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Institution: Oklahoma A. and M. College Location: Stillwater, Oklahoma

Title of Study: METHODS OF INCREASING STUDENT AND TEACHER EFFICIENCY IN THE HIGH SCHOOL CHEMISTRY LABORATORY

Pages of Study: 36 Candidate for Degree of Master of Science

Major Field: Natural Science

Scope of Study: Preliminary searching of literature revealed that most information could be obtained from journals relating specifically to instructional methods, since the subject of the report was directly related to high school teaching. With the exception of Volumes 20 and 21 of The Science Teacher, all volumes of School Science and Mathematics, Journal of Chemical Education, and The Science Teacher from 1940 through 1956 were examined. The indexes were scanned carefully. Key words used were: apparatus, assistant, chemistry, demonstration, equipment, experiment, high school, laboratory, safety, semimicro, teaching and technique. Every article which, by its title, gave promise of revealing information concerning laboratory efficiency, was given careful attention. Information which was statistical in nature, recently published, or given as a result of many years of experience, was given greater consideration. All worthwhile information was outlined and evaluated as to content, consistency, conformity to normal standards, and degree of correlation with related information from other sources.

Findings and Conclusions: Many methods of increasing high school laboratory efficiency were assembled. The final analysis as to the value of any particular method must rest with individual teachers in specific high school laboratories. However, among the methods found for increasing efficiency, the following appear to hold forth greater promise of success: (1) the use of the semimicro method in student laboratory work, (2) the utilization of student assistants, whose services are compensated for by extra grade points, (3) strict adherence to safety factors, (4) the practice of economy in laboratory administration, (5) the strategic location of references, equipment, and chemicals in the laboratory or classroom, (6) improved methods of dispensing chemicals and equipment, (7) fuller use of available equipment, (8) use of the laboratory to its optimum extent, (9) the use of demonstrations when feasible, and (10) greater dependence on short quizzes for evaluation of student laboratory work, rather than on extensive laboratory reports for every experiment.

ADVISER'S APPROVAL James H. Zant

METHODS OF INCREASING STUDENT AND TEACHER EFFICIENCY IN THE HIGH SCHOOL CHEMISTRY LABORATORY

BY

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Bachelor of Science
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1954

Submitted to the faculty of the Graduate School of
the Oklahoma Agricultural and Mechanical College
in partial fulfillment of the requirements
for the degree of
MASTER OF SCIENCE
May, 1957

METHODS OF INCREASING STUDENT AND TEACHER

EFFICIENCY IN THE HIGH SCHOOL

CHEMISTRY LABORATORY

Report Approved:

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Report Adviser

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Dean of the Graduate School

PREFACE

Many methods of conducting student activities in high school chemistry laboratories exist. Some of these methods are conducive to an efficient system of laboratory training, while others contribute to less desirable practices.

Recommendations related to numerous aspects of chemistry laboratory administration are herein made, these recommendations having arisen chiefly as a result of extensive analysis of comparatively recent articles in educational journals dealing with such problems.

Indebtedness is acknowledged to Dr. James H. Zant for his constructive criticisms concerning various mechanical features of the report, and for frequent statements relative to scientific laboratory work, which were offered during regular scheduled class periods. Also, appreciation is expressed for constructive comments by Dr. Imy V. Holt during discussion of the problem in a scheduled period.

Much information was gained from informal discussions with participating Fellows in the National Science Foundation Program for High School Science Teachers.

Acknowledgment is sincerely extended to the administrators of the excellent library facilities, whose methods of handling library materials lessened the problems encountered during library research.

Writing of the report would have been impossible without the financial assistance provided by the National Science Foundation during the entire period of time necessary to complete requirements for the Degree of Master of Science.

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CHAPTER I

INTRODUCTION

The purpose of this report is to discuss and evaluate some methods of increasing efficiency and performance in the high school chemistry laboratory. It is obvious that much valuable time is wasted in high school laboratory work simply because of a lack of systematic procedures. Much inefficiency in high school laboratory work is due to inexperience on the part of the teacher, or the failure to realize the vast potentialities which stand at his command.

During the process of coordinating information, the following important factors were given careful attention: (1) In order to increase efficiency, safety should not be sacrificed; time to practice and teach safety is not wasted time. It is sheer folly to proceed with instruction without emphasizing this important aspect. The welfare of the student must be given constant attention, for a lifetime of good laboratory practice can not compensate for the loss of an eye, a hand, or a human life. (2) Since proper training of students is the aim of laboratory work, it would not be feasible to deprive the student of the best laboratory education possible, merely for the sake of achieving false efficiency. The learning process is an important entity, and it must be nurtured constantly by unselfish devotion of the teacher to the task at hand. Therefore, if a change in laboratory teaching methods should prove to be less desirable than a former method, this latter change should be discarded in favor of the former plan, or some other plan. Analysis and evaluation should be continuously practiced. They should be accompanied with an open mind and a strong desire to improve teaching techniques. (3) A balance in methods and procedures should be maintained. Variation in methods of presentation is a necessity if interest is to be prolonged. Some students may be able to grasp important concepts from theory alone; some may require sensory vision, but most students undoubtedly can attain a higher degree of progress by a combination of several different teaching methods. It is important to refrain from overindulgence in one particular phase or method of teaching the usual high school chemistry class. In addition to laboratory work, other processes should be given careful attention. Clear explanation of theory, together with audio-visual techniques, such as filmstrips, movies, bulletin board maintenance, meaningful demonstrations by the teacher or capable students, visitation by resource personnel, and field trips to industrial processes when applicable can help to stimulate intense interest. (4) All suggestions for improvement of teaching methods should be treated cautiously and with a questionable and scientific attitude. A system which works best for one individual may be the downfall of another. Numerous other things, such as available facilities, size of classes, and specific objectives for specific communities should be taken into consideration and weighed carefully. The teacher must act as his own evaluator, with full realization that the final outcome of any laboratory situation must serve a worthy purpose.

