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HOW CHEMISTRY IS BEST TAUGHT.*

BY CHARLES F. MABERY, CASE SCHOOL OF SCIENCE, CLEVELAND, OHIO.

THE subject "How chemistry is best taught," which has been proposed to us for discussion, has a serious interest for all persons who are engaged in teaching chemistry, and it is of especial importance to those of us who have in charge the preparation of young men for professional employment. In view of the prominence of scientific subjects and methods in the present systems of education, it is incumbent upon the adherents of these methods to demonstrate by their results that they are not in error in assuming that science should have an equivalent place with other departments of knowledge. In the higher institutions this question has received a definite answer; in the secondary schools evidently much has yet to be accomplished in the direction of general education as well as in the preparation for higher study.

That the importance of a knowledge of elementary chemistry is apparent to all who are capable of appreciating its usefulness, is evident in the recent extension of instruction in the secondary schools. In the larger portion of our high schools, however, physical science still occupies a subordinate place, or it is taught merely from text-books with little, if any, laboratory training. Probably the chief hindrance to any radical change is a lack of appreciation on the part of the public. If parents could be brought to see that their sons and daughters would receive a better education if physical science properly taught formed an essential feature of the high school course, the change would not be long delayed. That the training of many teachers is scarcely more comprehensive than they are called upon to impart is of less importance, since at present those who are educated in the higher institutions have better opportunities, and those who are deficient can improve their knowledge in special courses for teachers. Doubtless the many popular movements of the present day will exert a beneficial influence in extending an acquaintance with the application of scientific principles. Such unique and instructive object lessons as that which has been designed, under the direction of Prof. Ellen H. Richards, for the Rumford kitchen, in the Columbian Exposition, cannot fail to attract public attention. It requires no particular training in observation to recognize the difference in nutrition of foods which have a widely different nutritive value; but when an appetite whetted to the sharpest edge in an endeavor to see all the exhibits in the Liberal Arts building in one visit, and the unavailing efforts to extract a crumb of comfort from the places so improperly named, is brought in contact with the wholesome dishes prepared in the Rumford kitchen, and their satisfying influence, the numbers representing the food values will be in a favorable connection to awaken a desire for further information. The same principle is applied in a different manner in the exhibits from the agricultural stations which explain the composition of dairy products, of animal foods and the methods of chemical investigations. These exhibits have a particular interest for persons engaged in agricultural pursuits since they are a part of the well-directed efforts of the stations in disseminating knowledge. Probably in no department of education has there been a more substantial growth during the last twenty years than on the part of intelligent farmers in applying the practical information coming to them from the results of investigations carried on at the experiment stations. These illustrations may seem somewhat removed from the main question before us, but I am convinced that the efficiency of higher instruction in chemistry will be greatly improved when students coming to us from the secondary schools shall have had the advantage of practical training in elementary physical science, and I believe this will be the sooner accomplished through a recognition of its benefits in the affairs of every-day life.

I think we shall all agree that the best argument to be urged in favor of a prominent place for chemistry in any grade of instruction is the value of experimental methods for the development of mental power. This feature should naturally appear with especial prominence in courses leading to the degree of Bachelor of Arts; and if the schools of science are to be maintained on a higher plane than the trade schools or shops, the courses of study must be conducted with reference to the attainment of mental discipline and scholarship. In the courses in chemistry I am unable to see why this should interfere with the acquisition of practical knowledge.

The guiding star to successful teaching in chemistry is the personality and enthusiasm of the instructor. With the great increase in attendance in many institutions the earlier relations between student and instructor, which were frequently mingled with deep personal feeling, somewhat akin to veneration on the part of the student, are well-nigh impossible. Nevertheless, an enthusiastic teacher with tact and good judgment has little difficulty in maintaining a profound interest even in large classes. In successful teaching we all know how much depends upon the attitude of the instructor toward his students. Courteous relations, with a clear understanding that teacher and students are mutually interested in the acquisition of knowledge, readily secure the confidence and esteem of a body of students, and the instruction need seldom be interrupted by questions of conduct. A faithful teacher does not limit his attention to the brighter minds; students slow in comprehension but earnest in application secure a store of information which will be used later to the best advantage. It was a wise teacher who said: "I am faithful in my duty to dull students; in my old age I may need favors of the men of wealth."

