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Phoenix From Ashes: Chemistry in High School

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Survey

Phoenix From Ashes: Chemistry in High School

THE official emblem of the American Chemical Society is the phoenix. Egyptian mythology has it that this amazing bird lived in the deserts of Arabia for five or six hundred years, and when its time came to die it consumed itself in fire, only to rise renewed from its ashes and start another long life cycle. Chemistry is aptly represented by the fabled phoenix. Since its obscure beginnings in the musty cellars of alchemists it has renewed itself many times in response to the challenges of the times. In our own nuclear age the revival of chemistry teaching at the secondary level of education is being crystallized in various forms. The object of this paper is to acquaint the reader with its more dynamic assumptions, and its structure.

Two developments in the recent history of science have stimulated these new approaches in the teaching of chemistry: growth and dissatisfaction. The expansion of the horizons of chemistry has been prodigious. The body of chemical knowledge in 1960 was crystallized in some 132,000 scientific papers and reports. It is estimated that by 1970 that number will increase by more than fifty percent. Chemical knowledge is doubling every thirteen years.

The growth has been accompanied by increasing dissatisfaction with the teaching of chemistry. Dissatisfied criticism has been especially aimed at the needless duplication of high school and college freshman courses; at the minimal influence of the former on first-year college chemistry; at the lack of an effective unifying theme in high-school chemistry; and at current texts and manuals which one professor has described as merely handbooks with pictures.

Fully aware of these conditions, fifteen high school and eighteen college teachers met at Reed College, Portland, Oregon, from June 17 to 28, 1957, under the the sponsorship of the Division of Chemical Education of the American Chemical Society and the Crown Zellerbach Foundation. The main concern of this assembly was integration. They sought to correlate high-school and college-freshman chemistry. A subcommittee discussed, in particular, the formation of an outline for high school chemistry based on chemical bonds as the unifying theme. This idea was suggested by a paper read by Dr. Strong, now director of the Chemical Bond Approach (CBA) Project. This outline was eventually to become the backbone of the present CBA program, and was the most important recommendation of the assembled group.

Chemistry as taught in high school and first year college should, in the opinion of the Reed Conference members, have the following objectives: (1) Present the *fundamental principles* of chemistry not as memorizable data alone but also as a *logical construct*, with its own capacity to foster *intellectual discipline.* (2) Develop *analytical and critical thinking,* specially stressing logical and quantitative *relationships.* (3) Form a *scientifically literate citizenry.* This is to be attained mainly through (a) an *understanding* of the *methods* of science; (b) the *appreciation* of chemistry's role in modern civilization. (4) Identify *potential careers* in chemistry and related fields. (5) Stimulate *interest* in the *profession* of chemistry. (6) Provide *adequate preparation* for further studies requiring a *background* of chemistry.

The present trend is thus that chemistry should be taught with particular stress on its scientific value, and consequently as characterized by logic, quantification, empiricism, and articulation. Because chemistry is a science it is *logical.* This is emphasized by transferring attention from its technological and gadgetry aspects to its conceptual structure, that is, to the analyses and deductions involved in arriving at chemical conclusions. Because chemistry is a physical science, it is *quantified*, and therefore cannot be divorced from mathematics. On the contrary, it relies on mathematics for accuracy, precision, and abbreviated generalizations. Because it is an inductive science chemistry is *empirical*, knowing by doing, and confirming its conclusion by experimentaton. This accounts for the growing emphasis on *individual laboratory* even at the high school level, as against the "squad" approach of a decade ago. Finally, as a developed science chemistry is *articulate*; that is to say, capable of expressing fundamental concepts in clear and precise language understandable by the non-specialist, and likewise able to assimilate, even as a pedagogy, new techniques and new developments. This is the reason why today chemistry curricula are becoming more flexible, giving the teacher more freedom to adopt programs fitted to specific situations, and why there is more cooperative planning between elementary, high school and college chemistry faculties.

In the CBA program an effort is made to stimulate the inborn *curiosity* of the student. It supposes that any science, particularly chemistry, is more easily learned through *key concepts* correlated, and key ideas stressed, than by the memorization of data and information. The CBA program leans heavily on the belief that chemistry is by its nature fascinating, and that the students may be induced to recognize this from the very start. This of course presupposes that in late high school and early college the student has acquired sufficient logical development to be able to bring it to bear on his study of a natural science.