It was exceptionally difficult to arrive at definite conclusions concerning laboratory methods. The greatest amount of literature investigations were made in the following journals: Journal of Chemical Education, School Science and Mathematics, and The Science Teacher. With the exception of Volumes 20 and 21 of The Science Teacher, which were not available, every volume of the above named journals from 1940 through 1956 was examined.

Critical examination of the literature revealed that a great deal of disagreement exists. After reading numerous articles dealing with a considerable number of laboratory topics related to efficiency, and after analysis of a large portion of available statistical experimental results, most conclusions reached were in accordance with what appears to be the most predominate methods and practices in some of our progressive schools today. More significance was usually given to the most recent articles.

The result of this study is the accumulation of information which, if used, seems to promise more efficient methods of laboratory instruction than is the case in a number of high school chemistry laboratories at the present time.

By keeping in mind the diversity of conditions in different schools, by making variations accordingly, and by adherence to some of the ideas presented in this report, the following goals should ultimately be realized: (1) Chemistry teaching should be made more pleasant, and a greater feeling of satisfaction should be attained. (2) Several types of subject matter may be taught more efficiently with greater retention on the part of the students. (3) A type of chemistry student better prepared for college work should emerge from high schools. (4) Revitalized interest by students in chemistry should become more apparent. (5) The chemistry teacher should realize a fuller life by the elimination of some types of drudgery, which may be dispensed with while still maintaining high standards of teaching. (6) Because of better efficiency methods, chemistry teachers should become more available for community work and recreational facilities. More time to improve oneself by keeping abreast of some of the recent developments should be realized.

May it be emphasized that it was not the writer's intention to attempt to solve all details of laboratory work. Specific methods which could apply universally to all high school chemistry laboratory instruction are not to be found. Rather, it was an attempt to correlate ideas, practices, and recent developments which could have strong suggestive power for helping to promote more efficient laboratory methods, along with better student performance and achievement, without endangering the tried and proven methods already in existence.

CHAPTER II

SAFETY IN THE LABORATORY

Safety is directly related to efficiency and performance in the laboratory, since the lack of proper safety practices can cause a tremendous loss of time by the teacher or students. Consequently, this report would be incomplete without a brief treatment of this important aspect.

It is imperative that the high school chemistry teacher familiarize himself with current recommended safety practices. He should take ample precautionary measures and, in addition, he should educate himself sufficiently so that he will be able to contend with most emergency situations.

Safety becomes increasingly important with the advent of our recent increased enrollments, which have caused some laboratories to be filled to the point of overflowing. Also, with the progress of nuclear processes and their development, another science teaching aim may well be to instill attitudes of safety into the students' minds.

Periodically, it is necessary to make a systematic check of the laboratory. Particular attention should be given to the following items: exits, floors, illumination, fire extinguishers, fire hoses, safety showers, fire blankets, goggles and masks, shields, screens, gas masks, hoods, catch pans, flammable liquids, corrosive liquids, methods of pipetting liquids, glass handling, and general housekeeping.[1]

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[1]Howard Fawcett, "Safety Checks for Chemistry Laboratories," Journal of Chemical Education, Vol 24, (1947), p. 296.

Burns has offered the following suggestions for helping in the elimination of many accidents occuring both in the chemistry laboratory and outside the laboratory:[2]

(1) Eliminate potassium metal and red and yellow phosphorus from high school and home chemistry laboratories.
(2) Emphasize the idea that potassium chlorate may be as dangerous as potassium cyanide.
(3) Attempt to have some uniformity of ideals and practices by the retail chemical supply houses toward sale of chemicals to minors.
(4) Discourage (parents may prohibit) interest in pyrotechny and rocketry.
(5) Encourage amateur chemists to confine their activities to a chemistry laboratory in a basement, garage, or shed.
(6) Inform adolescents and particularly amateur chemists of the dangers of potassium chlorate and gunpowder explosives, colored flares, and rocketry.

Instead of using potassium in laboratories, it is entirely safe to use calcium, which illustrates the same principle in many cases. Even the use of sodium should be largely curtailed in high school laboratory work. If either sodium or potassium must be used, it is much safer if their chemical properties are demonstrated by the teacher.

In view of the many recent articles which have appeared in numerous newspapers and magazines, the wisdom of using carbon tetrachloride is seriously questioned. The same may be said of ether.