In assimilating their methods from European laboratories, the chemists of the United States, untrammelled by traditions and unrestrained by the influence of any particular school, have been in favorable conditions to appreciate the labors of the great masters of other countries. Unfortunately, it may be, in the wonderful development of our natural resources, the temptation to enjoy material benefits may have retarded the growth of orig-

*A paper read before the section of Didactic Chemistry in the World's Congress Auxiliary of the World's Columbian Exposition at Chicago, August 26, 1893.

inal investigation; yet looking toward the future the erection of so many large laboratories cannot fail, under judicious control, to contribute to the advancement of knowledge. A marked individuality in our methods is apparent even in a casual inspection of American laboratories. Variation in details is a natural consequence of differences in the temperament of different peoples; and teachers educated abroad have perceived the necessity of adapting the methods in which they were trained to the peculiar conditions.

With some hesitation I approach that aspect of our subject which relates to the details of methods, since the best success in teaching is so dependent on the personality of the instructor that it would seem presumptuous to suggest a rigid scheme for all. There are certain principles at the foundation of successful teaching, however, which may properly be presented for consideration, especially since this paper is intended as an introduction to general discussion. I have already alluded to an unsatisfactory condition in the methods employed in the secondary schools. In some of the high schools, as we all know, there are teachers who are thoroughly imbued with the spirit of scientific study, yet competent teachers are often limited in their efforts by a heavy burden of other work, or by a need of the necessary appliances. There can be no question that the high school courses would be benefitted if every pupil received systematic training in elementary physical science, and I believe it is consistent with due attention to other subjects, and that it can be accomplished without any unreasonable pecuniary burden. As an expeditious and effective method for teaching chemistry in the high school, I would have the teacher meet the class before the lecture table and demonstrate, experiment and explain, simply as a convenient mode of teaching classes as one pupil should be taught. The experiments should be repeated by the student in the laboratory, under the immediate oversight of the teacher, with the note book close at hand. A text-book is necessary, to give information which the teacher has not time to include; but no text-book can supply the need of personal teaching. Occasionally teachers with limited knowledge are led to adopt methods of questionable utility by the arrangement of certain text-books. Some years since a teacher in one of the high schools in the East, in which little attention was given to laboratory work for students, remarked that his pupils must have a thorough knowledge of valence and structure symbols. The topical arrangement of the subject may be left to the discretion of the teacher, and the quantity to the length of time available; but it should never be forgotten that the educational value of such instruction depends upon the development of skill in manipulation, of correct habits of observation and in recording notes, and of the true spirit of scientific thought. Whatever of practical information may be included will enhance the utility of the instruction.

In the higher institutions the first course is general and descriptive chemistry, of which every person who expects to engage in any scientific pursuit should have a thorough knowledge; and, as has been suggested, this subject should have a suitable place in college courses. Concerning details of the most efficient methods in teaching general chemistry, no doubt an extended course of experimental lectures, closely connected with laboratory practice, affords the best training. The ground can be fairly covered in seventy or eighty lectures, with four to six hours a week of laboratory work, so arranged that the lectures of each week shall include the experiments for the laboratory. Weekly recitations on the subjects of the lectures and laboratory work enable the instructor to control the progress of his students. When students first enter the laboratory it is essential that they are impressed with the necessity of accuracy in the details of experimental work. This important lesson may easily be taught by means of experiments capable of affording quantitative results; by some instructors such experiments are occasionally introduced throughout the course, with the same object in view. There should be sufficient instruction in the laboratory for careful oversight of the experimental work and the note book of each student. Moreover, I am convinced that it is unwise, in any grade of undergraduate study in chemistry, to allow students in laboratories without constant supervision; when left to themselves they are apt to loiter, to contract careless habits and to waste material. Then a laboratory is held responsible for accidents, even though they occur through inexcusable carelessness of students. Every instructor in charge of a laboratory will, no doubt, recall heedless moments on the part of students. Some years ago, just as I entered my qualitative laboratory one day when the assistant was out of the room, I observed a student inflate his lungs twice from a bottle containing a freshly charged solution of hydric sulphide; he immediately fell into the arms of a companion, and it was some time before he recovered. Probably another inflation would have proved fatal.

