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Scope of Study: The basis for this study was the underlying principles of education. These principles were stated and modified into specific objectives for science laboratory work in education. The current methods of conducting laboratory experiments were studied. Recent literature concerning faulty laboratory practices and studies of improved methods and laboratory procedures were consulted. The criticisms and suggested improvements were studied in relation to the laboratory objectives.

Findings and Conclusions: The effectiveness of the high school laboratory depends to a great extent upon the way that the laboratory is used, the preparation of both students and teachers, and the careful planning of laboratory exercises.

The basic objectives of the laboratory should be kept in mind at all stages of planning and executing the laboratory period.

The greatest weaknesses in the laboratory were found to be lack of interest on the part of the student, lack of student participation, automation type experiences in the laboratory, and failure to develop scientific attitudes and methods of study or work. These can be remedied through better planning, creating an atmosphere that leads to student participation, the use of openended experiments, and encouraging students to undertake original research.

ADVISER'S APPROVAL ____________________

EFFECTIVENESS OF HIGH SCHOOL LABORATORIES AND SUGGESTIONS FOR IMPROVEMENT

By

CARL ARTHUR DWYER

Bachelor of Science

Texas Technological College

Lubbock, Texas

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EFFECTIVENESS OF HIGH SCHOOL LABORATORIES

AND SUGGESTIONS FOR IMPROVEMENT

Thesis Approved:

James H. Zant
Thesis Adviser

L. Herbert Bruneau

Robert MacVicar
Dean of the Graduate School

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CHAPTER I

INTRODUCTION

The purpose of this research paper is to try to determine if high school laboratory experiments are meeting the objectives for which they were designed. If they are not, the areas that are in fault will be discussed and suggestions given for needed improvements. The paper will also serve as a guide for the author and help him become more aware of shortcomings in supervising laboratory exercises. It will aid in correcting these weaknesses.

A study of the objectives of laboratory exercises is necessary to measure the effectiveness of laboratory techniques. A standard for comparison is essential for the measurement of any quality or quantity. A scale or balance is used to determine weight or mass. The scale or balance is a standard for comparison. The ruler, yard-stick, meterstick, or other standard is used to measure lengths. The objectives that laboratory experiments are supposed to meet will be the standard used to determine whether or not the present laboratory methods are effective.

There are four different methods used in the laboratory at the present time to accomplish the desired objectives. The method used and the way it is used determine whether the experiment will be a success or a failure. An understanding of each method is necessary for a complete study of the effectiveness of the exercise. Therefore, a portion of this report will be devoted to a short discussion of the various methods used in laboratory classes, and some of the advantages of each and the disadvantages of each.

Most of the report will be devoted to two phases relating to the effectiveness of laboratory procedures. First, a thorough study of the reasons underlying laboratory failures will be presented. Second, possible ways of helping the laboratory instructor become more effective as a teacher will be given. The results achieved in the laboratory depend upon the way the laboratory is used. The presence or absence of a laboratory exercise does not guarantee the realization or lack of realization of the goals.

Most of the information obtained for this report came from current literature such as magazines and science digests. Some of the ideas, which have essentially remained the same over a period of time, were taken from older literature and books.

This report is not intended as a "cure-all" for the illnesses existing in many of the laboratory classes. However, if it serves as an incentive for other teachers to examine their own programs, it will be worthy of the effort of preparation.

CHAPTER II

THE OBJECTIVES

> The nature of experience can be understood only by noting that it includes an active and passive element peculiarly combined. On the active hand, experience is trying, a meaning which is explicit in the connected term experiment. On the passive, it is undergoing. When we experience something we act on it, we do something with it...... The connection between these two phases of experience measures the fruitfulness or value of the experience.[1]

The high school laboratory experiment, to be of value, must include both trying and undergoing. It should provide ample opportunity for questions to arise, then time and opportunity for questions to be answered to the student's satisfaction.

The following list of laboratory objectives should be carefully considered by the laboratory instructor.

LABORATORY OBJECTIVES

1. To arouse student interest
2. To acquire and verify facts.
3. To realize the tentative nature of facts.
4. To achieve scientific attitudes.

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1. John Dewey, Democracy and Education, (New York, 1916), pp. 163-164

5. To practice scientific methods.
6. To develop laboratory skills.
7. To provide drill in use of skills.
8. To develop initiative and self-direction.
9. To demonstrate cause-effect relationships.
10. To provide some measure of student success.
11. To inspire individual research.

Perhaps one of the principal objectives, certainly an important objective, of a laboratory experience is to arouse student interest. This interest should not only be presented in the facts or current demonstrations, but should also extend to related phenomena. One interesting experiment should be the opening door for additional questions and the foundation for both personal study and future class experiments. The sensation of actual discovery is a part of interest. The student should come to feel what the scientist feels. He should encounter both the joys of discovery and the sorrows of failure. He should be able to meet unexpected results and have the privilege of working himself out of difficulties.

A laboratory should be a place to acquire and verify facts. Information should be gained with each experiment. The information may be scientific facts or the acquaintance with new procedure. These facts should be discovered as a result of the student's work and not simply accepted upon assertion.

The student should work so intensively with a subject that he realizes the tentative nature of facts and how little we know about science. He needs to realize that accepted facts are open to question, and are in a state of change because of the questioning.

The student should be led to form the mental habits that are called the scientific attitudes. He needs to learn how and why to raise questions and the basis upon which to accept statements of others.

At all times acquiring scientific methods ought to be a goal. Students should learn to pose relavent questions, plan procedures to answer the questions, solve problems, and recognize the factors that enter into success and failure. They need to draw proper conclusions from facts and explain any discrepiences in the facts. They should learn to report on their work and be able to defend their procedure and conclusions.

The skills of laboratory technique are important. The student should become proficient in the use of common laboratory apparatus; he needs instruction and practice in their use. He should develop the ability to observe and measure accurately and evaluate his observations.

The laboratory should, above all, demonstrate the cause-effect relationships. The student should be able to see for himself the actions and inter-actions of scientific principles. He should be allowed to discover the causes and effects of phenomena, to bring about certain effects. This is the true essence of science, to observe, even to take part in and to discover the circumstances that bring about certain facts.

