The Importance of Science in American Education

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ABOUT FOUR YEARS AGO the editor of one of our leading chemical journals said that the dramatic story of the atomic bomb had proved once again that most of the advances in pure or fundamental research (and by this he implied not only physics, but also biology, chemistry, and medicine) had been made by citizens of other countries, or by American citizens who had received their education in Europe, or by Europeans who had emigrated to the United States (*1*). Since I had my education in Europe and spent more than ten years in industry there before joining the faculty of Massachusetts Institute of Technology twenty-two years ago and, since then, have also had intimate contact with some of our largest industrial concerns, I feel that I can offer an explanation as to why the statement referred to is absolutely correct. I also hope that an unbiased analysis of this situation, which under prevailing world conditions must be disturbing to every loyal American citizen, may lead to a satisfactory solution.

This opinion is shared by many others. At a recent meeting sponsored by the American Institute of Chemists, the problem of whether present education properly trains chemists for industry was the main topic. When one participant was asked if our education gives a truly satisfactory preparation in fields other than the technical to chemists entering industry, he answered with a categorical no (*2*). Another speaker said that, although our education provides the fundamentals, it hardly shows us how to apply them (*3*). At the annual meeting of the American Pulp and Paper Mill Superintendents Association, the president of the American Society of Mechanical Engineers made the following statement, in his address on "Technical Knowledge Is not Enough": "In fact, I think it can be shown that our failure to recognize and respond to our broad responsibilities as citizens and human beings, our failure to understand that technical progress is not enough, is the key to many of our greatest difficulties in America today" (*4*). This was pointed out long ago by Plato, when he said, "The direction in which education starts a man will determine his future" (*5*).

Quite recently this was emphasized again by Don G. Mitchell, president of Sylvania Electric Products, Inc., in a speech he gave in November 1950, at Northeastern University. As he expressed it, what worries industry most is that so many are able to obtain degrees but are unable to express themselves concisely and logically, orally and on paper. Industry expects graduates to have a mature outlook and a realization that they are no longer children to be cared for but are individuals who must be worthy of their hire.

The situation may be viewed through the eyes of men who already have offered ample proof that their primary interest is the improvement of our educational systems. Recently the U. S. Commissioner of Education drew attention to the undeniable fact that a very great number of educational institutions still organize their curricula in watertight compartments, and that all efforts to penetrate the barriers between departments are jealously resisted (*6*). In an article of very recent date, a former college professor and president points out that we are far too reluctant to insist on those formative disciplines which alone can promise proficiency in doing and thinking, and that our schools are seriously crippled by the assumption that the acquiring of the skills and the understanding necessary for effective thinking and honorable living is really quite easy. He also expresses the opinion that the teacher's art should be to devise ways of imparting to the learners a respect for the basic wisdom of their forebears (*7*).

The basic difference between a German and an American university or college is that the latter permits the student to devote himself to a specialized branch of science or technology far too early, so that the last college years are used as preparation for an advanced specialized education, thereby cutting down the time that should be devoted to general education (*8*). Another essential difference between our training technique and that used in Europe is that we use systematic drilling as a method of instruction; this can provide sound knowledge, but is hardly likely to promote self-reliant thinking and the spirit of research. The excessive use of the textbook may also be criticized because it works in the same direction (*9*).

To find a truly satisfactory explanation for this difference, it is necessary to probe more deeply into the educational systems of Europe and the United States. First of all, it must be borne in mind that throughout most of Europe only those who have graduated from the *Gymnasium* or *Realschule* may enroll in a university or comparable technological institute. When graduating from one of these schools, which they have had to attend for eight years (having left grammar school at about ten or eleven), students have acquired a background of general education at least comparable to that of American students starting the junior year in college.

Having given this problem considerable thought ever since becoming fully acquainted with our educational system as a faculty member of the two leading technological institutions in the Commonwealth of Massachusetts, and also after having been closely connected with industry, where prosperity will always depend on the qualities acquired by the younger generation during their education, I have come to the conclusion that what we need more than anything else is to offer all students a more general appreciation of what science actually stands for. As President Conant, of Harvard University, has said:

> One of the difficulties in presenting science as part of general education at both the school and college level is that of selection. The progress in all the sciences in the last three hundred years has been so great that the factual information is enormous. Even the selection of the major principles to be expounded is no easy matter. Questions of the reality of atoms, molecules, electrons, neutrons, not to mention photons and light waves and three-dimensional space, we should want to postpone to a college course. And even at the college level some of us would doubt the student's ability to handle them adequately as part of science. Rather, we should direct our students to study philosophy to see the various types of current answers (*10*).