Extreme caution should be taken if volatile combustible substances such as methanol and carbon disulfide are used. Only recently, the writer witnessed four minor accidental explosions of methanol in the same laboratory period of a college organic chemistry class. These four explosions caused rather painful burns in two instances and did severe damage to two expensive textbooks. Had it not been for the alertness of the laboratory assistants and several fellow laboratory

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[2]Craig Burns, "Chemical Accidents Involving Minors," Journal of Chemical Education, Vol. 33, (1956), pp. 508-11.

workers, the damage would certainly have been more pronounced.

It is a well known fact among chemistry teachers that preparation of the halogens involves a variety of dangers, one of the chief hazards being the likelihood of breathing the deadly fumes which emerge during the process of preparation. Until more modern methods of preparation involving improved techniques with economical apparatus are developed, it would be wise to minimize the prevalence of dangerous fumes by having the halogens prepared by pairs of students, or in the case of chlorine, only by the instructor or capable students as a demonstration. Of course, if hoods are part of the laboratory equipment, as they are in the most modern school buildings, they should be utilized to the fullest extent. It is suggested that bromine be prepared in a small retort. In the case of each halogen, it would be well for the students to calculate the theoretical yield and use only a very small excess of reactants. In addition to being safer, this would be a valuable aid in helping students to gain computative skills.

Iodine may be conveniently prepared by mixing dilute solutions of sodium sulfite and sodium iodate. To this should be added a dilute solution of sulfuric acid. This method has the advantage that the iodine forms beneath the surface of the water without noticeable sublimation. Since the iodine formed is only slightly soluble in the solution, it will remain in the bottom of the beaker as the solution is poured from it.

For preparing chlorine, some experience has shown that vapor damage may be reduced by the addition of a sufficient amount of hydrochloric acid to the manganese dioxide in the generating flask to produce approximately one collecting bottle full of chlorine at one time. This collecting bottle may be covered with a cardboard cover through which the delivery tube passes. A fter filling, another bottle may be substituted.

Customary precautionary measures, such as keeping ammonium hydroxide close at hand for emergency use, staying well above the apparatus set-up, and the use of gas masks with appropriate fillers cannot be overemphasized.

It is suggested that the semi-micro laboratory method discussed in Chapter V of this report has a tremendous value in reducing hazardous conditions due to toxic vapors.

In all chemistry laboratory work, the instructor should set an example before his students by using aprons, eye protective equipment when needed, correct procedures in glass working, and various other safety measures.

An invaluable aid to every laboratory instructor is a Fisher laboratory emergency chart, which may be obtained without cost from the Fisher Scientific Company. The same company also publishes a manual dealing with laboratory safety. Conscientious study of this manual should minimize many dangers of laboratory work.

CHAPTER III

SOME EFFICIENCY ARRANGEMENTS AND METHODS

In addition to the ordinary multiple duties of the chemistry teacher, he must be sufficiently versed in salesmanship and psychology. He must possess the ability to put across important ideas out of the classroom, as well as in the classroom. The teacher's duties must be performed with diligence and perseverance. He must cooperate with fellow workers, with administrators, and with the public. In short, the teacher must realize that his capacity is that of serving the community and the people with whom he is associated.

The foregoing is not meant to convey the idea that one should satisfy the whim and fancy of every individual who dares to intrude upon his carefully worked out plans. Rather, one must possess a considerable degree of negotiating ability, somewhat akin to that possessed by some of our outstanding statesmen and foreign diplomats.

In order to convince the administration and the public of his sincere efforts, the instructor must achieve results which express the idea that professional judgment has been used in working out trying situations.

If some type of laboratory equipment is badly needed for better instruction or for greater efficiency, it should be possible to obtain it. "A costly item of equipment is justified if its contribution is great over a long period of time, and if it releases the teacher's energies in the right direction."[1]

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[1]Morris Meister, "Science Rooms for Secondary Schools," _The Science Teacher_, Vol. 15, (1948), pp. 75-6.

Realizing that funds are never unlimited, he should judiciously select new equipment and fully utilize present equipment. Therefore, ability to economize and demonstrate that economy is a desirable asset. To this end, efficiency, economy, and performance go hand in hand.

If science instruction is to proceed at its maximum potential, funds must be available for purchasing equipment, once the need has been ascertained and justified by mathematical argument.

References for the Classroom

Provision for a sufficient number of chemistry textbooks should be made. These books, and other reference material, should be located in the chemistry classroom and made easily accessible to the students by convenient permanent location or by placing in portable bookshelves.[2] Cards for checking out books should be arranged similarly to systems used in modern libraries, in order to prevent wastage of time in looking through a maze of papers which may be in the teacher's possession. Books should be kept in shelves in some systematic arrangement, such as arrangement according to content, or perhaps preferably, according to authors' names.

It is relatively easy for the chemistry teacher to accumulate a great deal of valuable reference material with a minimum of expense by writing to various industrial organizations, and by carefully scrutinizing the feature sometimes termed "Free and Inexpensive Material" in many scientific educational journals. In just a few years, an exceptionally well equipped classroom library may be built up. The NSTA Packet Service will contribute many valuable items toward this end.

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[2] Addison Lee, "Order in the Department," The Science Teacher, Vol. 14, (1947), pp. 117-19.

