

PROBLEMS IN THE EXPERIMENTAL PEDAGOGY OF CHEMISTRY.

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The justification for including a subject in the curriculum of the secondary schools is either that through the study of it the pupil shall acquire useful information, or that it is well adapted for developing him mentally. The multiplication table is learned because it is useful in after life; it is a time-saver. Geometry, on the contrary, is taught not because it is essential to the majority of high school graduates, but rather because it is said to afford an excellent means of mental training. Luckily, the study of most subjects not only imparts useful information, but at the same time tends in some degree at least to increase the mental capacity of the pupil. That chemistry belongs to this latter class will scarcely be doubted by anyone at all familiar with the subject. In addition to a large number of very desirable facts, it offers excellent opportunities for training in manipulation, in specifically directed and intensive observation, in the correlation of ideas, and in logical reasoning. It should also stimulate the visualizing and creative imagination, foster the spirit of investigation and verification, and contribute toward the development of the so-called scientific spirit which, in the last analysis, is none other than the desire for truth.

From a consideration of an overcrowded curriculum the educator in a secondary school is called upon to decide whether or not chemistry offers equal or greater advantages than do other subjects for development along the lines just indicated. The field opened by the study of chemistry is very comprehensive, and it may be argued by some that this fact militates against material progress in any one direction.

Closely associated with the question of the desirability of

teaching chemistry is that of the amount of time necessary to give tangible results in the subject, and the manner in which this time shall be distributed. Is it, for instance, worth while to spend one year—approximately two hundred hours—on chemistry and then stop? Or would it perhaps be more efficacious to concentrate less and distribute the time over two or more years? Nor is that quite all. There must be due consideration of the manner and time of introducing this study. These are questions that can be answered partially at least by experimental investigation, and the possible lines of attacking the problems will be suggested under specific headings in the course of this discussion.

In order to determine the progress that has been made as the result of the pursuit of any given study, standards of measurement and methods of testing the results must be devised. Where the effect of the teaching is definite and tangible, the standards and tests are correspondingly simple and direct in their bearing. Spelling and drawing are taught in order that the pupil may be able to spell or draw, arithmetic to enable him to determine with facility and accuracy the amount of the grocer's bill or the contents of a pay envelope. The complete effect, however, of the teaching of these subjects may be much wider than this, and, as a result, more difficult to measure by any experimental method.

The few elementary facts of chemistry that are acquired and retained by the average high school pupil are of little value to him unless he can follow up the study after he has left the secondary school either in an institution of higher learning or in a trade in which he will use chemical processes. This will be the case with the smaller proportion of the pupils, as the majority of them will go into occupations where no such practical use of chemistry is made. The time spent by them in this study in the high school would be wasted, therefore, unless they have derived mental training along some one or all of the lines indicated in the opening paragraph. Although such training is difficult to measure, because of its intangibility, it is nevertheless in this direction that we must turn our attention if we are to obtain experimental evidence of the comparative value of the work.

It is not within the scope of the present article to discuss at length the nature of the tests best suited for the purposes of this sort of investigation. That is the province of experimental education; and it will doubtless be found that the methods at present employed in other branches are applicable in this new field of research. In general, it may be said that any tests applied must be made with the pupils before, during the progress of, and at the conclusion of the course. The same tests must be made with pupils taking courses other than chemistry, and the advancement of the various groups compared. Finally, these tests, to be of any real value to the educator, must be made on large numbers of pupils in many different schools in order to eliminate as far as possible the personal factors involved in the teacher and the type of pupil.

Let us next turn to a detailed analysis of the topics mentioned in the first paragraph of this article, and to the consideration of their fundamental and dynamic relations to the intellectual growth of the pupil.

MANIPULATION.

The problem of the education of the young by the use of the hands is a vital one, whether in the home, the school or the factory. It is pertinent in experimental chemistry because of the many opportunities for making, setting up and handling apparatus varying greatly in nature and use. Pupils on entering the course differ in a marked degree in inborn manipulative ability. To what extent this ability can be cultivated and improved by experimental work of such a special character is an interesting consideration for the educator. Furthermore, granting that improvement can be made, what should be the nature of the apparatus in order to increase the pupil's dexterity with the hands to the greatest possible degree in the time at the disposal of the teacher? The apparatus may be varied a great deal and less time devoted to any one mechanical action, or the operations may be repeated a great number of times until the pupil becomes proficient, as is necessary in successful glass-blowing. The handling of delicate apparatus, such as the chemical balance, should improve the

pupil's manipulative skill, but the results may not repay the outlay of time and energy necessary to obtain them.