The logical approach to the study of chemistry acquires pedagogical consistency through a theme, the *chemical bond*. As a matter of fact, chemical bonding and valence are the two topics differentiating chemistry from the other natural experimental sciences. This does not mean, however, that the other fundamental topics like atomic volume and molecular geometry are excluded. Rather, by stressing the key differentiating factor in the science it becomes easier for the teacher to present chemistry as an independent discipline, and bring more into bold relief the role of such subordinate concepts as volume and structure. The chemical-bond concepts are built into a matrix of chemical facts, and are described in terms of the limiting models referred to as ionic, covalent, and metallic bonds. Such models are introduced early in the course and then the properties of elements and compounds are related to them and deduced from structure.

Besides bonds, *energy* is another fundamental concept stressed by the Chemical Bond Approach. For closely linked with the architecture of atoms and molecules are the energy manifestations of bodies which are in a way dependent on the former, at least to the point of altering the reactivity of chemical bodies.

This concept of energy leads to the study of kinetic molecular theory, and the parts played by temperature and thermal energy in chemical changes. The failure of heat of reaction to predict chemical reactions brings up the topic of the quantity known as free energy, but discussed in its most fundamental aspects alone. The application of free energy as a means of describing equilibrium systems is brought out, as well as the correlations between the equilibrium constant and change in free energy for a reaction.

Chemical facts in this new approach are presented not in isolation but encased in concepts which are themselves capable of generating other ideas. When, for example, the elements carbon and bromine are studied questions like the following are brought up: Why is it that when carbon combines with hydrogen to produce methane the product formed at room temperature is a gas like hydrogen rather than a solid like carbon? Or when bromine reacts with sodium why is the product a solid rather than a liquid, and what has happened to the red color of the bromine? Why is it that compounds have a set of properties which are not merely the sum of those of the components?

After a brief and elementary presentation of chemical stoichiometry and the kinetic molecular theory, the core of the CBA course is taken up with the study of chemical change as a function of chemical bonding. Covalent bond is treated first since covalent compounds can be synthesized from starting materials which themselves are covalently bonded. Methane is used by way of illustration because of its natural occurrence and the ease with which it can undergo substitution reactions. When introducing and discussing ionic bonding the concept of metallic bonding is likewise treated since, in general, ionic bonds are produced by the reaction of ionic compounds with metals. For illustrative material of this type of bonding the course suggests substances of considerable industrial value like sodium chloride and magnesium oxide.

After surveying the main bond types the periodic table is brought in and studied with profit. Only the first twenty elements are the object of this study to avoid the complications that arise from the presence of the transition elements. Then follows a study of ideas closely related to the bonding concepts: bond polarity, acidimetry and alkalimetry, the non-mathematical aspects of chemical equilibrium, and oxidation-reduction. The oxidation of ammonia to yield nitric acid provides a smooth transition to the concept of polyatomic ions.

By introducing the student to the cardinal ideas that govern chemical phenomena he is enabled to acquire early in his chemical training a sense of the satisfied possession of what appears to the layman a complicated maze of magical formularies. He is at the same time being shown how to utilize key concepts to correlate facts and to organize details so as to produce an understandable and well-digested body of chemical knowledge.

In its laboratory aspects the Chemical Bond Approach does develop some very essential attitudes and traits. Careless work is not tolerated, but neither is good technique worshipped. The real purpose of an experiment is to enable the student to propose restricted answers to a question, restricted by the very design of the experiment. This instills in the student the sound scientific principle that a natural and empirical science is neither all-knowing nor infallible. It is always limited by its assumptions, its incomplete knowledge of natural phenomena at the time the experiments are performed, and the imperfect precision of the instruments utilized. The morrow may bring new outlooks and new tools. But for that new challenge the scientist knows he may count on a rich background of assimilated experience.

Laboratory work is also presented as leaning heavily on observation and analysis. It instills the idea that the first time a student looks at a reaction he sees only *a part* of what is going on. Only patient observation will unravel the full meaning of Nature's hidden processes. Observation requires, of course, manipulation, but only as an aid to investigation which is fundamentally an intellectual process.