The student needs to feel some success. The greater his feeling of success, the greater his achievement will become. He needs to understand that failure can be an achievement if it leads to greater effort.

The final goal should be individual research. When the student has developed the skills and habits of experimentation he should undertake an original investigation. This will increase the value of the other objectives and bring about a greater appreciation for science and a deeper understanding of laboratory work.

CHAPTER III

METHODS OF CONDUCTING LABORATORY EXPERIMENTS

There are four general methods of conducting the laboratory that are in common use. Each of these methods has some merit if it is used with the correct kind of experiment and conducted in the proper manner. Each method also has certain inherent defects when used incorrectly.

The method which is usually thought to exist in high school laboratory classes is the one in which the students do the actual experimenting and the instructor only supervises the experiment. This method can be a powerful teaching tool if it is handled properly. It should motivate the students to seek additional information by the scientific method.

The other extreme is the one that includes no student experimentation, and relies entirely on demonstrations carried out by the instructor. This has been used a great deal and has certain merits such as requiring small amounts of laboratory equipment and eliminating most of the dangers connected with experimentation. Its main weakness is due to the fact that students actually have no part in and no "feel" for the experiment.

Another method which is common in use is student demonstration. An individual or group performs the experiment while the remainder of the class observe. The individuals or groups are rotated so that at some time during the year each person has an opportunity to experiment. This method requires only a limited amount of equipment, and still provides a small measure of individual experimentation. However, in a large class, a student will have very little opportunity to develop a laboratory technique.

A combination of the three methods discussed is the most common procedure used, and it offers the best opportunity for an effective laboratory period. It can utilize the advantages of each of the other methods and avoid most of the disadvantages. For instance, the dangerous experiments and those above the student level of achievement can be used as demonstrations by the instructor. This can be quite effective if the equipment is large enough and properly arranged so that all students can accurately observe the experiment. If the demonstration fails to yield the desired result, the instrctor and students should try to determine the cause of the failure. This can serve as a teaching device. It is advisable for the instructor to perform the experiment before the laboratory period in order to become familiar with its faults. This type of procedure is especially useful in experiments involving the production of poisonous gases such as chlorine or the production of explosives such as gun powder. The instructor who lets his students indiscrimnately experiment with dangerous chemicals is "asking for a lawsuit".

The main excuse for offering the student demonstration type of experiment is limited equipment and space in small schools. It should never be used where it is feasible for individual experiments to be carried out. In some cases, this method is used for difficult experiments that can be done by the superior students in a class, but are too advanced for the average students. It also lends itself to some of the more dangerous experiments, because the instructor can observe the methods of the small demonstration group more easily than he can observe individual experimentation. As with the instructor demonstrations, this type of experiment must be arranged so that all students can observe accurately.

Individual experimentation is preferable to the other methods in most cases. Only when the laboratory is too crowded, the equipment insufficient, or the experiment too dangerous or too complicated, should the instructor resort to demonstration methods in the laboratory.

CHAPTER IV

CRITICISMS AND SUGGESTED IMPROVEMENTS

INTRODUCTION

High school science laboratories fail to meet the needs of the students in many respects. Alberty says, "Modern psychology of learning includes the acquisition of thinking, creativeness, initiative, and self-direction."[1] Many of the science programs fail to produce these signs of originality.

One hundred forty teachers of science[2] have listed the following functions as the most important ones related to the laboratory activities.

1. A means of securing information.
2. A means of determining the cause and effect relationships.
3. A means of verifying certain factors or phenomena.
4. A means of developing skills.
5. A means of providing drill.
6. A means of applying what is known.
7. A means of helping pupils learn to use scientific methods.
8. A means of carrying on individual research.

The study shows that in relation to these functions of the

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1. Harold Alberty, Reorganizing the High School Curriculum, (New York, 1953), p. 10

2. Milton O. Pella, "The Laboratory and Science Teaching", The Science Teacher, Vol. XXVIII, No. 5, pp. 29-31

laboratory and the objectives for the science laboratory there are several areas in which many schools have weaknesses. Not every science program is at fault, nor are all weaknesses found in any one situation. They are presented here in order that each teacher may examine his program and determine whether it has any of these faults.

1. Student interest, initiative and self-direction are not given due consideration. Problems are not based upon the students' needs and interests. Lack of individual planning eliminates initiative and self-direction.

2. Concepts are taught by assertion by the teacher rather than as discovery by the student.

3. The scientific attitudes are not practiced or developed.

4. There is undue regimentation in the choice of experiments and methods. Students are assigned problems that are identical and are expected to arrive at identical answers.

5. Necessary preparations are not completed before the experiment begins. The student does not always understand the question and the procedure.

6. The student does not achieve a feeling of success. Often he is met with unnecessary failure.

7. Scientific methods are not taught and emphasized as being important in procedure.

8. There is neglect in acquiring proficiency in laboratory skills. The lack of experimentation and the experiments that follow a fixed format cause the skills to be neglected.

9. There frequently is not sufficient time allotted for experiments.

10. The value of individual research is not stressed. The student is not encouraged and guided toward individual effort.

11. There is too much automation and not enough opportunity for originality.

> In theory....the high school science laboratory should provide boys and girls with some of their most useful and exciting science experiences. In fact high school laboratories are often unimaginative, unproductive, and even anti-scientific.[3]

These criticisms can only be answered by correction of faults. The faults can be remedied if teachers unfailingly keep the objectives of their course before them as a standard of the work being done. The student should be inspired to become a true scientist. He should question the statements of teachers and books in a scientific manner and prove or disprove them through investigation. It is necessary that scientific methods be used and scientific attitudes be developed. The work needs to be related to the interests of the students. Skills need to be taught and practiced until the student becomes proficient because the results of unskilled laboratory work is often destructive to the students' progress.

The eventual goal should be to achieve skills, methods, and attitudes that will enable each student to successfully carry out an individual research project. The teacher should work toward this goal by becoming the guide and not the dictator in the laboratory. The student should be allowed to assume all possible responsibility.