A systematic method of filing teaching aids should be developed. The teacher's ingenuity can determine a satisfactory method for his own particular service. Boxes of various shapes and sizes may be obtained at an almost unlimited number of sources. As crude as this may sound, these boxes may be dressed attractively, thereby serving the worthwhile purpose of helping to conserve time.

Location, Transportation, and Use of Equipment

In many laboratories, much time is lost in searching for needed equipment and reagents. Time required for cataloging all equipment will be repaid many times during the school year. This may be done at inventory time.

Reagents in most laboratory storerooms are placed in alphabetical order unless safety considerations necessitate some other arrangement. Also, larger containers of reagents are normally placed near the floor. Labeling of shelves and reagents will facilitate ease of location when materials are needed.

In order to save time in assimilating demonstration equipment, apparatus for specific demonstrations that may be used from class to class and from year to year should be left assembled.

Many steps may be saved in transferring chemicals and apparatus between storeroom and classroom by using some type of portable table on rollers. This transporting medium should be narrow enough to facilitate easy accessibility to the storeroom and other rooms. For this type of table, it would be well to have a retaining strip around the edges to prevent possible dropping of materials transported. In addition to saving time, a table of this type will contribute to economy by prevention of equipment breakage.

In order to avoid repeated re-examination of damaged equipment, there should be a definite place for such equipment while it is awaiting repair. Special repair equipment is a must for efficient laboratories.

Among this maintenance equipment should be steel wool and emery cloth, which may be used periodically on ringstands, tripods, burners, and other hardware.[3] Black or aluminum colored paint applied during the periodic repair sessions will do much to help preserve equipment, in addition to increasing the appearance of neatness in the laboratory. Much work of this type may be done by student assistants if a satisfactory student assistant program can be incorporated into the system.

Repair work such as this will prove to be a great economizing factor, and will serve an additional purpose of helping to convince the administration and the public to be a little more understanding whenever requests for more equipment are made.

Pure Water for High School Laboratory Use

Available water of high purity is an item of varying importance in high school laboratories. The necessity for a system of producing high purity water depends on a number of factors which must be considered by individual teachers. The total number of students enrolled in chemistry classes, the amount of qualitative and quantitative work carried out in classes, and the impracticability of obtaining satisfactory water from other sources are three factors which can justify the purchase of equipment for producing high quality water. Also, water of high purity may be in serious demand by capable students who are interested in projects and advanced work. Keep in mind, too, that most water solutions should be

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[3] Gerald Osborn, "Maintaining Laboratory Hardware," School Science and Mathematics," Vol 52, (1952), p. 527.

prepared from high purity water.

It might be well to consider the possibility of producing satisfactory laboratory water by utilizing one of the several types of deionizing systems, which are very economical in comparison with traditional types of gas or electric distillation systems.

According to Dickinson, some of the advantages of producing deionized water are as follows:[4] (1) The purity compares favorably with and sometimes exceeds that of distilled water. (2) Installation is more simple and less expensive. (3) A source of heat and a continuous flow of water are not needed. (4) The rate of production is five or more gallons per hour. (5) Water equal in purity to that obtained from a single distillation is produced.

Some Economy Measures

There are a number of methods of economizing, especially in relationship to purchase of equipment. The following methods are offered:[5] Pupils may be asked to bring glass jars from home. These may be used for the collection of gases. By purchasing a small inexpensive glass cutter, it is possible to obtain squares of glass from pieces of scrap window glass for cover plates. Perhaps it might be a good idea to heat gently the edges of such squares in order to smooth them to some extent. Labels may be obtained from a roll of gummed paper.

In purchasing chemicals, it is well to refrain from buying chemicals

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[4] Joseph E. Dickinson, "Laboratory Water for Less," <u>School Science and Mathematics</u>, Vol. 54, (1954), pp. 743-54.

[5] Elbert C. Weaver, "Demons in Demonstration," <u>Journal of Chemical Education</u>, Vol. 22, (1945), pp. 339-41.

of higher quality than necessary for the purpose they are to serve. Many chemicals may be bought from local stores at a substantial saving. Unless research of exceptionally high standards is carried out, there appears to be insufficient reasons for paying excessive prices for such chemicals as sucrose, when it can usually be obtained locally at less than half the cost than would have to be paid to a chemical supply house. The same applies to sodium chloride, sodium hydroxide for most purposes, and many other items.

It is true that some of the above suggestions require more time than would be consumed by obtaining everything from the same source. However, student assistants may be utilized in carrying out some of the suggestions. Also, the savings made over a short period of time may be applied to some badly needed efficiency equipment, such as an extra centrifuge, an extra balance, or anything which might be urgent at any given time.

Easing the Dispensing Problem

Under proper supervision and with proper facilities and conditions, there should be no legitimate reason for not allowing students to obtain most of their own reagents from side shelves. This does not mean that they should be allowed to enter the storeroom. If they are allowed to obtain their own reagents, they should previously be instructed as to proper methods of obtaining them so as to avoid contamination and waste. These reagents may be kept out in containers conducive to easy procurance. Close supervision, especially during the first part of the year, should be given. Enough side shelf space should be provided to keep a sufficient amount of the most frequently used chemicals available. In relationship to the side shelf situation, the careful judgment of each individual teacher must be exercised. For example, it would be out of the question to use the side shelf method of making chemicals available unless the chemistry laboratory could be kept locked at all times when not being used. Other specific local situations might prevent the carrying out of this method. If the method is used, it is imperative that the chemicals be located in a systematic manner, so they can be found by the student easily.