Another point that demands attention in the consideration of the training of the pupil through the hands is the value of quantitative, or semi-quantitative, experiments as opposed to the purely qualitative. The latter tend to make the pupil careless and inaccurate in his habits, while the former are of necessity time-consuming. Last, but not least, the problem should be investigated as to whether the pupil learns to manipulate best by imitation (demonstrations by the teacher) or by being required to experiment with the apparatus until he discovers the most advantageous method or methods.

OBSERVATION.

Observation is, of course, of two kinds: that which is casual and that which is directed with some specific object in view. It is doubtful whether the study of chemistry will increase the power of the pupil to observe casually; but it would be interesting to have data on this point. The real problem, however, is whether the training he receives through the agency of chemical experiments enables him to observe more efficiently when called upon to do so in the ordinary occurrences of life, for it is with this end in view that we should endeavor to develop the pupil. The value of lecture experiments for the cultivation of observation is a question worthy of consideration in this connection. As a result of lectures copiously illustrated by experiments or of demonstrations given by the teacher, does the pupil's capacity for comprehensive observation improve materially? Now, it is true that a great deal of his knowledge in life is derived from observing the performances of others, hence it follows that the cultivation of his powers in this direction is highly desirable.

With regard to the experiments that the pupil is expected to perform himself, the question may be raised whether he should be given careful directions for the operations involved and left to observe all he can, or be warned to look for important points and for special phenomena. There is undoubtedly much to be said on both sides of the question, but at present we have little upon which to form definite opinions. If

the pupil is left to his own devices, he is liable to see the most spectacular phenomena only, and miss oftentimes the more vital. Take this instance. If a pupil is asked to record what he sees when copper filings and sulphur are heated in a test tube, he will probably note with the utmost care the exact manner in which the fumes of sulphur come off, missing entirely the fact that the reaction when once started will proceed by itself, causing the mass to become red hot on account of the heat generated. If this experiment was intended to show that some mixtures may burn without the presence of air, most pupils will fail to make the proper observation. This brings up another issue, *viz.*, precisely how can the pupil be trained to distinguish between the important and the minor or non-essential aspects? More than that, what is the educative value of the repetition of experiments when the pupil has omitted some important observations?

CORRELATION OF IDEAS.

From the fact that the pupil's knowledge of material things consists of relationships, similarities and differences, it follows that the recognition of these relationships by the pupil is of vital importance in acquiring a knowledge of chemistry. It is here, however, that the beginner is confronted by one of his greatest difficulties. He is met by a bewildering array of new facts and complicated phenomena. He is obliged to employ new processes of thought, and to express himself with exactitude (perhaps for the first time in his life) by means of a vocabulary where even the terms and expressions are unfamiliar to him. It is not astonishing, therefore, that the pupil should have difficulty in realizing the connection between ideas in a subject that presents so many new experiences to him.

It would be a fruitful line of research to investigate what can be accomplished by way of inducing the pupil to correlate fact with fact, fact with theory or theory with theory. It is still more important perhaps that he should connect what he learns in chemistry with the phenomena encountered in everyday life. A question for careful consideration here is the effect of closely-connected experiments on the pupil as a test

of his tendency to correlate. In other words, it behooves the teacher to ascertain whether the experiments the pupil is called upon to do should be chosen to illustrate the specific point at issue regardless of their connection with one another, or whether they should be correlated as much as possible. For example, combination of synthesis can be illustrated very well by heating magnesium or lead in the air, and metathesis by mixing a colorless solution of lead acetate with a reddish brown solution of copper chromate. In the latter experiment the double decomposition is manifested by the resulting blue liquid and the yellow solid. The same two changes may be equally well illustrated by heating copper and sulphur together, showing combination, and treating the copper sulphide thus formed with nitric acid to give an example of metathesis. Until we have evidence to the contrary, it would seem that the pupil's chances of realizing the relation between synthesis and metathesis would be greatly enhanced by having the experiments illustrating the two phenomena closely connected, yet this is a device seldom made use of in our laboratory manuals of chemistry.