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3. National Science Teachers Association, Quality Science for Secondary Schools, (Washington, D.C., 1960), p. 84

STUDENT INTEREST AND INITIATIVE

One of the primary objectives of a science course is to arouse student interest. By the nature of learning, when a student is interested in what he is learning he will take the initiative for individual study and be more willing to explore new concepts. The matter of arousing student interest is always a controversial issue. Almost every educator has a different point of view as to the methods that best arouse interest. Too often they attempt to meet the problem head on without sufficient attention to the underlying framework. They ask apecific questions about whether the laboratory experience should precede, accompany or follow the class discussion. They become more concerned with the mechanical aspects of the process and often fail to ask about how children learn science concepts.[4]

Advances into the interests of students are not made by direct attack, but by slowly teasing out the basic relationships. After they are established, the relationships become useful, general operation principles. Teachers must know how to create an environment which will encourage the student to express his interests. This environment must include permissiveness and latitude for the student

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4. William W. Cooley, "Challenges to the Improvement of Science Education Research", Science Education, Vol. XIV, No. 5, December, 1961, p. 384

to develop his interests. Time must be given to allow the student to follow his individual thinking pattern; his questions must be given due consideration, even if they are not of interest to the teacher.

The problem in an experiment must spring to life in the mind of the student. The teacher should create situations which challenge the student's imagination. He should tantalize the student with questions relating to his environment and then leave those questions unanswered. These unanswered questions are often the origin of the student's interest in the problem. The best problem solving occurs when the student is self-motivated, when he performs an experiment because he desires to know the answer, rather than because he was told to do so.

The teacher should realize that a problem for a student is not necessarily inherent in any question, interesting as it may be to the teacher.

> Science experiences are being built around the solving of problems which are significant to pupils rather than on answering of unimportant questions that stress the recall of unrelated scientific fact.[5]

High School students often show an amazing lack of desire to pursue new curriculums and methods of study or learning. Their lack of desire is most apparent in areas that require the use of initiative, originality, or the ability to plan their own work.

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5. Glenn O. Blough and Albert J. Huggett, Elementary School Science and How to Teach It, (New York, 1951), p. 8

Their interest has not been stimulated to make them desire the knowledge being presented, or they have not had the opportunity to plan their own work in order to learn the habits of interest. The high school should be concerned with basing its program on the needs, interests, and problems of youth in the field of science. Students need the experience of posing questions and being allowed to answer them. Instead, they frequently are answering questions that have been posed by the teacher or are having their questions answered by the teacher. Either of these methods is deadening to interest. Interest is a growing thing; it must be nourished with knowledge and given room to grow through individual discovery.

TEACHING FACTS AND CONCEPTS

In the teaching of concepts, possibly the greatest mistake some teachers make is their regimentation and demand for surrender to assertion. "...boys and girls can hardly be expected to evaluate information and to appreciate the tentative nature of science when so many present-day school experiences require their almost unconditional surrender to assertion." [6] This demand is contrary to the principles of learning and recognized by the scientist as actually anti-scientific. One of the principal objectives of a science course is to learn to respect the tentative nature of scientific facts and conclusions and to question the current state of knowledge.

If accepting conclusions of others without question becomes a habit, it is impossible for the student to develop truly scientific ideas. It is, therefore, wrong for students to be forced or even allowed to accept assertions until they can prove them by experiment or until the authority and basis for the statements have been established. Frequently science teachers fail to realize the importance of this training. The student's questions too often are not welcome. The right and duty of the scientist to challenge facts and processes is often not recognized in classes which supposedly hope to inspire

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6. National Science Teachers Association, p. 83

future scientists.

A report of the National Science Teachers' Association states: "Science cannot be taught in a vacuum of facts".[7] This "vacuum of facts" is present all too often. Laboratories are used according to a fixed format to repeat the assertions that text books and teachers have already set forth. The idea of proving or testing is not always entered into. This type of laboratory at its best becomes a demonstration of an already accepted fact; at its worst it becomes a worthless and uninspired manipulation that accomplishes nothing more than alienating the students. When laboratories are used to arrive at a fore-known conclusion, they are enforcing the habit of regimentation.

The laboratory can and should be used as a teaching tool. The concepts that are so often presented as unrelated facts to be memorized for later recall can effectively be presented in the laboratory as discoveries. Each concept can be categorized and classified at the time of its presentation, then it is easily related to what is already known.

In chemistry, for example, the new ideas of atomic structure, valence, the nature of elementary particles' configuration, and the other basic concepts are entirely foreign and have no relation to the students' backgrounds. These can be taught and related to each other in the laboratory.

These concepts can be introduced with a study of the reactions of various metals with different acids of varying concentrations.

7. Ibid., p. 82

If equivalent measures of metals are used the student will note a difference in the degree of activity. By tabluating the results of the tests and listing the metals in an order of decreasing activity, the student will be ready to ask why the difference between various metals as effected by the same acids. Here there is a discovery of a concept that leads to the related concepts of the composition of metals.

The strategies for this teaching method according to Berger and Baumel[8] are:

> 1. To insure that the concept will be attained after the minimum number of encounters of relevant instances.
> 2. To insure that a concept will be attained with certainty regardless of the number of instances one must test en route to attainment.
> 3. To minimize the amount of strain on interference and memory capacity while at the same time insuring that the concept will be attained.

"Laboratory work which is not a mere repetition of classwork already covered is more interest-compelling and hence motivates a pupil to a greater degree of learning."[9] The need is for the presentation of true questions. Much can be gained by posing questions or by causing situations that will cause the students to raise questions that can be answered in laboratory experiments. While not all questions could or should be dealt with in the laboratory class period, the student can be led to select the most worthwhile ones for his

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8. Joel J. Berger and Howard B. Baumel, "Developing Concepts in High School Chemistry", The Science Teacher, Vol. XXVIII, No. 1, February, 1961, pp. 15-19

9. Sister Ernestine Maris, "A Comparison of Inductive and Deductive Methods of Teaching High School Chemistry", Science Education, Vol. XIV, No. 5, December, 1961, p. 438

attention. Accepted facts can be presented as being in question; by working to prove or disprove them, the student gains a greater understanding of the facts. Processes can be questioned as to purpose and effectiveness. The important thing to remember is that the questions need to come from the students and they should be encouraged to ask questions.

