

New Bases for Science Teaching

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Today there is more concern for the teaching of science than ever before in the history of education. This concern is not without cause. In the last twenty years civilization has progressed from an electrical age into an atomic age. National power rests upon science and technology, while millions of dollars support the scientific enterprise. Life as we now know it rests upon the foundation of science. It is therefore obvious that a modern science education is required for both the specialist and the layman.

Certainly, we must develop scientists to maintain the present civilization. One need only mention the disease "cancer" and the need for further scientific investigation becomes self-evident. But education in science for the specialist only is not sufficient. We must also educate the citizen, for in a democracy it is the citizens who are the ultimate policy-makers. Therefore large numbers of people must be educated to understand, and even pass general judgment on the work of specialists. The consequences of atomic fission and fusion, increasing longevity, and the exploration of space affect everyone.

It was, therefore, with alarm that educators and laymen alike treated the growing evidence that many science courses were inadequate. The concern for high school science courses was ably stated in 1960 by D. Wolfe, Executive Officer of the American Association for the Advancement of Science:

For some years there has been a growing gap between school teachers and administrators, on the one hand, and scholars and scientists on the other . . . Despite the interdependence of the two groups, there has been a gulf between them, with harmful consequences to the student. Schools have been cut off from the stimulating effect of close contact with research scholars who are advancing knowledge. Some courses — most notably those in mathematics and science — have grown sadly out of date and no longer give the student an adequate picture of current thinking and problems . . .¹

Inadequacies in Conventional Courses

Science in our schools has too often been taught as dogma, that scientific knowledge is certain, unchangeable, and not open to question. Conclusions have been given, but no understanding as to how these conclusions have come into existence has been fostered. "Fact" has been confused with "theory." Textbooks talk about "hypothesis," "theory," and "fact." "Hypothesis" has been defined as an insightful supposition. "Theory" has been defined as supposition supported by inconclusive evidence. "Fact" conveys the idea that the theory has been unquestionably proved. In reality, a "theory" does not become a "fact" but rather becomes another theory which is more adequate, comprehensive, and more inclusive. There has been confusion as to the distinction between a concept and a literal fact. Thus Mendel is credited with "discovering" the gene. The principles which form the frame of reference of the knowledge have been neglected. Students have been taught in biology that definite ratios of characteristics result from certain crosses. In reality this is a simplified situation. The results should be stated in terms of probabilities.

These are but some of the more obvious short-comings of science courses.

New Trends in the Science Classroom

What then are the new trends in the teaching of science? Generally speaking, it can be said that there is the attempt to teach

science courses that will reflect science as science actually is — not what an out-of-date textbook perceives science to be. Both process and conclusions are treated.

One of the more significant new trends in the teaching of science is fostering the idea that scientific knowledge is not absolute and unchanging. Many conclusions of science are, of course, built upon assumptions and there are areas where uncertainty and speculation underlie conclusions. It is true that many textbooks, in their opening sections, do mention the tentativeness of scientific conclusions; but then they go on to treat science as absolute. Statements such as “the inert elements do not form compounds” may be found. However in the materials of various newly developed science courses (such as the BSCS Biology,² PSSC Physics,³ CBA Chemistry,⁴ and Chem Study⁵) components of doubt are found throughout the texts. Scientific conclusions are shown to arise from experiment and observation, which in turn grow from problems. The problems come from gaps or contradictions found in previous knowledge. The new courses also show that scientists can err and much scientific investigation has come from attempts to correct such errors. They point out that the value of summarizing concepts lies in the type of questions that grow out of the concepts; and by answers found to these questions, the original concepts are replaced. Various phrases found in the Biological Sciences Curriculum Study illustrate the points just raised. Outright expressions of uncertainty are made, for example: “We do not know,” “We have been unable to discover how this happens,” “It is not certain how this happens.”

