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## TEACHING CHEMISTRY IN THE LABORATORY.\*

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In the year 1872 a young man was called to the chair of chemistry in a well-known Eastern college. He possessed to a remarkable degree the ability of interesting his pupils in his subject, and one of his students, becoming fascinated by the classroom discussions, asked permission to enter the laboratory in order that he might for himself become acquainted with the experimental side of the subject. So unusual was the request that it was found necessary to refer the matter to the college faculty, which after due deliberation replied it would not be feasible to grant such a request because the young man in his inexperience would quite certainly break valuable glassware and use up expensive chemicals. An inventory of American universities and colleges of that period reveals the fact that there were only six of the most progressive institutions of the country which were equipped with chemical laboratories to which students were admitted. In all the other institutions, if chemistry were offered at all it was as a purely classroom exercise.<sup>1</sup>

In the forty-six years which have elapsed since this simple incident took place, the young college professor has come to be recognized as one of America's foremost chemists and educators. That he is still active as an earnest searcher after scientific truth merely emphasizes the shortness of the intervening years. Yet within the active career of this one teacher, what a change has come over our methods of teaching chemistry! Today not

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<sup>1</sup>For a description of the sort of science instruction given in American colleges of this period, see the interesting article on "Laboratory Teaching," by President Eliot, in *SCHOOL SCIENCE AND MATHEMATICS*, Vol. 6, November, 1906.

only every university and college but nearly every high school the country over, boasts of its chemical laboratory and its facilities for teaching the experimental facts of the science. The advance has been general and so rapid that there is small wonder at the lack of uniformity and bewildering array of pedagogical theories and "methods" of instruction for laboratory teaching. Under such conditions a paper, entitled, "Teaching Chemistry in the Laboratory," might be expected to present some new theories, or some original plan of operation, or at least some method which has become a hobby. The present effort will not concern itself with any of the various theories concerning laboratory instruction, however interesting and valuable they may be. The present desire is to show how successful laboratory instruction may be an accomplished fact and to recall the importance of such work.

Most of the elementary textbooks attempt to give in their introductory chapter a definition of chemistry or a statement of what sort of phenomena the beginner may expect to find in the new subject. It is interesting to compare these statements of the various authors. With striking regularity they emphasize the experimental nature of the work as may be seen by considering two typical cases: (1) "The study of substances and their properties is the particular field of chemistry." (2) "It is the function of the chemist to investigate the action of each substance on every other, and to study the properties of the combinations resulting from this action." From ten elementary books which were easily accessible, statements similar to these were taken, while only one mentions the fact that chemistry deals also with laws and theories as well as certain manufacturing interests. Thus it appears that to the authors of our textbooks the subject of chemistry is almost wholly experimental in its nature, since its chief concern is to study the properties of substances and the changes in those properties which may be brought about by chemical means. If this is a true conception of chemistry and its province, then it must follow of necessity that the most important part of our chemical teaching must be done in the laboratory, since it is there and there only that we study substances, properties, and chemical changes. In the recitation room we may talk *about* some object, property, or change, but in the laboratory we see and handle the substance, test its properties, and observe the changes which it is capable of undergoing. Our efforts in the lecture and recitation room

are more or less indefinite, abstract, confusing, or even misleading, since we are talking about things more or less remote, while in the laboratory the study should be definite, concrete, and illuminating.

It is necessary to add hurriedly that the instruction in the recitation room is a fundamentally important part of chemical teaching and must be carried along faithfully and thoroughly. But the argument here presented is that instruction in the quiz room is *about* chemistry, while in the laboratory the inquiring mind is really studying chemistry itself. The former is necessary to systematize and correlate facts gleaned in the laboratory, while the latter should be the real backbone of the course.

When laboratory instruction was first introduced into our educational system it was considered a sort of scientific supervised play, a kind of busy work to fill up time or at best a means of illustrating certain facts which had already been "learned" from the textbook. It is to be regretted that this viewpoint has by no means disappeared even among teachers of chemistry themselves. But I believe that it is no longer possible for a teacher to give satisfactory instruction in the laboratory when he regards his duty as that of a monitor; or as a dispenser of supplies; or as an agent of the Red Cross to care for the unfortunate bungler; or even as an encyclopedia of ready information to answer a perfect torrent of questions of all sorts. The successful teacher in the laboratory must teach, which, according to Webster, means "to show, guide, counsel," "to make to know how," "to direct as an instructor." There is no better place anywhere in our educational system to "educate" than in the chemical laboratory. For there the teacher must literally "draw out" the meaning of the experiments and develop the ability to observe, to reason, and to think.