At all times that it is possible, the facts and concepts with which a course is concerned should be presented through laboratory experiment. This method allows the student to see for himself the cause-effect relationships, and to gain a fuller understanding of the workings of basic scientific principles. Every effort should be made to correlate the findings with what the students already know, and to develop an understanding that will lead to discovery of new concepts.

SCIENTIFIC ATTITUDES

> Learning to know is not the whole of laboratory work; acquiring the ability to feel what a scientist feels is equally important. In the laboratory, the student should be a "scientist for a day". He should encounter the joys and the sorrows of experimenting, the elation and despair. He should come upon the unexpected, run up blind alleys, and work himself out of tight places.[10]

Feeling what the scientist feels can be very important in developing correct attitudes of mind in the student. These attitudes have been called the "spirit of science". These attitudes are frequently ignored in the high school laboratory. Often the student is regimented, encouraged to accept facts without justification, and not led to appreciate the implications of science. One objective of the science teacher should be to develop scientific attitudes.

The scientist has a sincere curiosity as to causes and effects. The student should have the opportunity to explore these relationships; he needs to see and discover the cause-effect concepts of science.

The scientific attitudes include a respect for others' opinions. The scientist will give consideration to the work and conclusions of other scientists. The student needs to learn to respect the right of other students to hold different ideas, and give due value to their opinions.

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10. "Laboratory Instruction in General College Physics", American Journal of Physics, Vol. XXV, October, 1957, p. 437

The student, while respecting other opinions, should develop a tendency to entertain honest and reasonable doubt in accepting dogmatic or unsupported statements of fact or personal beliefs. He should learn to question facts and opinions until he can prove or substantiate them. The questioning attitude should be developed.

A desire to be accurate in observations is important. Only by creating a desire for accuracy can accuracy be assured. The student, if he realizes the importance of accuracy, will develop this desirable attitude.

The scientist needs a willingness to hold conclusions as tentative and to suspend judgement until sufficient facts have been secured. Often the student tends to draw conclusions without sufficient evidence. He needs to be led to draw tentative conclusions as indicated by the facts and then continue working to prove his assumption.

The habit of planning before executing a problem-solving procedure is a basic attitude of science. To effectively arrive at an acceptable conclusion, the student needs to plan his methods of examination carefully.[11]

The scope of scientific attitudes as defined by different writers is almost limitless. They should all be considered by the teacher and the basic ones accepted as a part of the laboratory training. The attitudes of a scientist are important in giving the student a feeling for science and a base for his growth in other science objectives.

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11. Claire W. Elmore, Orean Keeslar and Clyde E. Parrish, "Why Not Try the Problem Solving Approach?", The Science Teacher, Vol. XXVIII, No. 8, December, 1961, pp. 32-37

Davis and Sharpe give the following as the scientific point of view.[12] They suggest these as the basic scientific attitudes.

1. Command of factual information.
2. Familarity with laws, principles, and theories.
3. Power to distinguish between fact and theory.
4. Comprehension of the cause-and-effect relationship.
5. Ability to observe.
6. Tendency to base judgement on fact.
7. Ability to formulate working hypotheses.
8. Open-mindedness.
9. Freedom from superstition.
10. Appreciation of the contributions of science to our civilization.
11. Appreciation of natural beauty.
12. Appreciation of man's place in the universe.
13. Appreciation of possible future developments of science.
14. Possession of an interest in science.

Those who establish a sterile science laboratory without the inclusion of these attitudes of mind are causing students to miss the essence of science.

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12. Ira C. Davis and Richard W. Sharpe, Science a Story of Progress and Discovery, (New York, 1940), pp. iii-iv

IDENTICAL ANSWERS

When the instructor plans experiments with the expectation that all the students in the laboratory are to get identical answers, problem solving is discouraged rather than encouraged. The student needs to discover his errors, select his data, weigh his evidence, and make judgements on his own. When experiments are carried on with every student expected to get the same answer none of these can be done realistically. The aim of identical answers is unrelated to scientific objectives and a detriment to the science student.[13]

A number of factors must be considered in the results of laboratory experiments. It is more important that students learn to recognize errors and to account for their presence than always to get the correct answer. The solving of a problem necessitates trying a number of hypotheses a number of times in order to arrive at an answer that is acceptable as a conclusion for the facts observed. The lack of skill, or the unequal skills, of the high school students will cause errors in procedure and in observations and measurements. The degree of error is not constant among high school students and neither is the degree of accuracy; so in truth, for the entire class to achieve identical answers is almost impossible. Even if by

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13. Elmore, Keeslar and Parrish, pp. 32-37

accident they should all arrive at the same answer they would not necessarily draw the same conclusions.

Expecting identical answers calls for identical procedure and does not give the student any opportunity to plan and execute the experiment in his own way. The student must have these opportunities if he is to develop the habits that are necessary to the scientist. Here the point of concern is not the solving of the problem, but the method of solving the problem. It is the method that is scientific in character. If an individual is to develop a reliable disposition to use scientific methods whenever he attacks one of his problems, he must have repeated opportunities to experience these procedures and to gain proficiency in using them. He should, through use, gain confidence in their results and confidence in his ability to carry out a plan in a scientific manner. These methods of experiment cannot be taught by conversation or demonstration by the teacher. They can be learned only by actual practice, by being used repeatedly in real problem situations.[14]

Identical answers also negate the necessity for comprehensive reports of laboratory work. If each student, by the same procedure, manages to arrive at the same answer there is no real need for each student to report that he proceeded just as every other student did. He does not have a need to defend the conclusions that he draws, and he cannot claim any original effort or discovery.

If an honest question is placed before the group and each student given the opportunity to formulate his own specific question,

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14. Ibid., p. 33

the possible hypotheses, and a procedure of investigation, then, though the initial question will be the same, each individual student will achieve an original experience. In allowing the student to plan his procedure, execute his own plan for investigation, draw his own conclusions, and be forced to support them in a report, the laboratory is fulfilling its true purpose.