Before concluding the discussion concerning the correlation of ideas, it might be pointed out how this close association between experiments may be extended to a very considerable degree. For instance:

1. Solid copper nitrate, which the pupil can make by evaporating down the solution obtained from the experiment with copper sulphide and nitric acid, may be left standing exposed to the air whereby the solid takes on moisture, thus illustrating deliquescence.

2. A few lumps of the solid placed at the bottom of a tall breaker or flask filled with water shows nicely how a dissolved substance diffuses throughout the entire liquid.

3. Copper oxide may be made by heating the nitrate, and it may also be made by heating copper in the air.

4. Copper hydroxide is easily obtained by adding a base, such as sodium hydroxide, to the nitrate.

5. Copper, copper oxide and copper hydroxide treated with nitric acid are typical examples for the formation of a salt.

6. Nitric acid, because of its volatility, can be driven from

its salts by heating them with sulphuric acid, as instanced by the formation of copper sulphate from the nitrate.

7. The water of crystallization of blue vitrol may be expelled and added again at will. In this manner the pupil acquires the idea of hydrates.

LOGICAL REASONING.

Generalizations, involving as they do one or more judgments or conclusions, are not only the necessary result of the study of any subject, but are made by every man in every walk of life; it matters not whether he sells typewriters or occupies the speaker's chair. These judgments will be justifiable only in case the premises upon which they are based are correct. The trouble with the untrained and the prejudiced man is that he often does not examine these premises carefully enough to be able to determine their validity. Now, this examination of the evidence is not so simple as it may seem at first sight. It frequently necessitates a form of analysis that is peculiar to the subject in hand, and is, therefore, largely dependent upon training. One common source of error is not being in possession of all the facts; another is the failure on the part of the reasoner to take into consideration all the facts he already has in his possession.

It would be no more reasonable to hold a man responsible for all the facts in every subject than it would be to expect him to be able to make all the manufactured articles on the market. It is within our rights, however, to insist that he should realize when facts fail him, and also that in such cases he is either not capable of passing judgment at all or his conclusions are only tentative and subject to revision on the presentation of further evidence.

Chemistry offers abundant opportunity for training the mind in the examination of evidence, and also for the forming of judgments, both tentative and final. The processes of thought are often very complicated, because of the element of uncertainty that enters into the premises upon which the deductions are based. So far in the pupil's career he has been accustomed to reason from axioms more or less self-evident, but has rarely been required to test the accuracy of funda-

mentals before arriving at his conclusion. A few illustrations will make this quite clear. In geometry the student begins with axioms, and the result follows logically therefrom. Witness the following example: The sum of the angles made by three straight lines completely enclosing a finite plane surface is equal to two right angles. This is of the nature of an imperfect induction, because there is an infinite number of such triangles possible. Yet the proof of a single case serves to make the pupil confident of the universal truth of the proposition. In an attempt to apply a similar line of argument to a case in chemistry difficulties are liable to be met with. For instance, the pupil who has been working with solutions of copper salts, such as the chloride, sulphate, nitrate or acetate, would very likely come to the conclusion that all copper salts give a blue color in water and a precipitate with hydrogen sulphide. His conclusion is, of course, fallacious, for if sufficient potassium cyanide is added to the solution of any of the above-mentioned copper salts, the blue color disappears, and hydrogen sulphide fails to give the anticipated precipitate.

The following subtle case is even more disconcerting to the young pupil. Experience leads him to believe that the rate of a reaction (rate being defined as the amount changed in the unit of time) is proportional to the temperature. For example, if he heats copper, it oxidizes more rapidly than it does at room temperature. Lead, iron and tin behave similarly. Barium oxide heated to 500 degrees centigrade obeys the same law, and takes on oxygen to form barium dioxide. If the law holds up to 500, it should hold at 1000 degrees; yet the pupil will find that it is impossible to form any large amount of barium dioxide at this temperature. In the light of this experiment it would be natural for him to suppose that the law had some exceptions. A little more experience, however, will teach him that the law is probably of universal application, and that the case of barium oxide and dioxide is a striking illustration of its validity. The explanation of the unexpected result is that the decomposition of barium dioxide is also proportional to the temperature, but that the temperature co-efficient of the decomposition is much greater in the neighborhood of 1000 degrees than that of the formation. As a

consequence, barium dioxide is broken up at high temperatures just as fast as it is formed.

We see from these considerations that deductions in chemistry are often fraught with great danger, because the premises are so frequently of the nature of imperfect inductions. Viewed from the standpoint of the pupil's training, this uncertainty should be a blessing in the hands of the skillful teacher.