Much information has been printed in laboratory manuals and journals suggesting that chemicals for use in a particular laboratory period should be located in the same vicinity of the laboratory room. Some experience in using this method as compared with a method of distributing the several chemicals at various strategic spots throughout the laboratory has convinced the writer that the distribution method is a more satisfactory method. True, it may require a few more steps per student, but a student is very seldom capable of carrying the entire list of reagents to his desk at the same time without danger of breakage accidents. Distribution of reagents at several spots throughout the room brings about a reduction in both clutter and clatter. Long lines are avoided. Traffic is diverted from a main pathway, and the overall result is a quieter and more orderly laboratory period. Of course, the exact positions of the various chemicals must be made known to all students, and insistence on maintaining proper positions should be emphasized.

A considerable amount of time may be saved during the issuing of equipment at the first of the year. Also, some economy may be realized at the same time. Moore outlines a method of handling equipment whereby the students may have as much, or even more equipment than is the usual case in many laboratories which may already be considered well-equipped.[6] This may be accomplished with less total equipment.

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[6]Fred W. Moore, "Providing Apparatus and Equipment for Teaching High School Chemistry," <u>School Science and Mathematics</u>, Vol. 51, (1951), pp. 629-34.

Type "C" Equipment (Continued)

Motor driven stirrer
Colloid mill
Various volumetric flasks
Up to 12 inch evaporating dishes
Casseroles
Weighing bottles
Crystallizing dishes
Filter flasks
Hand balances
White base burette stand
Various thermometers
Hydrion paper
Cobalt glass
Ignition tubes
Nickel crucibles
Iron crucibles
Glass beads

Laboratory Partners

Evidently, very little experimentation has been carried out recently concerning the wisdom of allowing students to work individually, in pairs, or in larger groups. Some investigations carried out by W. W. Carpenter in the early 1920's uphold the individual system. His results showed that the individual method brings about better learning processes, and that the learning process is reduced as more students work together.[7]

However, under certain circumstances, it would be allowable to permit students to work together. Certainly it is better to allow students to work together than not to work in the laboratory at all. Therefore, at least one justification of allowing work by pairs would be the lack of ample equipment.

No statistical data could be obtained from the more recent periodicals. However, it appears that there should be definite advantages and disadvantages to both systems. Some advantages of working in pairs should be as follows: (1) Less time should be required for many experiments, especially those requiring extensive manipulation of

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[7]Francis D. Curtis, "Individual Laboratory Work Must be Retained," *The Science Teacher*, Vol. 17, pp. 63-4.

equipment. (2) Tension in some types of students should be less. (3) Less material may be used. (4) Working with others should be a normal situation; therefore, working in pairs should be the more natural method. (5) The work of the teacher should be less, because of the necessity of issuing only half as much equipment.

On the other side of the picture, some expected disadvantages should be: (1) One student may do most of the work. (2) Less chance to develop self-confidence and self-reliance would be present. (3) Each student would have less working room. (4) Individual responsibility would be decreased. (5) A noisier laboratory period would probably exist. (6) There might be less opportunity for indvidual work on topics of special interest to the student.

Regardless of which of the above methods is used, it is doubtful if the increased educational damage of either of the systems over the other would be injurious to the student in a pronounced manner.

A Method of Approaching Peak Laboratory Usage

A plan for using the chemistry laboratory to its maximum extent was initiated at Temple University in the late 1940's.[8] If a critical shortage of equipment deems it necessary, the plan should improve the high school laboratory situation admirably.

It is a plan whereby the same set of apparatus is used for a succession of students in different sections. This would reduce the amount of necessary equipment. It would necessitate the leaving of a clean and complete locker for the next student. It would be the duty

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[8] Wilbur C. Dunning, "The Maximum Use of the Chemistry Laboratory," *Journal of Chemical Education*, Vol. 26, (1949), p. 490.

of the incoming student to report his set incomplete if it is found as such. A specific location within the locker would be necessary to facilitate ease of checking equipment by the student.

At Temple University, the conventional "check in" and "check out" was eliminated, thereby easing the problem of transportation between the classroom and laboratory.

This method was undoubtedly an asset to those who experienced it, and it could certainly be used in similar situations. However, its use in high school would pose several problems. First, since the usual high school laboratory period is fifty to sixty minutes in length instead of the usual three to four hours of the college laboratory period, the time required for the student to check his equipment would have some bearing on whether it could be used. Second, the time for cleaning up at the end of the period would be limited. Third, since high school students are ordinarily less mature than college students, they might have some dislike of following a student who leaves the desk in an untidy appearance. Fourth, if much qualitative or quantitative work is to be done, it is sometimes necessary to leave some unfinished business for completion during another period.

If the system could be used in high school, it would be a tremendous boon to economy and ease of laboratory administration.