FIXED LABORATORY SCHEDULE

A laboratory period set at a certain hour a certain day every week has a tendency to become mechanical and to lack the sponteneity of a successful experience. "The laboratory work should never become in the estimation of the classes merely an adjunct to classroom instruction."[15] The concept of performing an experiment simply because it is "lab day" has no place in a science program. When students see no need for a laboratory period and feel that no personal questions are involved, a laboratory experience is useless. The work should be properly motivated and the students prepared for the experiment.

The early proponents of "activity curriculum" held that any activity was learning. By their standards, if a student manipulated laboratory equipment for an hour, or engaged in any other activity for an hour, he should have gained an hour of knowledge. Since to them mere activity was learning there was no attempt to connect activity and past experience or present interest. In contrast, the proponents of subject centered curriculum stressed the acquisition of facts and information with no relation to activity. In fact, both subject and activity are important teaching devices if they are properly related, one complementing the other. Alberty[16] states:

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15. Herbert Brownell and Frank B. Wade, The Teaching of Science and the Science Teacher, (New York, 1925), p. 4

16. Alberty, p. 141

"In any complete learning situation activity and interpretation are always present".

The laboratory with a fixed schedule too often falls into the pitfalls of either the activity curriculum or the subject curriculum. The instructor of the set laboratory period should take extra care to see that it is effectively utilized by relating activity to the learning at hand. "For effective problem solving to be accomplished by the students in the schools, the teachers must know how to create an environment which will encourage problem solving."[16] The teacher must overcome the idea that the problem is secondary in importance to the maintaining of schedule. If the student knows before time that one day of the week he will be in the laboratory he often fails to make the proper connection between the class instruction and the laboratory activity. For the same reason, the instructor often fails to properly prepare either himself or his class to the best possible degree.

The answer to this problem is obviously to eliminate the fixed schedule for laboratory work. However, in most schools because of the limited time and the increased number of students enrolled in science courses coupled with the fact that im many schools several classes may use the same laboratory facilities, this is not always possible. The possibilities of working with instructors of other classes to schedule the use of the laboratory facilities when they are needed for experiments and not on a rigid schedule should be explored. In some cases a more flexible arrangement might be made.

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16. Peter Dean, "Problem Solving Techniques in Teaching Secondary School Physics", Science Education , Vol. XLV, No. 5, December, 1961, p. 399

If this is not possible, and the instructor is faced with the fixed schedule, he should make every effort to prepare the class to recognize the need of each laboratory experience and consider it unique. Time should be spent in class raising questions for study so that at the beginning of the laboratory period each student has fixed in mind the questions he is posing and the procedure he prefers in answering them.

STUDENT FAILURE

Failures by the student should be, as far as possible, eliminated. The laboratory should give each student some measure of success. Actual failure to properly execute a plan of procedure is not so damaging to the student as discouragement from the feel of failure. Conditions should be under control so that the possible failure in procedure is apparent to the instructor. The instructor must be prepared to guide the student to the proper conclusions. The experiment that appears to be a failure because it yields the incorrect answer can be considered a success if the student realizes that it is a part of the experimenting process to fail, explains the reasons for errors, and attempts another experiment. The failure of an experiment is an excellent teaching opportunity for the laboratory teacher. The teacher who shrugs off a malfunction misses the opportunity for teaching analysis of problem solving. The following evaluation of tactics used in problem solving may be used to illustrate to the student the cause of failure.

1. Whether the problem was stated simply, clearly, and concisely.
2. Whether the investigation was planned well.
3. Whether the investigation was carried out well.
4. Whether the conclusions were empirically obtained by observations and experiments.
5. Whether the observations were accurate.
6. Whether the data were grouped and classified properly.
7. Whether the hypotheses formed concerning the solution of the

problem accounted for a fair part of the available information, since some of the data might be incorrect or irrelevent.

8. Whether apparatus was designed appropriately for the experiment.

9. Whether the apparatus works properly.

10. Whether each hypotheses was tested, used or eliminated.

11. Whether he tested his ideas again and again, and checked them against the work of others.

12. Whether objective measurements were used for which the limits of accuracy were known by the student.

13. Whether the observations and experiments can be verified.

14. Whether the concepts formed from the data and from the solution of the problem were sound.

15. Whether new problems and experiments were suggested from the solution of his problem.[17]

Often the student is faced with failure because he has not developed the necessary skills for the procedure that is called for. The instructor should attempt to build the necessary skills with the students and should guide them to procedures that will not be beyond their present abilities.

A student may be faced with failure if the laboratory apparatus is too complicated. "In choosing apparatus the simplest forms which give satisfactory results are always to be preferred."[18]

Sometimes it may not be best for students to perform in the laboratory. Although the necessary skills and procedures need to be used and developed, the teacher may have to limit the participation

17. Donald Wynant Huffmire, "Criteria for Independent Study Projects", The Science Teacher, Vol. XXVIII, No. 4, May, 1961, p. 37

18. Brownell, p. 15

in certain areas at certain times because of the element of failure. At times when the skill of the student is not adequate and his laboratory experience is supposed to teach certain concepts, the teacher demonstration method, a projection microscope technique or projected slides may be preferable. For example, research of the relative values of instructional processes in biology show superiority for the lecture demonstration method over individual laboratory work by pupils when the principles of biology are being taught. Time spent by students who are inept in disection usually is amateurish butchery which yields when carried through to its end specimens quite impossible of any satisfactory study.[19] If the procedure is principally to teach a biological principle the students deserve the opportunity to observe specimens that may be studied. Often students who are not expert in disection become nervous and fear that the observations they are able to make after disection will not be valid. They are likely to find pictures of the biological specimens and draw or study from that. This procedure of finding and using pictures is in itself acceptable, but used in place of expected performance it leads to dishonesty and a sense of failure.

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19. Brownell and Wade, p. 245

SCIENTIFIC METHODS

Often the student does not realize the basic principles with which he should be concerned. To succeed in problem solving the student must have at his command certain methods of procedure. He must be able to organize his scientific facts into meaningful relationships. He should be able to visualize them as new concepts, principles, and generalizations. The teacher's role is one of guidance toward the habit of the use of scientific methods. He should seek to get the measure of each student's thinking and reasoning ability, and call attention to unrecognized errors, false assumptions, and reasoning that is not logical. Then the student will become aware of and correct his faults in order to succeed at problem solving.