This end, which comes close to representing the purpose of all education, can doubtless be obtained in many ways, but the only successful methods which have come to the notice of the writer involve careful individual attention to each pupil in the class. Watchfulness and opportune suggestions are necessary during the process of setting up a piece of apparatus, during the carrying out of the experiment, but most especially after the experiment is completed and the record made in the notebook. It seems to be an undebatable axiom that the more promptly the students' conclusions are reviewed by the teacher, the more willingly will mistakes be corrected and the more clearly will

the point of the experiment be understood. In our work we have found it extremely beneficial to have the teacher pass around his class, examining notebooks, inspecting work that is in progress, and above all asking questions upon various points of the work. We have found it impossible to depend solely upon the student's written record, for the reason that frequently he may be able to write an acceptable record of an experiment which in reality he does not comprehend. A few judicious questions will reveal the thoroughness of his understanding and the amount of real thought which he has put into his work. Frequently the questioning may extend to points quite beyond the purpose of any given experiment, in order to cultivate the pupil's power of observation and reason.

An example of a conversation in the laboratory will illustrate the method of treatment. A student has just completed the simple experiment of heating of mercuric oxide, and his notebook shows that he has noted the change in color of the material, the deposition of metallic mercury on the side of the tube, the escape of oxygen, and the reversal of the reaction as the residue cools. He has answered all questions concisely, and the equation for the reaction is written in the most approved form—in short, a perfect record. What possible need is there for questioning the student further, or suspecting that he has not obtained the maximum good from this simple experiment? The teacher approaches and asks as he examines the written record<sup>2</sup>:

- Q. "Why did the mercuric oxide change color when you heated it?"  
A. "The chemical change produced the change of color."  
Q. "What was the chemical change?"  
A. "The decomposition of mercuric oxide, giving mercury and oxygen."  
Q. "Which of these two products caused the dark color?"  
A. "Well, it must have been the mercury."  
Q. "Why?"  
A. "Because oxygen is a colorless gas and it could not produce a dark colored powder."  
Q. "Then the dark colored powder in the bottom of the tube was mercury?"  
A. "It must have been."  
Q. "What is this deposit on the side of the tube?"  
A. "Mercury."  
Q. "How can that be when its appearance is so different from the dark powder in the bottom of the tube, which you just told me was mercury?"  
A. "I don't know, but I am sure this is mercury on the side of the tube."  
Q. "Why?"

<sup>2</sup>This supposed conversation is based on actual experiences with students in the laboratory

- A. "Because it is bright and shiny, and collects in little drops."  
Q. "Did the mercuric oxide change color suddenly?"  
A. "No, the red color grew darker gradually, becoming chocolate colored, and finally black."  
Q. "What caused the chocolate color?"  
A. "I don't know."  
Q. "Is it possible that mercuric oxide is red when cold and black when hot?"  
A. "I suppose it might be."  
Q. "If that is true, what caused the dark color?"  
A. "The fact that it was getting hot."  
Q. "Then did the chemical change produce the change in color?"  
A. "I thought it did."  
Q. "Is it possible that the change in color is due both to the change in temperature and to a partial decomposition?"  
A. "It might be."  
Q. "What is the color of mercury vapor?"  
A. "I don't know."  
Q. "How did the mercury get up here when it condensed on the side of the tube?"  
A. "I don't know."  
Q. "Did you see any mercury particles jump up and cling there?"  
A. "No."  
Q. "Well, how did the mercury get up there?"  
A. "I suppose it was like frost collecting on the window pane."  
Q. "You mean that mercury had assumed the vapor form?"  
A. "Yes."  
Q. "What is the color of mercury vapor?"  
A. "I don't know."  
Q. "Did you see any colored gas in the tube as you were heating it?"  
A. "No."  
Q. "What is the color of mercury vapor then?"  
A. "I don't believe it has any color."  
Q. "You mean that mercury vapor is colorless?"  
A. "Yes."