The CBA laboratory experiments are offered in the form of problems which the student is gradually taught to solve by himself. Some information from the laboratory and some from the existing literature are woven into a logical scheme based on a set of assumptions and, quite often, some mental model. The student thus learns that logical reasoning is what leads to the solution of problems.. In some instances the solution of the problem itself or some aspect of it opens up new paths to be explored. Where time and facilities allow the student is urged to follow up these "open-end" experiments. It is important to note that in such a system the experiments do not automatically lead to predetermined results known only to the teacher. Rather the student is trained to construct a line of argument which will stand up scientifically. At the same time, quantitative and reproducible work, while not made an end in itself, is still duly insisted on. Laboratory manipulations are similarly studied not for their own sakes but as means to solve chemical problems. .

The Chemical Bond Approach outlined at the Reed Conference acquired added impetus a year later, in 1958, when a second conference, held at Wesleyan University, Middletown, Connecticut, recommended introducing it on an experimental basis in as many high schools as possible, and evaluating its results during the summer of 1959.

During the summer of 1959 seventeen chemistry teachers spent six weeks at Reed College writing the draft of the text for the CBA program. This first trial edition was then tested in various high schools of the United States. The recommendations received were used in the preparation of the second revised edition. In August of 1961 the CBA staff met with various high school teachers to discuss further revisions of text and laboratory manual. Then Dr. Strong and Dr. Scott started working on the second-edition text. From February 15 through 17 of 1962 the staff and several high school teachers met on the campus of Earlham at Richmond, Indiana, to discuss the revised materials. On the basis of these discussions the final copy of the third edition manuscript will be prepared. This third edition will incorporate what has been learned through the trial programs. For the most part, the order of topics will be as in the present second edition. Greater continuity of development is being sought, as well as better linking of the text and laboratory work

Here in the Philippines the CBA course is still on a trial basis in some high schools. It was offered at the Ateneo de Manila to the participants of the Summer Institute sponsored by NSDB and the Asia Foundation in 1961, and again to those taking part in the 1962 Summer Institutes held at the Ateneo de Manila and the Ateneo de Davao College. Dr. William J. Schmitt, S.J. put out a trial Philippine edition of a CBA textbook in the summer of 1962.

A second new approach in the teaching of high-school chemistry in the United States is the *Chemical Education Material Study*, also known as the CHEM Study. This project was put forward by a committee set up in 1959, two years after the first CBA Reed Conference, by the American Chemical Society under the chairmanship of Professor A. B. Garrett of Ohio State University. The committee was asked to examine the objectives and content of high school chemistry courses with a view to producing a drastically improved course. The recommendations of this committee were submitted to the National Science Foundation (U.S.A.), along with a proposal from the University of California for a similar revision study of secondary-school chemistry. The NSF decided to finance the University of California study and at the same time to support the erection of a second study center at Harvey Mudd College, Claremont, California, with Dr. J. Arthur Campbell as director.

The CHEM Study is only one part of a series of studies to revise high-school science courses in the United States. This overall improvement program includes the Physical Science Study Curriculum (PSSC), the School Mathematics Study Committee (SMSC), the Biological Sciences Curriculum Study (BSCS), the Teaching Resources Development in Geology Study, and the Chemical Bond Approach Project (CBA). The CHEM Study is, in the mind of its originators, supplemental to and not in any sense competitive with the CBA project. As a matter of fact coordination was set up from the very beginning.

The Steering Committee of the CHEM Study met for the first time on January 9, 1960 in Berkeley, California, under the chairmanship of Dr. Glenn T. Seaborg, Chairman of the U.S. Atomic Energy Commission. The general objective of the Study is to prepare new teaching materials for high school chemistry, which will include a textbook, laboratory experiments, and films. The more specific objectives include: (1) to encourage closer collaboration between research scientists and teachers in the understanding of science; (2) to stimulate and prepare future professional chemists; (3) to create a sound understanding and appreciation of the importance of chemistry in modern living among students who will not major in science; and (4) to help chemistry teachers undertake further studies and in this way improve their teaching methods.

The CHEM Study program has two guiding principles. First, it is designed to fit the average high-school student rather than the talented. For the latter's needs the CHEM Study offers supplementary textual material and additional experiments. Secondly, the program leans heavily on experiments, so that the textbook is thoroughly dependent on and woven into the laboratory work. Films integrated with the text and laboratory experiments are provided as supplemental material.