Classroom practice is affected in a number of ways by the new trends in science teaching. In the classroom, the emphasis is on the analysis of knowledge, as opposed to the passive reception of facts from the teacher or textbook. The function of the teacher in this situation is to teach the student how to learn and how to grasp an appreciation of the scientific enterprise in all its ramifications. The skill the teacher seeks to impart is that of asking questions which will enable the student to teach himself. Examples of such questions are:

- (1) What did the scientist do?
- (2) Why did he do it?
- (3) What other methods might have been used?

The teacher will encourage different answers from the students and the merits of these responses will then be considered. By this means, something of the nature of science will be learned and it may be demonstrated that majority opinion is not necessarily correct. The desirability of informed discussion, with consideration for opposing viewpoints, may be established.

One technique for stimulating insight into the scientific process involves the use of original scientific papers. In dealing with these, questions such as the following may be asked:

- (1) What inadequacies in existing concepts gave rise to the investigation?
- (2) On what assumption does the investigation rest?
- (3) What data are sought?
- (4) What related data are deemed to be irrelevant to the problem?
- (5) What are the conclusions of the investigation?
- (6) What new concepts arise from the conclusions?
- (7) What assumptions are these concepts based on?
- (8) What new problems arise from the new concepts? Do the new concepts contradict former knowledge; if they do, what new frame of reference is needed to resolve the contradiction?

The use of original papers presents problems, however. Papers produced many years ago may be written in styles difficult for the present-day high school student to understand. Moreover, the sentence structure of many scientific papers will be much more complex than the textbooks the students have been using. To overcome these difficulties, edited scientific papers can be profitably used, with sentence structure and vocabulary simplified, explanatory phrases added.

New Trends in the Science Laboratory

Some of the most important changes in the teaching of science are occurring in the areas of laboratory work. Traditionally, the high school lab demonstrated phenomena already known by the student, lab exercises usually followed the presentation of material in the classroom. Moreover, a rigid pattern was common — there was a definite beginning in the form of a problem stated, then the student was given explicit instructions in procedure and was expected to form final conclusions.

Such laboratory methods have usually given a misleading picture of science. In reality, the laboratory functions to test hypotheses; from the laboratory comes new ideas. Hypotheses may be proved wrong and from the unconfirmed hypotheses grow new ideas, which in their turn are subjected to tests. If the laboratory is to convey something of the nature of science, it is critical that the student experiences the difficulty of defining the problem, collecting and interpreting data, struggling with the unknown and dealing with tentativeness. In order to achieve these aims, many changes in the high school laboratory have been made. A significant proportion of the laboratory work precedes either classroom discussion or assigned readings. In other words, the laboratory is fulfilling more than a demonstration function, it is allowing the student to take part in the act of discovery.

Other laboratory methods permit the student to engage in genuine research projects. Various degrees of participation are possible. At the simplest level, the laboratory manual states the problem and describes in detail the procedures to be followed in order to arrive at the desired explanations. The student does not know the conclusions beforehand. At the next level, only the problem is stated. The student must decide upon the procedures to follow and materials to use in order to solve the problem at hand. At the most sophisticated level, neither the problem nor the method to be followed is given. The student is confronted with a phenomenon. He must formulate a problem, devise a method which promises to solve the problem and proceed toward the solution.

For example, the student might be given two bar magnets. Traditionally, he would be instructed to determine the polarity of the magnets, being given detailed information how to do so. He would be directed to suspend one magnet by a string and to bring the north-seeking pole of one magnet near the north-seeking pole of the other magnet. Then he would be told to bring the unlike poles of the magnets together. In contrast to such explicit instruction, the new approach to science teaching might deal with the situation in either of two ways. At the simpler level, the student would be directed to determine the details of the laws of magnetic attraction and repulsion. He would need to devise a method of determining the polarity of each magnet, and then by bringing the appropriate poles together, determine the laws of magnetic attraction and

repulsion. At the more sophisticated level, the student might be confronted with one bar magnet suspended from a string and another magnet nearby. Then, unaided he would discern the problem to be investigated, as well as the procedures to be followed in order to solve the problem.

