Research in Review

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Science Education

INTELLIGENT living and participation in the events of the world today call for a literacy that encompasses considerable success in relation to the objectives of science education. Stated variously, the purposes include helping students (a) learn and understand concepts, principles and generalizations descriptive of our physical universe; (b) develop skills useful in discovering and validating knowledge; and (c) develop attitudes consistent with scientific knowledge and sound methods of inquiry.

Though our nation has made remarkable advances in science and technology, there is discouraging evidence that a very large proportion of youth and adults today are at an immature level of understanding with respect to the nature of science. Thus, there is a real need to examine and reexamine our current teaching practices.

In science teaching, as in other areas of instruction, teachers tend to perpetuate their own experience with the subject. Often this means teaching conventional subject matter in conventional ways with the hope that pupils are achieving in relation to the accepted objectives. The hope is sometimes, but not always, well founded. There continues to be a healthy doubt among many teachers as to whether the conventional content is appropriate and the methods effective. It is not surprising, then, that current research in science education continues to deal with the perennial questions of what should be the content and what should be the teaching procedures at every level of schooling.

The current relook at *what* to teach throughout the elementary and secondary school has doubtless been stimulated by an awareness that the sheer quantity of scientific knowledge continues to grow tremendously each year. No pupil can learn more than a small part of what is known. Selection is necessary. Thus a trend toward more careful selection of concepts is in the offing: Are certain concepts more basic than others? Which concepts are essentially simpler and can be learned with fewer prerequisite experiences? Which are more complex? Though several current studies related to this aspect of science education are being made by curriculum committees and research groups, they will not be reviewed in this summary.

As it has become clearer that the study of science cannot (and indeed should not) result simply in encyclopedic knowledge about the universe, more persuasive arguments are being given on the importance of helping pupils learn and understand the processes and procedures used by scientists. What are these processes and, to the extent that they can be generalized, how can they be taught and learned? It is in this context that several research studies have been selected for brief review and comment.

In a study of the ability of fifth grade children to "discover through inquiry," Suchman (7 and 8) found that they lacked basic intellectual skills to probe systematically into questions and problems. Their marked lack of autonomy and productivity seemed to stem from their dependence upon authorities, teachers, parents and books to shape their concepts. In his opinion, children rarely gathered more data, rarely raised and tested hypotheses or drew inferences. They "blocked" completely and began to offer unsupported conclusions. Possibly because they were accustomed to having concepts explained to them, the children were unwilling or unable to initiate action with the purpose of discovering for themselves.

This situation prompted Suchman to develop a procedure of inquiry training designed to help pupils develop generalizable intellectual approaches to discovering knowledge. In the training program, children view short motion picture films of physics demonstrations that pose problems of causality. They are asked to discover why the demonstration had the results that it did. They learn how to attack problems, how to inquire into the conditions for the event and how to search for universal physical principles underlying the relationships observed. They are taught how to identify goals toward which inquiry should be directed for greatest productivity.

To move toward these goals children require additional information. They get this by asking questions in a form that can be answered either "yes" or "no." This procedure requires the "discoverer" to formulate an hypothesis of some kind. It tends also to eliminate teacher-structured answers which may take the direction and control of data flow out of the minds of the children.

The pupils are assisted in learning to become "autonomous inquirers." To be successful requires the ability to formulate a "search plan," to ask fruitful questions, to discover pertinent data, and gain confidence that there are ways of pursuing difficult questions. It was found that early successes in autonomous discovery had enormous motivational value.

As the children learned how to use the inquiry training scheme they overcame their initial blocking and designed sequences of related questions with increasing ease. Their questions also became more precise and controlled. As training progressed, they showed increasing willingness to pursue difficult problems for long periods. They found themselves discovering workable generalizations that permitted them to predict and control physical events with increasing speed and accuracy.

Suchman reports that most of the children who receive training become more productive in their design and use of verification and experimentation. They develop a fairly consistent strategy which they can transfer to new problem situations. They make fewer untested assumptions and they formulate and test more hypotheses.

However, Suchman points out that children have little apparent desire to improve their inquiry skills *per se*. The chief motivating force is the desire to comprehend the causation of the observed episodes. Wherever inquiry is not directly related to the satisfaction of their need to find out *why*, they show little interest in the strategies and tactics being discussed.

The role of the hypothesis in learning has been studied also by other investigators. For example, Atkin's (1) analysis of the development of selected aspects of problem solving revealed that elementary school children tend to express hypotheses of their own after having science learning experiences. The study was based on an analysis of tape recordings of children in grades 1, 3 and 6. He found that children in the lower grades rely more on their own experience in formulating hypotheses, whereas those in the upper grades depend more on authority. Children in the lower grades suggested more tests for their hypotheses than did children in the upper grades. He reported also that children in "permissive" classrooms tend to suggest more hypotheses than children in the less permissive classrooms.

A study by Fonsworth (2) further illustrates the interest of science educators in improving the processes of thinking. He devised and tested procedures using "the reflective thinking approach" in teaching chemistry and compared the results with teaching procedures that emphasized acquisition of facts and principles. In experimental chemistry classes, students and teachers cooperated in selecting problems and methods of solving them and in acquiring the necessary skills and techniques. A "factual information" approach to the subject matter was employed in other groups.