The foregoing paragraphs have been leading up to the question of the choice of experiments for laboratory work. Many teachers contend that they should be kept as simple as possible, with but a single object in view. That this is desirable at first can scarcely be doubted by anyone. It is not so clear, however, just how far this policy should be continued. How is the pupil to learn to test his premises if we do not frequently give him the opportunity? Much experience has convinced the writer that continued plain sailing and simple examples tend to make the pupil unguarded in his conclusions, and lead him to form hasty judgments. The following experiment is a very good instance of a correction for this error: The pupil is given directions to melt, but not boil, potassium chlorate and test for oxygen with a glowing splinter. Next he is to add a portion of *manganese dioxide and again test*. Oxygen is now given off copiously, and most pupils conclude at once that manganese dioxide is thus proved to be a catalytic agent. A little reflection soon convinces them that from this experiment, as they have performed it, there is no proof as to whether the potassium chlorate, the manganese dioxide or a chemical reaction between the two is responsible for the evolution of the oxygen. It would be very instructive to test the effect of experiments of this type on the ability of the pupil to analyze carefully the evidence before him.

As has been already pointed out, another very common source of error is the failure on the part of the pupil to interpret results in the light of his previous knowledge. In fact, this is one of the most difficult problems the pupil has to face in his struggles with the subject. There are usually so many facts that must be brought to bear on the question at issue that the pupil becomes confused. For instance, he will prob-

ably conclude that hydrochloric acid contains free chlorine because starch paper turns blue if held in the vapors from a boiling solution of hydrochloric acid and potassium iodide. He forgets that hydriodic acid is not very stable and breaks down at the temperature at which he made his tests. Experiments of this nature involve reasoning from analogy, a very effective agent or a dangerous pitfall in argument, depending upon the ability of the reasoner to use it judiciously or otherwise. These experiments are splendid opportunities for correlation. Their effect where the pupil is called upon to concentrate many points of view on a single issue should be systematically investigated.

Another problem for research is whether the pupil should clearly understand the object before he begins the experiment or be left to conclude what the purpose was from the results he obtains. The scientist presumably knows what he is trying to show by his experimental work; but this knowledge often tends to make the pupil prejudiced, and therefore inclined to misinterpret his results.

IMAGINATION.

Imagination, although differing somewhat in kind and application, is just as essential for construction and invention in science as it is in literature or art. Chemistry is fertile soil for the growth of this important capacity, because of the many opportunities for visualizing, and for constructive problems. By constructive problems is meant those where the pupil is required to suggest the method of procedure and the apparatus necessary for the illustration or proof of the point under discussion. They need not be difficult, but should make demands upon the ingenuity of the pupil. This method of teaching is doubtless more time-consuming, as far as the accumulation of facts is concerned, but it is a question whether the pupil has not gained more at the end of the course. Data on this point are badly needed, especially in the case of pupils who have little or no natural ability for invention. While they are very much in need of developing in this direction, it may be that the headway made would not be great enough

to warrant the employment of so much valuable time. As to the type of the constructive problems, the pupil might be asked to suggest possible experiments to illustrate or prove the point under consideration. The difficulties in the way could be pointed out by the teacher or by other pupils, and means of overcoming these difficulties devised by the class. Variation in the apparatus employed for the same experiment offers opportunities for the development of mechanical inventiveness.

In the matter of visualization it would be of value to know what would be the effect of requiring the pupils to predict and describe before the experiment is performed what they expect to see during the operation. It is quite possible that many pupils would have such fixed preconceptions that they would lose more in open-mindedness than they would gain by the play of the imagination; but if proper guidance is given by the teacher, this should prove a valuable exercise to develop the power to visualize constructively. Another device to cultivate visualizing would be to have the pupils construct apparatus from description without the use of sketches or diagrams.

THE SPIRIT OF INVESTIGATION.

One of the difficulties in laboratory work with young pupils is the fact that most of them prefer the striking or spectacular. They would much rather make an explosion, or silver a mirror, than experiment with the object of deciding some disputed point. The desire to find out for himself and the willingness to examine the evidence are attitudes of mind so important that their development in the pupil is worthy of the most strenuous efforts on the part of the teacher. Such researches as have been suggested under the preceding heading would go far to reveal the best means of securing these attitudes of mind.