This fellow was a sophomore, having taken one year in general and descriptive chemistry; he was fairly bright and had been using this reagent during several months. But some question arose as to the odor of the unadulterated gas, and, forgetting the precepts of his freshman year, he attempted by a direct experiment to ascertain the truth. What has been said concerning the personality of the instructor applies, perhaps, in a more restricted sense to the student. While methodical habits are to be strenuously insisted upon, the methods may be sufficiently flexible to allow the student to reach his conclusions in his own peculiar way; the particular form of the lecture and laboratory notes, for example, can be left to the preference of the student, provided they are well written and complete.

For other students than those who desire special training in chemistry or in allied subjects, an extended course in general and descriptive chemistry provides ample knowledge of this subject. Analytical chemistry is next in the sequence of studies, and for evident reasons qualitative analysis is first undertaken. On account of its great disciplinary value I regard this subject as one of the most important in the whole course of chemical training. It enables the instructor constantly to test the faithfulness and proficiency of the student, and beside the mental discipline, the student acquires a comprehensive knowledge of methods of separation and identification, which is the foundation of quantitative analysis. Elementary theoretical chemistry, or chemical philosophy, may be conveniently and profitably taught at the same time with qualitative analysis, especially since a familiarity with stochiometry and chemical reactions is essential in a good understanding of quantitative methods.

Thus far, in teaching chemistry, probably the methods are not materially different in the college and the technical school. Indeed, in the more advanced subjects, the principal difference is in the attention which should be given to the acquisition of practical knowledge in the technical courses. The methods of quantitative analysis are well adapted for the development of skill and dexterity in accurate manipulation, and to the chemist they are indispensable. As a preparation for professional employment the training in methods should be sufficiently comprehensive and thorough to enable the student to appreciate the conditions of any analytical problem; and, further, I deem it of much importance that students have practice, under guidance, in all typical standard methods.

It is not sufficient that men are carefully trained in methods which impart skill and accuracy; it seems more desirable, for example, that men who enter the iron and steel industry are thoroughly familiar with the standard methods of iron analysis than to rely upon skill and general knowledge to acquire the special features in actual practice. The first lessons to be learned in the quantitative laboratory are accuracy and confidence; the importance of a close economy of time and effort must be appreciated, and an intelligent student will soon perceive the numerous ways for conducting analytical operations rapidly without haste. When a chemist assumes the duties of a position every motion has a pecuniary value, and results are demanded in the smallest limit of time. This requirement is sometimes urged in favor of undergraduate training in rapid methods. While some practice in this direction would, without doubt, be serviceable; in three terms, at most, which can be devoted to quantitative analysis, the time is fully occupied in gaining a familiarity with methods, and in passing from one analysis to another the conditions are not favorable for commercial rapidity. As in actual practice it is only possible to attain to the highest degree of accuracy and celerity when the attention of the analyst is limited to a moderate number of determinations which are continually repeated. Experience shows that well-trained students are not long in acquiring commercial dexterity, even to reporting the percentage of carbon within five minutes after a ladle of steel is poured into the mould, or a complete analysis of blast furnace slag within thirty minutes. If attempts were made to give such practice to students, there would still be much to learn in the different conditions in the laboratory of the manufacturing plant.

A branch of our subject, which has doubtless occasioned some of us much perplexity in our endeavors to give it a suitable place in an undergraduate course, is organic chemistry. Our difficulty is partly due to the feeling on the part of certain students when they have gained a good acquaintance with quantitative analysis, with the consciousness that they can secure some pecuniary return from their attainments, that they have learned all of chemistry that can be of service to them. Usually such students may be made sensible of their error, although, unfortunately, the importance of a broader view is not always appreciated until a knowledge of this subject is needed in professional occupation. That organic chemistry is a difficult subject students are not long in perceiving. It is not sufficient in a course of lectures that the principles and methods are understood, they must be learned. The importance of a broad and thorough training in theoretical and descriptive organic chemistry as a part of a chemical education is beyond question. As a part of the preparation for technological and applied chemistry, organic chemistry can most conveniently be placed in the third year; yet without some introduction I have found this subject too difficult for third-year students. The plan which I have adopted with satisfactory results includes recitations in the first term of the third year from an elementary text-book, with the following lectures extending throughout the second term and the first term of the fourth year. So far as possible laboratory work should accompany the lectures, although from the pressure of other work the greater portion of the experimental work may be pushed forward into the fourth year. In connection with the lectures, students should be required to extend their knowledge by reading, and recitations are necessary to ensure faithful application. With this arrangement the principal laboratory work of the fourth year includes organic chemistry and chemical technology, assaying, gas analysis; and such other special subjects as may seem expedient can be provided for here. A course of lectures in metallurgy are of advantage to students in chemistry, and they may be attended during this year; some additional instruction in theoretical chemistry can be given with profit.