Demonstrations

The utmost in saving of materials could be realized by performing all laboratory work by demonstrations. However, there are very few, if any, chemistry teachers who would sanction such a plan. After numerous attempts to return exclusively to the demonstration method in the laboratory in the 1930's and even later during World War II, when necessity demanded it in some instances, it was finally shown by experimental methods, common sense, and intuitive argument that the student participation laboratory method is far more desirable. Nevertheless, demonstrations, as mentioned earlier, still have their place in chemistry instruction. They should be used as a supplement to regular laboratory methods and theoretical presentation. Demonstrations may be presented to arouse interest, to clarify certain difficult points, to confirm or deny textbook statements, to illustrate formation of precipitates, or to present a problem at the beginning of a new unit.

Even though demonstrations are valuable teaching aids, they cannot take the place of student participation in laboratory work.

CHAPTER IV

STUDENT ASSISTANTS

Because of recent increased enrollments in many chemistry classes, it becomes almost imperative to adopt some system of student assistantship. In many cases, increased duties of teachers prohibits a sufficient amount of individual student attention. However, the use of student assistants can help conserve teacher time almost as much as any other single factor. In addition, the assistants will be receiving a type of training which will help to produce self-confidence, leadership ability, very close familiarity with methods of administration, and more lasting knowledge of many chemical processes.

Although it is possible to obtain student assistants without remuneration of any type, it is doubtful if a satisfactory degree of success can be attained in most cases without some type of extrinsic motivation. Since only limited funds exist in even the most fortunate schools, it becomes necessary to offer compensation in the form of extra credit points for services rendered by the students.

Lehmann divulges a workable plan which has proven successful in his teaching, and which may be adopted with minor changes if appropriate, by administrators of other high school laboratories.[1]

Two students who have the time and desire, and who have been recommended as capable and dependent, are selected from each class.

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[1]Glenn A. Lehmann, "Student Assistants in the High School Laboratory," Journal of Chemical Education, Vol. 24, (1947), p. 354.

They do their work on a preparation table in the storeroom during the laboratory period.

Each of the five pairs selected stays one afternoon in the week to help in the laboratory and with clerical tasks. They may utilize part of this time to complete experimental work. Some of their tasks are sweeping the storeroom, cleaning sinks, checking water and gas outlets, straightening and filling reagent bottles, cleaning soiled equipment, helping set up demonstration apparatus for the next day, straightening chairs, pulling window shades, and recording test scores. If any objective type tests are given, they may also assist in grading the papers.

A number of students who have ranked well in chemistry the preceding year are chosen as senior chemistry assistants. Students who have been assistants the previous year are given preference as senior assistants. These students work on elementary qualitative analysis during regular class discussion. They help to check apparatus set ups, observe students at work, make suggestions for prevention of dangers, sign workbooks when approval of certain experiments and weighings are required, see that students have desk, sink, and floor clean at the end of the hour, and perform various other duties. No one is permitted to serve as senior assistant if it prevents his taking physics.

CHAPTER V

THE SEMIMICRO LABORATORY SYSTEM FOR HIGH SCHOOLS

The greatest potential for increasing laboratory efficiency and performance in the high school laboratory seems to lie in the use of the semimicro method. This system has been used in high schools on a limited basis for a long enough period of time that definite conclusions as to its value have been reached. Its use can make chemistry teaching a genuine pleasure, while bringing about excellent achievement results on the part of the students.

Changing from the macro method to the semimicro method by laboratories already equipped presents the greatest problem. However, the change need not be abrupt, but it may take place over a period of several years. Equipment which would be an absolute necessity the first year would be smaller size test tubes, flasks, beakers, funnel tubes, and wide mouth bottles.[1] Semimicro centrifuges, general reagent bottles, and reagent trays or blocks would also be required from the first. The reagent blocks need not exceed one foot square, and they may be drilled to accomodate most of the liquid and solid reagents used by students during the course of the year. It is the usual practice to supply one reagent block for each two students. Students may refill their own dropper bottles from convenient dispensing bottles kept in an adjacent location. In addition to the reagents in the students' reagent trays, it is necessary to provide

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[1]Harry H. Williams, "Moving to Semimicro in High School Chemistry," The Science Teacher, Vol. 17, (1950), pp. 172-74.

a few other special chemicals on side shelves.

Some equipment which would never have to be replaced would be ring stands, rings, burettes, clamps, and bunsen burners, although specific semimicro equipment would generally be preferred.

Assuming that several sections of chemistry are taught, it would be necessary to continue the use of macro equipment on hand to some extent in all classes, and perhaps exclusively in some classes, until it could be replaced by a gradual change without drastic effect on the budget.

From reports concerning initial equipping of laboratories with semimicro equipment, there is no clear-cut difference in capital required for the semimicro and macro methods. The cost for equipping a new laboratory with semimicro equipment providing facilities for seventy-five students at a Minnesota High School several years ago was $1100.[2] "In converting an existing macro laboratory into a semimicro laboratory, the total cost for a section of about ten students, or of any number of such sections, run one after the other, is of the order of $100 to $150."[3] Present costs may exceed this amount. Most reports confirm a pronounced saving on both equipment and chemicals after the original expenditures have been taken care of.

If further information concerning necessary equipment and gradual change from the macro to the semimicro method is desired, see Semimicro Laboratory Exercises in High School Chemistry.[4]

Some of the changes which accompany the change to semimicro are

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[2]Karl J. Aaberg, "Semimicro Procedures in High School Laboratories," School Science and Mathematics, Vol. 55, (1955), pp. 486-88.

