics, the chances are that he will have to teach courses in one or more of the other fields. It would seem that, if one were to become a capable high-school science teacher, a broad background in the sciences would be one major qualification.

Difficulty in Applying Theory

Science teachers may accept the theory but find its application difficult. Most science teachers accept the point of view that science could be more meaningful and more functional if courses were organized around problems of personal and social significance to young people. They report, however, great difficulty in making the transition from their own subject-centered, compartmentalized science training to such a problem organization. Many try but few of them succeed.

In theory at least, science teachers will accept the effective teacher as one who guides students in cooperative learning ventures. They may also agree that the laboratory and the classroom should more properly become work centers where young people, with various needs, interests, and abilities, have vital experiences in science. But mere belief in such a theory is not the sole prerequisite for putting such things into practice. The classroom teacher must have professional know-how. Few science teachers, as a part of their preservice education, have had the opportunity to practice the competencies which would make it possible for them to function in such roles. In fact most of their education for teaching has been an open contradiction of such a teacher role.

An effective science teacher is one who uses related community resources and activities to enrich the science program. Teachers by and large accept the idea but report many difficulties in their efforts to implement it.

Continuous Education Necessary

To become a good science teacher, one should have a quality of preservice education not generally available in many institutions of higher learning from which science teachers come into the profession. Institutions that purport to educate science teachers should re-examine their programs. It may well be that the organization and content of science courses for prospective science teachers, as well as the methods used in those courses, should be distinctly different from the preparation offered to science majors for service in nonteaching fields.

To develop and maintain science teaching as the research indicates it should be carried on at the secondary level, will require planned inservice education for science teachers and their supervisory personnel. The recognized needs of science teachers for inservice assistance arranged in order of their importance include: relating science to the lives of young people; organizing content and developing methods to achieve the objectives of science teaching; evaluating for objectives other than factual assimilation; providing diversified pupil activity; and understanding the adolescent, his drives and interests. More and more, school administrators are assuming obligation for inservice programs to meet these needs of their teachers. This is being done by teacher-conducted curriculum study, supplemented by workshops and consultant service. Science teachers report that these inservice programs have assisted them in their efforts to improve their effectiveness as science teachers.

It would seem that one never becomes a successful science teacher in the sense that he arrives, sits back, and rests upon his achievements. Advancements in educational theory and our knowledge of young people are exceeded only by the rapid advancements in science and technology. Education and science are dynamic, and he who would become successful in a profession that weds the two can never become static. A truly successful science teacher is always in the process of becoming a better teacher. The education of science teachers should begin with a distinctively designed preservice education and be continued thruout the period of their professional services in the schools.

PROBLEMS FOR FURTHER STUDY

Because of the nature of their training, science teachers should feel more greatly both the need for research in teaching and the urge to do some of it than any other teachers in the secondary school. This may, in part, account for the extensive research in science teaching. Science teachers might also be expected to produce the finest types of educational research. Altho we know a great deal more today about science teaching than was known 50 years ago, there are many questions still unanswered. Some have never been investigated and others investigated only in a superficial manner.

Among the general references listed on page 32 are digests and reviews of selected research in science teaching. These are most helpful to one who feels a need for background.

The numbers in parentheses below refer to citations listed under "Selected Research References," page 31.

1. *What factors account for success in learning science?* Altho progress in the study of science is related to intelligence, ability to read, experiential background, and sustained application, Beauchamp (1), in an extensive study, found many exceptions to this general relationship. He concluded that individual progress can be interpreted only in light of observations of the individual's methods of work.

2. *Is the vocabulary in science textbooks too difficult?* From 100 separate investigations of the vocabulary of science textbooks for junior and senior high schools Curtis (3) reported that the vocabularies were too difficult for the students for whom they were intended. Other teachers can use the technics he developed for studying the vocabulary difficulty of the textbooks they are using.

3. *What factors determine effectiveness in science teaching?* Davis (4) synthesized from a number of authoritative sources a list of 17 factors related to effectiveness of a learning situation. Science teachers may find this list helpful in a systematic evaluation of their own teaching.

4. *What is the value of field trips?* Harvey (5) found that, when pupils in an experimental group in junior high-school science went on field trips as a part of a unit in conservation, they did significantly better on scientific attitudes tests than pupils in a control group who experienced regular classroom procedures on comparable material with the same teacher.

5. *What kinds of experiences will lead to an understanding of principles?* Smith (6) brought together and evaluated 248 "experiments" from workbooks and textbooks in general science. He found that these "experiments" would contribute to an understanding of 109 out of 212 principles in varying degrees.

6. *In what ways can the talented students in science be identified and their development provided for in the high school?* Brown and Johnson (2) reported that characteristics, such as extraordinary memory, intellectual curiosity, persistency, insight into abstractions, the ability to do abstract thinking on a high level, the ability to translate data into generalizations, and the ability to apply knowledge to new situations, have been used successfully by teachers in identifying the student with outstanding ability in science. Many in-class and out-of-class activities have been found effective in making educational provisions for the talented in science.

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