The discussion of the approaches used in an investigation becomes an integral part of the laboratory. The student might consider various problems that arise from phenomena he has been studying. He might also suggest alternative problems and methods and finally devise a plan for further investigation.

Long-term research projects, many of them resulting in student discoveries, foster the art of investigation. The Biological Sciences Curriculum Study, for example, has produced various laboratory blocks, each providing for a program requiring a six-week block of time during which the student examines a particular problem in depth. Throughout each step of the investigation the teacher is encouraged to have the students think about the questions: *How? What? Where? and Why?*

Problems in Implementation

Many believe the aims and methods that have been outlined are indeed laudable. But the problem regarding the impossibility of covering the usual number of topics arises. Perhaps the best answer to this criticism is to ask another question. "Why is it desirable to cover the traditional number of topics?" If covering many topics superficially results in the student's obtaining a false or misleading impression of the discipline, would it not be advisable to use another approach? Moreover, much of what is known today is soon obsolete. It is estimated that the total number of scientific periodicals published in the world are in the order of 35,000 separate titles and that the number is growing at the rate of 5 to 10 per cent every year. In these periodicals there are published approximately three million scientific papers every year and the amount of this literature doubles every ten to fifteen years.⁶

The only answer to the problem of coverage is to teach the students how to learn independently. The student must be taught to read and study for himself. He must learn to ask significant questions of the material before him. He must not despair when he

finds contradictions in science, but rather understand such contradictions for what they are — rungs in the progress of science, the never-ending process of the approximation of reality. The new science courses have been designed to meet the challenges that arise in the attempt to portray science as it actually is. In classroom practice, however, there is some evidence that the new science courses are best suited to the superior student.⁷

In summary, it can be said that the changes in science teaching are an attempt to portray the scientific enterprise in all its ramifications. The processes and spirit which give birth to scientific knowledge are stressed. Not among the least of the benefits to emanate from the new spirit in the teaching of science are the values of search, regardless of discovery; independence of thought; and originality. The importance of excellence in the teaching of science cannot be overly stressed, for as Bronowski has stated:

The world today is made, it is powered by science;
and for any man to abdicate an interest in science
is to walk with open eyes towards slavery.⁸

References

1. N. B. Henry (ed.), *The Fifty-ninth Yearbook of the National Society for the Study of Education*, Chicago: University of Chicago Press, 1960, p. 13.
2. Biological Sciences Curriculum Study, *BSCS Green Version*, Chicago: Rand McNally, 1963; *BSCS Blue Version*, Boston: Houghton Mifflin, 1968; *BSCS Yellow Version*, New York: Harcourt, Brace & World, 1963.
3. Physical Science Study Committee, *Physics*, Boston: D. C. Heath & Co., 1965.
4. Chemical Bond Approach Project, *Chemical Systems*, New York: McGraw-Hill, 1964.
5. G. C. Pimental (ed.), *Chemistry An Experimental Science*, San Francisco; W. H. Freeman, 1963.
6. George S. Bonn, "Literature of Science and Technology," *In Encyclopedia of Science and Technology*, New York: McGraw-Hill, Vol. 7, 1966, 542-43; and Scott Adams and Dale B. Baker, "Mission and Discipline Orientation in Scientific Abstracting and Indexing Services," *Library Trends* (1968), 16, 311-312.
7. Dale D. Rathe, "Certain Physics Generalizations Desirable for Students to Attain Before Taking the PSSC High School Physics Course," *Science Education* (1965), 49, 127-137; and Michael J. Urichek, "Research Proposal: An Attempt to Evaluate the Success of the CBA and CHEMS Chemistry Courses," *Science Education* (1967), 51, 5-11.
8. J. Bronowski, *Science and Human Values*, New York: Messner, 1956, p. 13.