[3]Foster H. Hoff and Alfred S. Brown, "Semimicro Techniques for High Schools," Journal of Chemical Education, Vol. 26, (1949), pp. 530-33.

[4]Fred Weisbruch, Semimicro Laboratory Exercises in High School Chemistry (Boston, 1956), D.C. Heath & Co.

changes in weighing, filtering, and measuring. Since the quantitative aspect of the semimicro method is much smaller, it is necessary to obtain balances capable of weighing accurately to within .01 gram unless such balances are already part of the laboratory equipment. Filtering in semimicro work requires one or more centrifuges, depending on the size of classes. In relation to measuring, students will learn to count drops, or to make estimations by careful observation of the amount of fluid in a dropper. Graduated cylinders of ten milliliter capacity are appropriate for usual close measuring, while small pipettes should be used for more exact measurement.

To the writer, the advantages of the semimicro method seem to far outweigh the disadvantages. However, it would be well for individual teachers contemplating a change to semimicro to consider the following factors: (1) More accurate weighing equipment is required. (2) Separate macro equipment for demonstration purposes must be maintained, since semimicro apparatus would not serve that purpose. (3) Much time is required for initial filling of reagent bottles. (4) The additional cost of changing over will be felt for a few years.

On the other hand, there are many decided advantages which have been stated, proven, and confirmed by a number of laboratory instructors since the inception of the semimicro method for high school use. Some of the advantages usually given are listed and briefly discussed: (1) The semimicro method brings about a greater sense of satisfaction, since it is possible to accomplish more in a given period of time. Also, a student is more apt to take pride in his work, and exert conscientious effort in order to keep his individual reagent block and equipment in good order. (2) Noteworthy savings in chemicals may be made, since only minute quantities are required to produce effective results. Other noted savings are savings on plumbing and general laboratory maintenance. Drains are less likely to become blocked, and there is less spillage of chemicals on floors and table tops. Ventilation requirements are reduced. (3) A saving in time is evident. The teacher has more time for individual instruction, since all his time is not used to search for and dispense chemicals. Students save time by having most necessary materials at their desks. In addition, semimicro apparatus is usually less elaborate than macro equipment; consequently, less time is needed for setting it up. (4) Because each student may remain at his locker throughout most of the laboratory period, the laboratory becomes more orderly. As a result, discipline becomes a minor problem. Cleanliness and neatness is easier to maintain, while sloppiness is avoided. (5) The chance of a hazardous explosion is much less, since only small quantities of materials are used. Bad odors and poison gases are reduced to a minimum. Therefore, the health of the student is preserved. (6) More space becomes available in storerooms, on top of desks, and in individual lockers. Because crowded conditions tend to facilitate breakage of apparatus, a saving in this respect may be realized. (7) Provision for individual differences becomes apparent. It is possible for slower students to work at their own pace, thereby easing tension caused by rushing and non-convincing results. The gifted student need not be held back with the rest of the class, but may, with adequate supervision, forge ahead to satisfy his own curiosity. There is no need for all students to terminate a given experiment simultaneously. (8) Responsibility for wastage, contamination, and breakage may be fixed individually. This has the effect of producing more careful students. (9) Initiative, originality, and judgment are not allowed to fall by the wayside. The inquiring spirit is maintained.

The overall result of the semimicro method is a more efficient system of laboratory work, better performance by the students, and better instruction.

CHAPTER VI

EVALUATION OF LABORATORY WORK

Many methods of evaluating laboratory work are in use today. It is an impossibility to make any particular method of evaluation acceptable to all teachers. Even if it were possible to do this, there is no assurance that it would be the best method. In the light of these facts, suggestions are herewith made which seem to promise a saving in time, while not endangering the educational value of the laboratory.

Modern present-day trends have been analyzed with careful consideration and conscientious effort.

The ability to write understandable reports is highly ranked among the educational objectives set by industry for many types of their employees. Therefore, this phase of training cannot be shunned completely if contribution is to be made to this important objective. However, if time is to be utilized efficiently, it seems wasteful to require written reports to be handed in for every experiment.

Although it should not be the goal of the teacher to gratify the wishes and desires of all students, neither should laboratory work be made distasteful to an excessive degree. If care is not exercised, the requiring of a great number of written reports may have that effect. "The amount of time needed for the instructor to read such laboratory reports, if he is conscientious, is entirely out of proportion to their value." [1] It must be kept in mind that students, as well as teachers,

[1] John H. Secrist, "Laboratory Quizzing in the Freshman Chemistry Course," Journal of Chemical Education, Vol. 29, (1952), pp. 283-85.

are pressed for time, and the requirement of excessive time for preparation of abnormal assignments may have the effect of suppressing the desire to satisfy individual curiosity. If individualism is to be developed to its desirable extent, time must be available for that development. Truly, opportunities for writing reports, giving oral reports, and working on projects must be given, but interest, curiosity, and constructive imagination must not be stifled in the process.

Some type of record for each experimental venture should be kept by the student, for keeping of accurate records is an integral part of all scientific endeavor. Pertinent information must be recorded as it is obtained.[2] Otherwise, the important points may be forgotten rapidly, while carelessness is tolerated. If a lengthy period of time intervenes between the process of experimentation and recording of information, very few of the results may be accurately recalled. This may result in the student's obtaining information from other students.