The student should learn that science is basically the search for knowledge or truth. Scientists use different methods and devices in order to arrive at the truth. The student has this same right to his own methods, but he should know that finding an answer is not enough if the answer cannot be verified by others using the same methods. Each answer must be checked again and again, especially if it differs from those of other experiments. This concept of testing again and again is a part of the basic pattern of thought used by most scientists. Even though procedure differs, this basic pattern of thought is so widely used by scientists that it has been called the scientific method; it consists basically of these nine steps.

1. The existence of a problem.

2. The analysis of the problem.

3. The formation of working hypotheses.

4. The testing of each hypothesis.
   a. Evidence is gathered.
   b. Two possibilities are considered for each hypothesis.

5. The elimination or modification of wrong or faulty hypotheses.

6. The formation of a tentative conclusion.

7. The checking of the tentative conclusion.

8. The acceptance of the tentative conclusion as a fact.

9. The use of the new fact.[20]

If the student is led to base his plans and methods on this scientific method many of his faulty plans and failures will be eliminated; his reasoning ability, skill in planning and carrying through with a certain plan will grow.

This method is a part of the inductive method of teaching. Sister Ernestine Maris has carried out research[21] indicating that the inductive method of teaching chemistry is superior to the deductive method.

Maris describes the deductive method as being descriptive, which means the traditional type theory and descriptive chemistry given in the classroom lecture. In this method the laboratory manuals are followed meticulously to perform experiments that have already been discussed

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20. Phillip Goldstein, How to Do an Experiment, [ed. Paul F. Brandween] , (New York, 1957), pp. 9-10

21. Maris, pp. 436-443

in the class. The teacher takes the responsiblity for posing questions in systematic order. The student interest is not taken into consideration.

The inductive method is a procedure in which class work covers only theory. The theory is presented in such a way as to elicit student response. The students question and then strive to answer their questions. The students discover laws and theories rather than memorizing them. Laboratory work stresses the investigative approach and is performed without the detailed directions of a laboratory manual. The teacher gives latitude for independent problem solving.

In the first plan of study there were twelve classes used. Three different teachers were involved. A total of four hundred thirty students entered into the study. There were six control classes and six experimental classes.

Before the study began the classes were given standard intelligence tests. There were no significant differences in the intelligence quotient between the control classes and the experimental classes.

All factors were held constant except the actual teaching method. The teachers used the same syllabus, the identical texts, the same tests. All were following the same time schedule. The same teachers taught both methods, one for the control classes and the other method for the experimental classes.

The control classes were taught by the deductive-descriptive method. Their material was presented by lecture demonstration method and they followed laboratory manuals for procedure in experiments. The experimental classes were taught by the inductive method. They posed their own questions and used the investigative approach in the laboratory.

At the end of the course the classes were tested using the Anderson Chemistry Test and the Cooperative Chemistry Test, Form X; in every instance the inductive groups performed significantly better as measured by these tests.

Being interested in the slower learner who was presented with inductive methods, Sister Maris compared the scores of students in the lower quartiles of the intelligence test. Again, those taught by the inductive method showed definite superiority. The slower learner profited as much if not more than the faster learner.

Maris concluded, "After a year's course in general chemistry, inductively taught students have a more thorough knowledge of chemistry as measured by the Anderson and Cooperative Chemistry Tests than do deductively taught students."[22]

In phase two of the study there were thirty-four schools, fifty-six classes, thirty nine teachers, and eighteen hundred students involved. A mental ability test was given showing no significant differences between the twenty-eight control classes and the twenty-eight experimental classes. The constants were the same as in phase one. All students were taught one unit on equation balancing in chemistry.

Again, inductively taught students of both upper and lower quartile mental ability groups surpassed those taught deductively. "Hence, it was concluded that students taught inductively are apparently

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22. Ibid., p. 439

able to grasp the fundamental concepts of equation balancing better than students taught by the deductive-descriptive method."[23]

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23. Ibid., p. 441

LABORATORY SKILLS

In some science laboratories there is not enough emphasis placed upon developing the skills needed in the laboratory. The skills are basic to laboratory work, and often mean the success or failure of an experiment. Acquiring skills should aid the students to acquire interest in science. The skills usually considered to be laboratory skills are the ability to plan procedure, to execute the plan, to measure and observe accurately, to select pertinent data, to draw logical conclusions based upon the facts, and to use graphs, charts, and reports to communicate discoveries. They include the ability to comprehend the reports of other scientists, and to recognize errors in one's work and in the work of others.

One of the most important functions of the high school science teacher is to offer opportunities for the students to conduct laboratory experiments.[24] The purpose of these experiments should include the developing of skills. The teacher should consider the careful introduction and orientation of laboratory work to the class in the light of the ultimate values derived from a correct start.

As a beginning of the laboratory course the teacher should explain the laboratory apparatus. He should give the students the

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24. Marc A. Shampo, "Do You Conduct Your Science Laboratory Efficiently?", Science Education, Vol. XLV., No. 3, April, 1961, pp. 224-227

names of common equipment and demonstrate its uses. The students need practice in setting up and disassembling apparatus. This knowledge and skill on the part of the student gives him confidence and adds to achievement later on. It saves time for the student to know what equipment to use and how to use it and facilitates the laboratory procedure. As a part of becoming acquainted with apparatus, the student should learn about its care and cleaning. The habits of cleanliness and organization are valuable work habits. Too often students are allowed to leave test tubes and beakers dirty and equipment disorganized.

The laboratory experiment, if conducted as a manipulation of laboratory equipment, will build skills in this area of learning. However, the laboratory should also afford students the firsthand experiences of solving problems, observing and collecting information, bringing experimental and observational techniques to bear on a scientific problem, and practicing effective scientific communication in the form of a laboratory report. These skills are not being developed in the laboratory which uses manuals with a fixed format and blanks to fill in with the correct answers.

Mark[25] has shown in his experiments that the continued use of the laboratory is necessary for the development of laboratory skills. They cannot be acquired by reading or talking about them. He felt that in light of greater numbers of students in the classroom science courses, the greater content in current science curriculum, and the

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25. Steven J. Mark, "Experimental Study Involving the Comparison of Two Methods of Performing Experiments in High School Chemistry", _Science Education_, Vol. XLV., No. 5, December, 1961, pp. 399-403

attention that has recently been directed upon the needs for investigation of laboratory procedures, it was important to discover which teaching method produced the most effective results.