This process of questioning might be extended to include such topics as the following: Could the blackening of the mercuric oxide be caused by the presence of impurities, such as carbon? How would you distinguish between such a mixture and pure  $\text{HgO}$ ? Which requires the higher temperature, the formation of  $\text{HgO}$  from mercury and oxygen, or the decomposition of this compound? Are mercury and oxygen elements or compounds? How would you proceed to prove experimentally that mercury is not a compound? Why does the test tube melt sometimes while  $\text{HgO}$  is being heated? Why does the black residue turn red so quickly when this happens?

Many other questions will suggest themselves to the skilful teacher, all of which bring out some simple fact which in itself may be worth very little, but the process is worth everything to the student. For in this way he is taught to see that even the simplest experiment is brim full of interesting deductions, but above all he is taught the necessity of close observation and careful thought.

It would not be feasible for a teacher to ask each pupil of his class all the questions upon any one experiment. Time would not permit such a process, and the fact that the conversation between teacher and student is overheard by those near by makes it necessary to vary the questions from pupil to pupil. The skilful teacher will readily learn to select questions suited to the interest, keenness, and intelligence of each pupil. Such a process requires ingenuity, skill, patience, and persistence on the part of the teacher, but the results are well worth while.

The advantages obtainable by such a method are many.

1. It stimulates interest in the work, cultivates the powers of observation, is conducive to thoroughness, and above all it develops a student's ability to think. One of the gratifying results of this procedure is the rapid development of the powers of thought and reasoning, so that the questioning process can soon become much more brief and concise.
2. It detects errors, misconceptions, faulty English, and poor expressions soon after they are set down, and at a time when the experiment is fresh in mind, so that errors are most easily and most effectively corrected.
3. The weary hours of "correcting" notebooks, the bane of the life of every teacher of a laboratory course, are almost entirely eliminated since the inspection given in the laboratory ought to be sufficient. The corrections made in the presence of the student are most effectively made because the teacher can insist that the pupil must understand every point.
4. This process of varied questioning reacts upon the teacher and makes it certain that he, too, may learn something from the experiment and thereby avoid falling into any stereotyped treatment of the course.

The successful operation of this plan of treatment not only involves the centering of effort on one pupil at a time, but the teacher must not become so engrossed with the one that he forgets the many for one moment. He must develop the ability to read from the notebook, ask questions, and at the same time keep watch of the other members of the class. This is a tiring undertaking, and at the end of a two-hour period the teacher is tired both mentally and physically. But no matter how strenuous the work becomes, the best tonic for a teacher is the knowledge of a task well done. The results of this treatment are so satisfying that I have never yet known a teacher to give it anywhere near a reasonable trial without becoming an enthusiastic follower of the plan.

In order to carry out successfully such a plan as this, certain conditions should so far as possible be insisted upon. First, the habit which was formerly general and still persists in some quarters of regarding two hours of the teacher's time in the laboratory as equivalent to one recitation hour is pernicious. If laboratory time is properly spent the teacher will teach as much chemistry in one hour as he can in the same time in the classroom; one hour in the laboratory is as great a drain upon energy and mental force as an hour in recitation; and laboratory instruction is fully as tiring as quiz work. So in self-defense the science teacher should insist that each hour in the laboratory should count as heavily on the schedule as an hour of instruction spent elsewhere.

In the second place, this plan does not permit large classes. A teacher can instruct from fifteen to eighteen by this method satisfactorily, but larger units begin to cause trouble. Under ordinary circumstances we consider twenty-two the maximum, but under war conditions we have been compelled to put twenty-five to twenty-seven in a few sections. Where this is necessary the pupils must be taught to depend more completely upon their own resources. But large sections rarely give good results in laboratory work under any conditions.

One of America's most successful teachers of chemistry says, regarding our laboratory instruction, that "while a large amount of chemistry may be learned, the object is not to teach chemistry, but to teach the pupils how to learn—to confer ability and not knowledge." I am afraid that we boast more frequently about how many pages we can cover than we do concerning the thoroughness of our treatment and the amount of ability we develop in our students. A little work well done is worth vastly more than a glance at many topics, and to my mind whatever practice we follow in the laboratory we will succeed splendidly if we keep in mind the maxim that "each chemical experiment is a question put to nature, and forethought and care are necessary in putting the question, and study and reflection in interpreting the answer."