Fonsworth concluded that the "reflective thinking approach" resulted in significant gains by students with respect to (a) growth in mental ability, (b) the application of abilities required in critical thinking and (c) the use of the scientific method in solving chemistry problems. Students in the experimental groups as well as those taught by a "factual information" approach made significant gains in the acquisition of facts and principles. But the investigator noted additional positive changes in the attitudes and behaviors of students in the experimental group that seemed to derive from experience with the "reflective thinking approach." This led him to conclude that, "since the totality of those changes are usually considered worthy objectives of democratic education, it is recommended that teaching methods be modified so as to emphasize reflective thinking."

The relative merits of *inductive* and *deductive* methods of teaching science continue to be explored. Sister Ernestine Marie (6) compared inductive and deductive methods of teaching high school chemistry using matched groups of students taught by different methods. One method featured "inductive class and laboratory teaching" and the other "deductive class and traditional laboratory teaching." Test results showed that classes taught by inductive methods showed significant superiority over classes taught deductively with respect to the full year's work in chemistry in general and with respect to a unit on chemical equation balancing in particular.

Neal (3) attempted to discover methods of developing skills of scientific inquiry in children. She selected and tested over 60 teaching techniques for their potential contribution to the growth of children in developing the ability to use methods of scientific inquiry such as recognizing and stating problems, selecting pertinent and adequate data, formulating and evaluating hypotheses, forming sound conclusions or stating correct concepts, applying concepts and seeing relationships.

The teaching involved children in making overviews of problems, demonstrating concepts, taking exploratory excursions, selecting readings, doing experiments, observing objects and processes, organizing ideas and determining criteria for evaluating their activities.

The techniques were evaluated through a study of children's written responses, creative expression, objective testing, and observation of overt behaviors which could justifiably be associated with the ability to use the methods of scientific inquiry.

Though Neal's study did not involve controlled and matched groups of children, it had the advantage of being conducted with normal classes in a normal elementary school situation. The data indicated that children can be aided through direct teaching procedures to identify and state problems, formulate plans to collect and evaluate data from a number of sources, formulate hypotheses, and to apply concepts and methods of inquiry in new situations. Also, there was a consistent pattern of growth for each method of scientific inquiry from grades four through six.

Clear thinking depends on the ability to identify and recognize assumptions. But can pupils be taught to identify and evaluate assumptions? Simendinger (5) gathered experimental evidence on this question. Her purpose was (a) to determine the effectiveness of two teaching techniques upon growth in the ability of eighth grade pupils to identify and evaluate assumptions, and (b) to compare growth in this ability with growth in general problem solving ability.

Three groups of pupils were taught by a problem solving method for 13 weeks. In one group, teacher-planned experimental exercises and assumptions were stressed. In a second group, pupil-planned exercises were used and assumptions were stressed. In the third group, teacher-planned exercises were used without emphasis on assumptions.

Simendinger concluded that unless emphasis is placed upon science assumptions, combined with pupil-planned experimental exercises, pupils will not be aware of these assumptions. Also, as a result of stress on science assumptions combined with either pupil or teacher-planned exercises, students will improve in general problem solving ability.

Further, it is possible to bring about significant growth in problem solving ability in normal teaching situations without loss of subject matter learning. The teaching technique using most pupil participation and stressing science assumptions, yields the greatest growth in the ability to identify and evaluate science assumptions. She cautioned, however, that training in science assumptions does not appear to transfer automatically to nonscience assumptions.

Summary and Implication

These few studies dealing with learning in science give support to the idea that if pupils are to develop skills of inquiry, of excellence in problem solving or in critical thinking, they must have consciously planned opportunities designed to achieve these abilities.

This point of view is reviewed nicely by Raths (4) who says that "we can best insure that curriculum processes have a problematic character if we are guided by some criteria for making assignments which emphasize thinking." He suggests a number of kinds of processes and activities in which pupils must be engaging if school is to contribute to growth in problem solving and thinking. Among these, for example, are *comparing, summarizing, imagining, planning, interpreting data,* and *doing research.* It is Raths' belief that such criteria are adaptable to all classes in the school, at every age level, and are relevant to all subject areas without exception.

Research studies reinforce the idea that if we expect pupils to become better inquirers, better questioners, better problem solvers, we must give conscious attention to developing these skills. The processes of learning must occur in an intellectually permissive atmosphere with much teacher-pupil, two-way communication about goals and procedures. When attention is directed to teaching skills of scientific procedures, students improve in these along with making substantial gains in subject matter. The question is no longer whether we should stress "processes of learning" over "learning subject matter." Rather, now we can move ahead with confidence, placing emphasis on pupils' processes of thinking and learning in various subject or problem areas, knowing that growth of content knowledge will follow richly in the wake of inquiry.

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Improving the Program

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is not enough. A year set aside for concentration on what constitutes good classroom teaching and how to bring it about would be a year well spent.

In connection with classroom teaching, *there is need at every level for better informed teachers.* The subject matter of science is indeed vast. No teacher at any level of instruction can possibly answer all of the questions asked of him. He is not expected to do so. If he recognizes his objectives he does not intend to be an automatic answering service. He exercises his leadership in helping students devise scientific plans for solving the problem but he cannot teach science if he does not know any, any more than he can teach arithmetic if he does not know the fundamental processes. A basic background that makes sensible leadership possible is necessary for success in teaching. There is no adequate substitute for a knowledge of science if the teacher expects success in teaching at any level of instruction.