In Mark's experiments these two hypotheses were tested.

1. No difference between students taught by experimental method and those taught by control method in mastery of unrelated facts, principles, problems, equations, and symbols of chemistry is evident.

2. There is no significant difference in abilities of students to interpret chemistry knowledge stated in the forms of graphs, tables, paragraphs, and diagrams between students taught by the control method and those taught by experimental methods.

In the research there were six schools represented. Two groups were in each school. There were one hundred twenty-five students in the experimental group and one hundred sixteen students in the control group. A test of mental ability showed no significant difference between the two groups. The instructors were similar in background, intelligence, and years of experience. The communities were similar. The control and experimental groups performed the identical ten experiments.

The control group performed ten chemistry experiments according to directions similar to those found in most present laboratory manuals. The material was discussed by the instructor before they performed in the laboratory. The students had no opportunity to pose questions, plan procedure, or draw their own conclusions. The results were recorded in blanks provided for this purpose.

Experimental groups devised methods of solving problems given to them before a discussion of that particular phase of work in the classroom. They carried out their individual experiments and recorded the results on special experimental sheets in the form of observations, equations, calculations, diagrams, and conclusions.

After the ten experiments were performed tests were given to the two groups. Ninety-eight times out of one hundred the experimental group would perform better in the interpretation of chemistry knowledge expressed in form of graphs, tables, paragraphs, charts, and diagrams of experiments.

Mark concluded that in the light of this evidence, it would appear to be advisable for an instructor to use the procedures of the experimental group if he and his students are interested in the development of the characteristics of the scientific method.

As an aid in teaching laboratory skills Brownell and Wade[26] suggest that the results of the laboratory experiment should be written. If a written report is required the student has the responsibility of recalling, selecting, and properly relating the essential facts involved. Accuracy in these reports should be demanded so that the student must give his thoughts and attention to his work. The student who is expected to give a comprehensive report of his work is more likely to observe and measure carefully. He will have a tendency to draw more valid conclusions and will be prepared to explain the reasons for any errors. The written report is often a deterrent to discipline problems. In the laboratory the student may play or pass time idly, but when it comes to giving an acceptable written account of what he did and saw and what he thought about it, the demands must be met.

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26. Brownell and Wade, p. 28

LACK OF EXPERIMENTATION, THE TIME FACTOR

> The heart of any science course should be the laboratory. Unfortunately, this has not always been the case. Sterile and uninteresting laboratory exercises coupled with the contraction of the double laboratory period to a single period in most schools have reduced the biology laboratory to an ineffectual level so far as teaching real science is concerned.[27]

To maintain its uniqueness and to achieve any real measure of success as far as the objectives are concerned, the science course must be taught in close connection with the laboratory. Students must observe phenomena rather than reading about or hearing about it. Too often, especially in the smaller high school, the time alloted for the teaching of science is not sufficient. In most cases it is the laboratory work that suffers as a result. Students are frequently bombarded with facts, but given neither the time or the opportunity to prove them or to see the cause-effect relationships as shown in the laboratory. They read about and are told about scientific methods and scientific attitudes, but if they have very little experience in the laboratory, they cannot develop these characteristics. The importance of laboratory skills often is no more than words to high school students.

All schools, especially the small high schools, need a double period daily so all work, preparation of lessons from experiments or

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27. National Science Teachers' Association, p. 95

books, discussions, and solutions of problems can be accomplished. The administration often is unaware of the problems of the science teacher in reference to time. The teacher should strive to have his time extended and to lead the administration to a greater understanding of the need for adequate laboratory time.

Often those teachers who try to crowd experiments into the busy schedule of other class work find that even by giving the entire period to laboratory work there is not sufficient time for all students to complete an experiment and some experiments cannot be completed by any of the students. This leads to a feeling of failure by the students and is a detriment to teaching, especially in the fields of accuracy, care of equipment and careful reporting.

If the extension of time is not possible the teacher must make all practicable preparations before entering the laboratory. The students should be familiar with the equipment they are to use and the plan they are to follow. The knowledge of how to use and assemble apparatus will facilitate the laboratory program. If students are instructed in the organization of equipment, they will not waste valuable time looking for the necessary apparatus. While not desiring to rush the students into premature conclusions or hasty and inaccurate observations, the teacher should make them aware of the need to use all precautions against wasted time.

It is possible, if planning and reporting of observations and conclusions can be done at another time, that the actual procedure of experimentation could be completed in one period. Care should be taken to see that students do not start an experiment that cannot be completed in one period unless the student can return later to complete it. Sometimes, if the experiment is of a type that may be left for a period of time and the facilities are available, the student may return at a free period or after school hours to complete the work that he began during the laboratory period.

INDIVIDUAL RESEARCH

Often a high school laboratory does not have the time to effectively answer all of a student's questions. He feels dissatisfied because the experiments, while answering one question, give others the chance to rise. If properly channeled, this dissatisfaction is good. It can be the means of meeting the objective of individual research. The student should be encouraged to carry out the investigation by himself. Every student should at some time explore one conceptual scheme intensively so that he may sense the limitations of what we know about natural phenomena. By intensive study he will develop his skills and gain valuable knowledge beyond what could logically be presented in the school laboratory period. He will also come to appreciate the tentative nature of facts and the challenges of science.

It should be the teachers' responsibility to direct these individual studies to see that the information is valid and that faulty conclusions are not accepted without furthur checking. The individual investigation should be, as nearly as possible, free from interference from the teacher, but, as far as necessary under his supervision. The teacher should not attempt to direct or control these investigations to the point of regimentation; he should allow the fullest possible measure of student individual self direction. The direction should be to help the student in areas where it would be to his detriment to proceed in the started direction. This would include areas where there is danger to students because of unsafe practices or where the students are following unscientific procedures and are arriving at conclusions based on faulty observations or not in conformity with the facts.