Perhaps of even greater importance for anyone interested in the problem of why science is essential in modern education are the following statements (*11*):

> What is needed are methods for imparting some knowledge of the Tactics and Strategy of Science to those who are not scientists. But even if we agree that it is not more knowledge about science (more facts and principles) but some understanding of science that is required by the general public our pedagogic problem is not solved. For there are two ways of probing into complex human activities and their products: one is to retrace the steps by which certain end results have been produced, the other is to dissect the result with the hope of revealing its structural pattern and exposing the logical relations of the component parts, and, incidentally, exposing also the inconsistencies and flaws. Philosophic and mathematical minds prefer the logical approach, but it is my belief that for nine people out of ten the historical method will yield more real understanding.
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> The objective would be to give a greater degree of understanding of science by the close study of a relatively few historical examples of the development of science.
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> The case histories would almost all be chosen from the early days in the evolution of the modern discipline, as for example certain aspects of chemistry in the eighteenth and nineteenth centuries. The advantages of this method of approach are twofold: first, relatively little factual knowledge is required either as regards the science in question or other sciences, and relatively little mathematics; second, in the early days one sees in clearest light the necessary fumblings of even intellectual giants when they are also pioneers; one comes to understand what science is by seeing how difficult it is in fact to carry out glib scientific precepts.

Along similar lines, I. Bernard Cohen, of Harvard, quite recently said that we can give students a more general appreciation of what science stands for by making them more familiar with the human side of those to whom we owe the greatest discoveries in science, and with the circumstances that led them to the accomplishments for which they are now famous (*12*). A few specific examples will lend support to my opinion that this would be the best way of demonstrating the importance of science in education.

Henry Louis Le Chatelier (1850–1936) pointed out that the factors most necessary for successful education are enthusiasm, judgment, imagination, and a large fund of organized knowledge. These factors must be imparted to the student by the teacher himself, because a textbook can never accomplish it (*13*).

In the Bakerian Lecture that Michael Faraday delivered in 1857 (*14*), he pointed out that, if a drop of a solution of phosphorus in carbon disulfide is added to a solution of gold chloride and the whole is well shaken together, the solution immediately becomes red. Although the solution was absolutely clear, Faraday concluded, on the basis of his knowledge of the reaction that must have taken place, that metallic gold should be present in the solution. On the assumption that this solution might be analogous to what looks like clean air in daylight but which in the dark will show the path of a concentrated beam of light, he placed the container of gold solution in a darkened room in front of a concentrated light source. The particles were then evident because the cone of light passing through the solution became visible, even though the illuminated particles themselves could not be individually distinguished because of their minuteness.

For fifty years thereafter the majority of scientists still claimed that the visibility of the light cone in such solutions was made possible only by the presence of impurities or comparatively large, suspended gold particles. One of the strongest supporters of this so-called solution theory was Richard Zsigmondy. By pure logical reasoning and strict adherence to the truth of experimental evidence, however, he was the first to prove and admit that he was wrong in his former deductions, and that the so-called heterogeneous theory of colloidal solutions, postulated many years before by Wilhelm Ostwald (*8*), was correct. He decided to replace the human eye with a microscope, place such a gold solution under it, and pass a concentrated beam of light through it. In the publication in which he discussed this experiment and in which he refuted the solution theory (*15*), he made the following statement:

> How entirely erroneous was this idea! A swarm of dancing gnats in a sunbeam will give one an idea of the motion of the gold particle in the solution. This motion gives an indication of the continuous mixing up of the fluid, and it lasts hours, weeks, months, and if the fluid is stable, even years.

Near the end of the year 1895 Wilhelm Konrad Roentgen, at that time professor of physics at the University of Wuerzburg in Bavaria, discovered that, if he placed crystals of barium-platino-cyanide near a Crookes tube, they became brilliantly fluorescent, even if he covered the tube with cloth. He also found that photographic plates, which had been well protected against light and had never been exposed, would show complete darkening after development if they had been left lying close to the covered tube when it was in use. This phenomenon had already been noticed previously by Sir William Crookes himself, who blamed the darkening on the manufacturer of the plates. When Roentgen found, however, that a piece of metal or bone placed between the Crookes tube and the photographic plate would show a white or slightly grayish reproduction of its shape on the developed plate, he immediately concluded that the tube was emitting rays invisible to the human eye, but capable of a reaction within the photographic emulsion. Furthermore, he concluded that this radiation must be of such a wavelength that it passed certain structures unhindered, but was absorbed by others to a greater or less degree, depending on their character. This is the basis for the discovery of the x-ray techniques now so important in many branches of science, including medicine.