Even though the student is not required to hand in every report, the teacher must make a concentrated effort to supervise methods of keeping records. The use of student assistants, along with the use of the semimicro method previously discussed, can help to free the teacher for this important duty.

The student is more apt to benefit from the suggestions offered him while he is making a report than from belated criticisms written with red pencil marks on his completed report. The longer the period of time between handing in a report and getting it back, the less will be the

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[2] Francis D. Curtis, "Improving the effectiveness of Laboratory Work," Journal of Chemical Education, Vol. 21, (1944), pp. 251-56.

derived benefits to the student.

Accuracy of recording must be stressed. Things actually observed, rather than things which should happen, are to be recorded. Because of this truthful and accurate recording, the student should not be penalized, but may be encouraged to repeat portions of the experiment. After all, why should the student be expected to achieve near perfection in results, when teacher demonstrations often fail? If extreme accuracy is demanded at all times, scientists are not being produced. Instead, this demand is conducive to conniving, swindling, and striving for results in a reverse procedure. It is much better for the student to utilize whatever reserve energy he possesses for repeating experiments and trying to determine why something failed, rather than trying to beat the clock.

If all reports are not graded, and extensive write-ups are not usually required, how, then, is the student's work to be evaluated?

Recent trends seem to indicate that more and more dependence is being placed upon short quizzes over laboratory work performed during a previous period.[3] Two advantages of this type of evaluation are: (1) much time is saved in grading of extensive reports, and (2) the knowledge of chemistry gained from laboratory work is tested, rather than ability to obtain answers from any source for the sake of completing a report.

Evaluation may be based on both reports and short quizzes, with greater emphasis, in the interest of efficiency, being placed upon the quizzes.

Some indication of student preparation for laboratory work may be gleaned by frequent short quizzes preceding laboratory work. A brief

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Carl P. Swinnerton, "Evaluation of Laboratory Work in Chemistry," Journal of Chemical Education, Vol. 31, (1954), pp. 44-5.

summary of principal objectives may be called for, or a few pertinent questions easily answered by students who have made preparation, even though they may not understand the complete mechanics of the experiment to be performed, may be given.

Good tests, devised specifically for testing laboratory work, are very scarce. However, Curtis has suggested the use of mimeographed diagrams for student labeling, and objective type tests designed to stress important experimental points.[4] Hendricks has proposed the use of questions designed to illustrate the use of apparatus or the "laboratory situation" in a paper-and-pencil test.[5]

Regardless of the methods of evaluation used, the complexity of modern-day teaching demands that individual teachers use selective judgment to reduce the evaluation time required, in order that their obligations may be budgeted wisely.

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[4]Francis D. Curtis, "Improving the Effectiveness of Laboratory Work," School Science and Mathematics, Vol. 44, (1944), pp. 251-56.

[5]Clifford Hendricks, "Paper-and-Pencil Tests for the Laboratory," Journal of Chemical Education, Vol. 22, (1945), pp. 543-46.

CHAPTER VII

SUMMARY AND CONCLUSIONS

The problem of increasing efficiency in the high school chemistry laboratory has been stressed in this report.

Although identical methods of conducting all laboratory situations are not likely to be adopted, some suggestions for improving laboratory efficiency have been given. These suggestions were made only after careful analyses of statistical information presented by writings in some of the most recent leading educational scientific journals by experienced laboratory administrators. A limited number of conjectures have been offered by the writer, as a result of past experience, or as a result of the correlation of available information.

Each distinct high school must be considered from specific points of view by individual chemistry teachers. Each school presents different problems which must be dealt with, while problems of one school do not necessarily imply that the same problems exist in other schools.

The adoption of the semimicro method of laboratory instruction appears to possess greater potential for increasing efficiency than any other single factor. Many advantages resulting from the semimicro laboratory system have been listed and confirmed by a considerable number of high school chemistry teachers. These advantages include the saving of time, space, and money, better order in the laboratory, less hazardous conditions, increased student and teacher satisfaction, and better instruction.

The systematic utilization of student assistants can contribute greatly to the reduction of some of the teacher's routine work. At the same time, student assistants receive an added degree of worthwhile training.

Since the lack of proper safety procedures can mean the loss of time due to needless accidents, proper adherence to safety factors must be considered a necessity for all laboratories.

In order to increase laboratory efficiency, proper attention must be given to the arrangements within the classroom and the laboratory. References and chemical reagents must be located conveniently; equipment must be arranged in a systematic manner, and provision for easy conveyance of all types of materials must be provided.

It is necessary to operate the laboratory economically in order that badly needed efficiency equipment may be obtained when the need arises. Some consideration must also be given to the optimum use of the laboratory.

Current reports indicate a distinct trend toward the greater dependence on short quizzes for evaluating laboratory work. This method of evaluation is accompanied by a reduction in the requirement of extensive laboratory reports for all experiments. It requires less time, and it places emphasis on training received in the laboratory, rather than on the necessity of filling out routine laboratory reports.

Only by a combination of many factors may laboratory efficiency be increased a desirable extent, while maintaining or elevating high standards of teaching.

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