In June and July, 1960 seven college and seven high school teachers joined the CHEM Study Staff for six weeks at Harvey Mudd College in Claremont to write the text and laboratory manual. The rough draft produced was used in twenty-four high schools during the academic year 1960-1961. Teachers from these schools were briefed about the new approach and its methodology during a four-week session at Claremont in August, 1960.

At the end of the school-year 1961 the trial teachers reconvened with the staff in Berkeley, California, to evaluate that first trial edition. The consensus of opinion was that in spite of imperfections in the material two qualities of the program were effective and commendable: the stress on the experimental approach to the study of chemistry, and the heavy reliance on discovery-type experiments. Both the content and the level of presentation were considered to be within the limits of the feasible. The course was duly revised during that summer of 1961 and given a preliminary trial in the laboratory and the classroom at CHEM Study Institutes held at Cornell University and Harvey Mudd College. The one hundred new teachers who attended these institutes decided to employ the materials in their classes during the academic year 1961-1962.

It is useful at this point to bring out by way of comparison some similarities and differences between these two new approaches, the CBA and the CHEM Study. The suggestion has been made that these two new programs should be merged into one single *best* chemistry course. The idea has not found favor among the staff members of both systems since such a move would defeat the very purposes for which they were started. No single course can achieve all the legitimate objectives of high-school chemistry and hope to attain them in the best possible way for all and any situations in which it may be taught. There are local differences and regional characteristics. Moreover one of the pillars of strength of the educational system in our times is the freedom it allows for experimentation. Acceptance of a single course, or of a limited set of norms with which to evaluate students and courses, would lead to a standardization stifling innovation and retarding improvement. Finally, both the CBA and the CHEM Study are still incomplete experiments. The interpretation of results requires that each of them be allowed due development and maturation as independent courses.

Both new programs deal with basically the same major topics. They differ in the order of presenting these topics and the methodology employed. Furthermore they each put a different relative emphasis on the secondary objectives of the course. Both CBA and CHEM put a greater stress on laboratory work than has been heretofore customary in high school courses, and both approaches strive to weave a closely-knit inter-relationship between the topics presented.

The two programs give different answers to the questions, "How precisely will the text and laboratory work be integrated?" The CBA believes that a student will appreciate chemistry in proportion as he is allowed gradually to perform the functions characteristic of chemists. The laboratory work is consequently an experiment that will clarify it, carry out the technical operations of the experiment, and arrive at some conclusion through an analysis of his own data. This progressive training of the student is under the guidance of the teacher, which however becomes gradually less intensive as time goes along.

The CBA textbook incorporates progressively new concepts and observations into an expanding body of inter-related topics. These inter-relationships are formed by requiring the student to analyze, correlate, and synthesize. The laboratory program and the text move parallel to each other in so far as topics are concerned, and thereby reinforce one another to a marked degree.

The CHEMS project, on the other hand, makes use of a different methodology when integrating the laboratory with the text. The laboratory is made an integral part of the next presentation and the student is required to make specific observations at a given point in the course. Detailed instructions for the performance and interpretation of each experiment help to achieve this objective. For this reason too the laboratory manual introduces many topics and the textbook carries direct references to laboratory experiences.

The CHEMS system employs a different technique to correlate the topics developed in the course. The first chapters of the text give a general view of chemistry in a categorical and not too deductive way. As the course advances many topics presented in the overview are recalled and discussed in greater detail. It is then that the theoretical concepts relating the various topics are presented.

In Europe secondary-school chemistry has also received a new impetus as a result of two inter-European conferences, the Greystones Seminar in 1960 and the Dublin Conference in 1961. The former was held in March, 1960 at Greystones (Ireland) and discussed "The Status and Development of the Teaching of Chemistry." It was sponsored by the Office for Scientific and Technical Personnel of the Organization for European Economic Co-operation (OEEC). The OEEC has since changed its name to "Organization for Economic Co-operation and Development" (OECD).