Using these deductions, the German physicist Max von Laue theorized early in 1912 that the lattices of crystals which indicated a periodicity of about 10^{-8} cm should act as gratings for x-rays and diffract them in definite directions. By passing a narrow beam of x-rays through a crystal and placing a photographic plate behind it, it was found that the plate was covered with a regular pattern of spots. This was exactly what von Laue had predicted. With rotation of the crystal while the exposure was being made, the individual dots changed into a series of dots showing a well-defined pattern. From this discovery Peter Debye and P. Scherrer reasoned that the various dots are due to every crystal plane coming into a reflecting position, the reflection then being registered on the photographic plate, and that it should be possible to obtain a pattern suitable for an evaluation of the structure by placing powdered crystal in front of the x-ray beam. They further reasoned that by the law of probability all possible reflection angles should be available in such a powdered column, comparable to results obtained when a perfect crystal is rotated in front of the x-ray beam. This is the basis for the development of the so-called powder method (*16*).

Other discoveries offer excellent proof of the important part logical thinking plays in any field of scientific research. In 1889 two physicians found that the urine of dogs from which the pancreas gland had been removed became sweet in comparison to that of healthy animals. From this observation, they postulated that this must be due to the withdrawal from the body of a hormone that regulated the metabolism of carbohydrates. In 1921 it was discovered that extracts of partially degenerated pancreas glands contained this substance. Soon thereafter it was found that this substance, now known as insulin, could be extracted with alcohol and purified by fractional precipitation. The foundation for modern diabetes theory had been laid.

In another branch of medicine similar reasoning has quite recently made possible a new approach to the treatment of kidney stones; unquestionably, detailed reports pertaining thereto will be forthcoming in the near future.

The rubber latex industry offers additional proof of how much more important logical thinking is than anything else for the further development of science and technology. In the early 1920s it was known that cow's milk could be concentrated by careful evaporation, and even made into a powder by spray-drying. If such milk powder was dissolved in the proper quantity of water, milk of unchanged properties resulted. When the same experiment was carried out with the milk exuding from the rubber tree, little rubbery particles formed that adhered to each other readily and could not be put back into solution. The experiment was considered a failure and was discontinued. One young man who witnessed these tests decided to get to the bottom of the problem, so he carried out some chemical analyses and made microscopic studies. He found that the butterfat particles in cow's milk are much larger than the rubber hydrocarbon particles in latex. He also found that the casein, which acts as a coating for the emulsified butterfat particles, is present in higher concentration for a given amount of butterfat than the protein constituent of the latex in relation to the rubber particles. Since the latter are much smaller, the interface between emulsified rubber hydrocarbon and water is much greater than the interface in cow's milk. From these facts he drew the logical conclusion that the failure of the concentration experiment was quite independent of the chemical composition of the two emulsions, and was due only to the lack of a quantity of emulsifier sufficient to cover the much greater interface in the rubber latex. The only solution of the problem indicated by these results was to add an appropriate emulsifier, or protective colloid, to make up the difference in concentration. The experiment turned out successfully. The first concentrated, redispersible rubber latex had been made.

I might also mention that our entire wartime production of synthetic rubber would have been impossible if we had not had at our disposal all the information that led German scientists, on the basis of straight, logical thinking, to the development of the process of emulsion polymerization.

Some years ago it was found that gels made from a certain type of natural clay known as bentonite would, when spread out on an appropriate surface, form a very thin, coherent film upon desiccation. Although this film exhibited dielectric properties comparable to those of the best mica available, it had the drawback of completely degenerating in the presence of moisture. It was decided to find out what might be the reason for the difference between this film and natural mica. As a result of careful chemical analysis, x-ray diffraction studies, and ultramicroscopic observations, it became evident that the main reason for the difference was the lack of potassium ions in the synthetically formed system. As soon as these, or other ions comparable to potassium in size and charge, were introduced into the film by a simple chemical process, a product resulted that was comparable in every respect to the finest mica available. It was this material that helped our nation during World War II to overcome the serious shortage of natural mica, which had previously been imported from India (*17*).