For the utilization of chemical skill the field of manufacturing or applied chemistry is full of promise, although in this country it has largely to be developed. Suitable preparation for industrial occupation demands thorough training in the directions already suggested, and beside, a good knowledge of technical processes with the aid of laboratory work, so far as it is feasible to experiment with these processes on a laboratory scale. Concerning the best methods for teaching this subject, no doubt courses of lectures, supplemented by reading, are to be preferred, especially if part of the lectures can be given by persons engaged in professional pursuits. Several recent compilations, in a convenient form for the use of students, are a valuable aid.

The range in laboratory work is of necessity somewhat limited; it must consist principally in the preparation of chemical products from crude materials, in the study of mordants and dyes and in testing the efficiency of certain features of industrial processes on a laboratory scale. The preparation of theses or written accounts of various processes should also form a prominent feature of a course in technological chemistry. Institutions fortunately situated near manufacturing establishments, afford valuable opportunities to students, who are enabled to study industrial methods in actual operation. Such instruction, supplemented by laboratory practice, constitutes the best possible education in applied chemistry that an institution can provide.

Any discussion of the details of a chemical education must be incomplete without some reference to related subjects, either such as are closely allied to chemistry, or those which are essential in the proper mental development of every well-educated person. Evidently this portion of our subject may be considered from more than one point of view. In a course of four years in the school of science, there should be thorough training in mathematics, so far as calculus, and it can be no disadvantage to make a certain portion of this subject required or optional. Every chemist who aspires to a position beyond that of an analyst will be called upon to plan and oversee the construction of appliances and buildings; in fact, ingenuity and mechanical skill may occasionally be as serviceable as chemical knowledge. There are, therefore, good reasons for the acquirement, by every student, of a good understanding of mechanical drawing and of elementary mechanics, and this may have led to the foundation, in several institutions, of a course in chemical engineering. No doubt this course is in demand by persons who desire proficiency in the engineering features, but students who expect to engage in applied chemistry can hardly afford to omit any portion of the undergraduate training in chemistry. Nothing need be said as to the importance to all chemists of a thorough discipline in descriptive physics with laboratory practice. A familiarity with the principles of heat and electricity and with the manipulation of electrical currents are among the more important requisites. The rapid growth of electro-metallurgy indicates large possibilities for the application of electrical energy in this form, and it can evidently best be undertaken by the chemist who possesses a good knowledge of electricity. The literary training in scientific courses is usually limited to the English branches and the modern languages; without a certain acquaintance with the latter the chemist would be seriously restricted in the sources of his information; and, moreover, to scientific students, it would seem that the French and German languages should be taught as much, at least, for mental discipline and culture as for their practical usefulness. Of the importance of thorough discipline in the English language and literature, history, logic and political economy it is not necessary to speak. Determinative mineralogy may be provided for in the second or third year. Courses in agricultural or pharmaceutical chemistry, or in other special fields, should differ in the details of the third and fourth years from the course outlined above.

In college and university courses, theoretical chemistry and chemical literature receive more attention, and in general less attention is given to practical applications. I do not accept the idea sometimes expressed, that original investigation should not be attempted outside of the university. We are all too well aware of the difficulties in the way of carrying on special study in connection with the responsibility of undergraduate courses; and yet I am sure we appreciate the influence of such work in the atmosphere of the laboratory, as well as upon the instructor himself. Then there are always in the laboratory bright students who are able to undertake with profit the study of special problems. As a part of the preparation for teaching I look upon a certain acquaintance with the methods of original research as an essential attainment; I do not intend to assert that without it there can be no good teachers, but it certainly strengthens the equipment of a teacher who aspires to a high position.