The Greystones Seminar was the first move in a cooperative program to rejuvenate the teaching of science subjects in European secondary schools. It was attended by delegates from Australia, Belgium, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxemburg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States. As far as chemistry was concerned the Seminar aimed at proposing specific steps toward a curriculum theoretically and practically better suited to the needs of twentieth-century chemistry. Among its final recommendations were that a working group of the then OEEC: (1) draft the outline of a modern chemistry course; (2) prepare a laboratory manual and demonstration experiments illustrative of the course; (3) examine the problem of the training and re-training of teachers of chemistry.

The Seminar also suggested that the following topics are essential in the teaching of modern chemistry at all levels: (1) atomic structure and electronic theory of valence; (2) chemical equilibria; (3) energy considerations in chemical reactions; (4) removal, especially from inorganic chemistry, of disconnected factual material not needed to illustrate underlying principles or to correlate the subject into a logical unit. It likewise stressed the necessity of teaching physics and mathematics to chemistry students so as to enhance their appreciation of chemical knowledge. In this regard it was considered desirable that physics (specially introductory electricity) and mathematics (specially solid geometry) should come before the study of chemistry. It also insisted that chemical theories, to whatever extent they may be developed, should be used as a means to correlate chemical facts and discuss chemical reactions.

The Dublin conference, also sponsored by OECD, was held July 3 to 28, 1961 at University College, Dublin, with almost fifty participants attending. The purpose of this conference was to present the topics of a new chemistry syllabus in terms of new experimental approaches developed in Europe and the United States. Countries represented were Belgium, Eire, Germany, Italy, Norway, Sweden, Turkey, the United Kingdom, and the United States. This meeting was the outgrowth of the earlier Greystones Seminar.

In the summary report of the working groups of the Dublin Conference there was a strong bid for the Chemical Bond Approach. This was, in the opinion of the Conference, one good answer to the problem of making chemical *facts* appealing to students of today. Another solution offered was to emphasize the mathematical approach to the study of chemistry, an approach which would not be too easy to adopt in the Philippines given the weak background in that discipline of our students when compared with their European counterparts.

We may take up some of the common objections put forth against these new approaches, particularly the CBA. They may be reduced to one difficulty with two implications. It is objected that the new course is too difficult for our local conditions here in the Philippines. The implications are that it is difficult to learn it and difficult to teach it. That the course is somewhat difficult to learn is true, but it is true of many things.

And granting that it is difficult for the *teacher* to learn, it does not follow that the *student* will find it equally difficult. This is because the teacher has to learn by *forgetting* the old method and approach in order to assimilate the new, while the student has nothing to forget.

That the new method is difficult to teach and perhaps not too easy to adapt is also true up to a point. But we have to do something about rejuvenating the teaching of chemistry, and it is certainly an easier task to adapt a method tried and found good than it is to start from scratch. Moreover, a method found good and applicable in one region must have something worthwhile to offer to other regions as well. After all there is a common element in all human experience, teaching included. The CBA has been accepted and tried by some 200 teachers and 10,000 students during the 1961-1962 school-year. That includes a secondary-school population spread out over such diverse places as Ponce High School in Puerto Rico; Carey Grammar School in Melbourne, Australia; Belcamp College in Dublin, Ireland; Itoshima High School in Fukuoko-Ken, Japan; and four high schools in Canada. Here in the Philippines about half a dozen high schools at least have adopted the CBA method. During the same academic year of 1961-1962 the CHEMS system was taught by 1958 teachers in 125 schools to about 12,000 students in the continental United States.

The CBA method has been critizized, even in Europe, as being too biased towards physics to the extent that the teaching of it becomes chemical physics rather than plain chemistry. First of all we must remember that even the latest CBA text is a trial edition subject to revisions. Moreover, the objection somewhat misses the point. Given the present progress of chemistry and the growing inter-disciplinary dependence in the natural sciences, it is not too soon to introduce the young to this new atmosphere. The recent advances in such inter-related disciplines as biophysics, biochemistry, geochemistry, astrophysics, and bioengineering are proof of this new trend in contemporary science. In fact, it would be a very happy situation for chemistry if our students came out of the course with a deep realization that chemistry today is not a separate discipline, isolated from physics or biology or mathematics.

The trend recently introduced in the Philippines to revise chemistry teaching should be heartily encouraged. This is most essential if we are to produce a scientific elite. Any improvement in the teaching of scientific disciplines in our high schools today will pay dividends in terms of industrial progress and fruitful research in years to come.

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