I have selected these examples because a survey of the textbooks now used to educate our young people reveals a serious lack of this type of information. The inclusion of such material explains to the reader in terms he can understand, even if he does not intend to become a scientist, not only what science stands for and how new discoveries are made, but also on what logical reasoning the latter are based. This would give the educator a unique opportunity for impressing on his students that the introduction of the history of science into general education need not be limited to prospective scientists. Its main purpose would be to offer the younger generation factual evidence of the importance of clear and logical thinking in the evolution of mankind, and to impress on them that this deserves more respect than acquiring a command of mathematical equations, chemical formulas, and the like. It is of far greater significance in a general education than a smattering of specific sciences without the basis really to understand them. In a world such as ours it is our duty to change the educational system so that every citizen is taught science in a manner he can understand, and without unnecessary and frequently outdated dogmas. At the Regional Conference on Teacher Education and Professional Standards held at Harvard University on December 15, 1950, Finis E. Engleman, Connecticut Commissioner of Education, said that "in this time of international strain, children are likely to be our first casualties through neglect of education." The true purpose of education should be not to make living textbooks, so to speak, but to do what Socrates proclaimed—namely, to achieve individual independence and spiritual self-reliance. The true purpose of science always has been, and should remain, to serve life and not to dominate it. What we must do is to give our young people such a grounding in the philosophical principles on which the evolution of science is based as will prove to them that textbook knowledge alone is insufficient. To accomplish this we must change our curricula so that more emphasis is placed on the disciplines that teach proficiency in doing and thinking—for example, by offering courses on the historical development of science and technology and what has been accomplished thereby in other countries, as well as in our own.

In addition, we must also realize that such a change will be difficult, if at all possible, as long as those responsible for the selection of high-school headmasters and college and university presidents are more interested in satisfying political, religious, economic, and local interests than in obtaining for such positions individuals who can offer proof that they already have devoted, and are prepared to continue to devote, their lives primarily to science in education.

References

1. MURPHY, W. J. *Ind. Eng. Chem.*, **38**, 665 (1946).
2. BROWN, C. L. *Chemist*, **27**, 161 (1950).
3. FREY, A. M. *Ibid.*, 165.
4. CUNNINGHAM, J. D. *Paper Trade J.*, **131**, (9), 26 (1950).
5. PLATO. *The Dialogues of Plato*. Trans. by B. Jowett, Oxford Univ. Press (1892).
6. MCGRATH, E. J. *Sci. Monthly*, **71**, 118 (1950).
7. BELL, B. I. *Crisis in Education*. New York: McGraw-Hill (1949); *Life*, **89** (Oct. 16, 1950).
8. OSTWALD, WI. *Die Forderung des Tages*. Leipzig: Akad. Verlagsges (1911).
9. PLANCK, R. *Chem. Eng. News*, **27**, 1784 (1949).
10. CONANT, J. B. *Education in a Divided World*. Cambridge: Harvard Univ. Press (1948).
11. ———. *On Understanding Science*. New Haven: Yale Univ. Press (1947).
12. COHEN, I. B. Lecture presented at 258th mtg., New England Assoc. Chem. Teachers (Dec. 2, 1950).
13. HAUSER, E. A. *J. Chem. Education*, **28**, 208 (1951).
14. FARADAY, M. *Trans. Roy. Soc.*, **A147**, 145 (1857).
15. SIEDENTOPF, H., and ZSIGMONDY, R. *Ann. Physik*, **10**, 1 (1903).
16. HAUSER, E. A. *Colloidal Phenomena*. New York: McGraw-Hill (1939).
17. ———. *Chem. Rev.*, **37**, 287 (1945).

Technical Papers

Studies on Pollination of *Hevea Brasiliensis* in Puerto Rico[1]

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Although many studies of pollination in the Para rubber tree, *Hevea Brasiliensis* (Willd. ex Adr. Juss.) Muell. Arg., have been made, the actual method of pollination in nature has remained a puzzle. The fact that *Hevea* is monoecious, with the anthers and stigmas borne on the same inflorescence but in separate flowers, makes it necessary that a transfer of pollen occur. Moreover, the indication that at least certain clones are highly self-sterile makes it necessary that pollen be transferred not only from male to female flowers, but also from one tree to another, for sexual reproduction to occur.

Evidence has pointed strongly to insect pollination in Hevea. The flowers are colored, have a character-

[1] Cooperative investigation with the Division of Rubber Plant Investigations, BPISAE, Beltsville, Md.

[2] Administered by the Office of Experiment Stations, Agricultural Research Administration, USDA.