Earlier in this paper I endeavored to give an outline of what seem to be the principal objects to be kept in view in teaching chemistry as an educational subject. Students continue in chemistry with the intention of securing professional employment either in teaching or in applied chemistry. How often are we met with the question as to what is the prospect of employment after graduation; whether the inducements are more promising in teaching or in practical fields. Concerning teaching as a profession, the reply is easy: a person with an aptitude for teaching and with broad training has little difficulty in securing a position commensurate with his attainments, especially at present, with the wonderful extension of our educational institutions. But the number of positions is limited and there are few vacancies; if they were abundant not all persons, even with the best possible preparation, would succeed in teaching chemistry. In applied chemistry the conditions are not the same. With our enormous stores of natural products yet undeveloped, vigorous enterprise in business operations and great industrial wealth, there cannot fail to be rapid developments in the fields of manufacturing chemistry. Within the ten years just elapsed we have witnessed great changes; manufacturers who, ten years ago, conducted their operations almost without the aid of chemical skill, now employ several chemists. Eight years ago I visited a large plant for the manufacture of sulphuric acid, which contained neither a Glover nor a Gay Lussac tower. Further improvements, which are necessary for the production at home of the chemical products that are now imported in large quantities, require broad qualifications with extended experience; if our graduates are not sufficiently well trained chemists will be secured elsewhere.

If there are portions of the educational field in chemistry which appeal to us with greater force than others, perhaps the elementary teaching in the secondary schools and the advanced study in preparation for teaching or for positions requiring independent skill and originality in methods are worthy of attention. The recent growth of knowledge within special fields has introduced new features into methods of instruction. In addition to courses which are adapted for all students, those who intend to undertake investigations in any particular direction should have training under the guidance of a specialist in that field. There are many economic problems of the utmost importance awaiting solution, which require not only the application of all accumulated knowledge, but the discovery of new methods. The maintenance of a healthful water supply and the economic disposal of sewage are serious problems for the present generation, and the engineer must be aided by the best skill of the chemist and of the bacteriologist.

Every laborer is directly interested in the promotion of investigations on an economic and healthful food supply. To the great army of workmen who are struggling to support families on incomes of three or four hundred dollars a year it is a matter of serious importance to secure the best nutrition at the smallest cost. Yet it is rarely, if ever, that a judicious selection of food materials receives attention; it is usually a question of individual taste, so far as the means at hand will permit, with a complete ignorance of any principles of economy or health. In these directions and others of no less importance there are great opportunities in the domain of sanitary chemistry to render inestimable benefits to humanity.

What has been said of sanitary chemistry applies with equal force to medical chemistry, to agricultural chemistry and to other special fields. But I feel sure that the details of methods of instruction, as well as a consideration of methods based on other recent discoveries, such as the use of models in teaching structural chemistry, can best form a part of the general discussion by teachers who are especially occupied in those particular fields. Perhaps, also, the great border land between chemistry and physics, or chemical physics, should receive attention from those whose investigations are extending our conceptions of the fundamental principles of chemistry.

If I have presented this subject more especially from the standpoint of the preparation for professional occupation, it is because this seems to be the principal demand for instruction in chemistry beyond the elementary branches. But if the value of training in chemistry as a factor in liberal education has not been set forth with due prominence, it should receive just consideration in the discussion which follows. I have not attempted in this paper to include methods or conditions outside of our own institutions; yet we cannot fail to derive great benefit in extending our knowledge of the methods in other institutions through the eminent professors with whom it is our good fortune to meet.

NOTES ON THE WOOD OR FALLOW ANT OF SOUTHEASTERN MASSACHUSETTS.

BY J. B. WOODWORTH, CAMBRIDGE, MASS.

ANECDOTES of the ant form, apparently, a large part of the minor contributions to journals of natural history. The fact that so many stories have been published, and the hope that the following will interest some student of the psychological habits of ants, encourage me to relate two observations of my own upon the behavior of the large Wood or Fallow ant (*Formica rufa*, Linné) of southeastern Massachusetts.*

While examining the sands of Horse Neck Beach, opposite Westport Point, Mass., on July 25th, 1893, I had my attention called to a large winged ant, with a reddish brown head and prothorax and black abdomen, which started to run away from a shell on which I had trodden. I stepped back a pace, when the ant, perceiving me, began to approach. Upon this movement I continued to retreat in order to get out of her way, but finding that the creature still pursued me, I was led to see how far

*I am indebted to Mr. Samuel Henshaw, of the Museum of Comparative Zoology, for reference to McCook's account of this ant in the Trans. Amer. Ent. Soc., Vol. VI., p. 253, and for naming the form here referred to.