The National Science Teachers' Association suggests that the teacher check out laboratory equipment and reference material to students so that their work might be carried on at home.[28]

The student should know how to carry out an investigation effectively. To carry out an investigation requires certain steps to be performed. The student should be aware of the implications of each of these steps. They are listed by Goldstein as these.[29]

1. The problem must be selected. The student should consider his interests first. Of secondary consideration should be the possibilities for obtaining the proper equipment and material for his work. The problem should fall within his ability to execute. The scope of the problem must be considered in the light of the time he will have to devote to his research, and if necessary be narrowed to fit his situation. He should consider the possible dangers associated with the work. The problem should be one that is worthwhile.

2. Various preliminary preparations must be made. The student needs to preceed his laboratory work with preliminary readings bearing directly on the problem. He should discuss the problem with someone who has a knowledge of the subject. He should investigate the basic

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28. Ibid., p. 132

29. Goldstein, p. 63

techniques that will be required and practice any that he is not proficient in.

3. The investigation must be planned. The problem should be stated clearly and concisely. A plan of procedure should be established involving the methods of collecting the necessary data. A list of the needed equipment should be made. Arrangements should be made for a place in which to work.

4. The investigation must be carried out. The student should observe these rules for a well designed experiment.[30]

a. The experiment must have two parts for comparison:

(1). the experimental or variable part testing a condition

(2). the check or control part which is kept constant.

b. There must be only one variable-only one difference-between the experimental group and the control group.

c. There must be a large number of cases in both the experimental group and the control group.

d. The experiment must be such that it can be repeated by any other person who wants to do so, and who has the necessary skills.

e. The conclusion must not be expected to include a wider area than the experimental materials allow.

5. The observations must be recorded. The student should make a written record of his observations as they are made to insure future recall and to insure against overlooking some detail that may later

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30. Ibid., pp. 40-41

prove to be important.

6. The data must be analyzed. The observations should be studied; important details should be taken into consideration and unimportant details eliminated. Errors should be recognized and explained. Evidence that supports the original hypothesis should be stated.

7. The conclusions must be formulated. Here the student should be cautioned to work objectively and neither be too bold in assuming that evidence supports his theory if there may be reasonable doubt nor be too hesitant to accept valid proof. Remember that a conclusion is valid only for those conditions that have been tested in the experiment.

8. The investigation and its results must be publicized. An investigation is of no use to the public if they do not know about it. Publicizing both successful and unsuccessful experiments is useful to those who may desire to investigate the same subject. In the case of high school students the publicizing will probably be in the form of a report to the other students.

If the student follows these suggested steps his experiments will probably be successful and he will gain from them. His appreciation of science will increase and he will have had valuable experience with the scientific method of investigation.

AUTOMATION VERSUS OPENENDED EXPERIMENTS

Too frequently the laboratory is reduced to an automation type factory. A student has before him a manual telling step by step the procedure that he is to follow for an experiment. Of this the National Science Teachers' Association says, "Utilization of the cookbook type of laboratory manuals and classroom workbook, both with prefabricated format, has very little place, other than as reference material..."[31] When this type of manual is used the student is deprived of the most useful learning procedures. He has no opportunity to ask his own questions. The questions or problems are those of the author of the manual and may or may not be related to the interests of the student. He cannot plan his own procedure because the experiment has already been performed in the manual with the exception of the actual manipulation of equipment. He does not select pertinent data because the manual provides specific questions and blanks in which to record the answers about his observations. He is told in advance what results are to be expected and what conclusions can be drawn.

> Merely performing a manipulation according to printed directions and recording the results in the blank spaces in a book is not enough. Following the recipe is generally an acceptable procedure in cake baking, but our objective is quite different.[32]

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31. National Science Teachers' Association, p. 121

32. Blough and Huggett, p. 24

A teacher should consider the objectives of the course he is teaching; he will see that the automatic manipulation type experiment will meet almost none of these objectives. The student will lose interest; he will not acquire scientific habits of practice or attitudes; he will not develop self direction; individual research will not be inspired; and the student will not gain the feeling of success that comes from an original effort.

Except for the ability to use laboratory apparatus the student will gain none of the important laboratory skills. In this type of experiment the student becomes overly concerned with obtaining the correct answer as indicated in his manual and the desire to investigate the causes for error or the significance of results is lost.

A selected group of experiments in which detailed directions are kept to a minimum are valuable because they give the student the opportunity to devise some of the procedure. Brownell and Wade state one of the objectives of the laboratory thus: "To promote the development of a scientific attitude in pupils; to enable them to become skilled in the acquisition and organization of facts."[33] These objectives can be achieved only if the student has actual personal experience in each of these areas. This means that he must take part in each of these areas and have a part in each facet of planning, observing, and concluding. When his skills have become developed through guided participation he will be ready to undertake and complete an experiment that is totally his.

In preparing the student to perform original experiments, the

33. Brownell and Wade, p. 14

use of openended experiments is valuable. "Openended" or "honest" laboratory experiments are ones that pose problems or questions but do not give the results or cause the student to anticipate answers before performing the experiment. In these experiments every student may perform in his own manner; each is allowed to plan a part of his procedure. Each can work according to his needs, interests, and abilities. If honest problems are presented the student must draw his own conclusions; thus he completes an experiment with satisfaction. The completion of the experiment becomes less important than taking the responsibility for conceiving of new directions and then following them through.

Openended experiments will help to decrease the automation of the laboratory experiment. The work will become real experimentation, meaning trying, rather than a manipulation. These experiments will also lead to the acquisition of necessary skills. By beginning with simple exercises and questions and leading in a step-wise fashion to more complex, openended experiments, the student is introduced to the elements of scientific investigation. Students cannot be expected to go immediately into scientific habits or to comprehend the scientific functions well enough to plan and execute experiments without supervision. However, the eventual plan should be, through observations and experiments, to lead the students to science understandings that will cause new experiments and observations. "Openended experiments are distinctive because students cannot anticipate the answers before they start the experiments."[34] The students pose questions and then answer

34. National Science Teachers' Association, p. 96

them. Scientific attitudes will be applied here as they should be. The student will use what he already knows and the skills he already developed to answer questions to the best of his ability. He will be expected to present and defend his conclusions using what he has personally observed.

Thirty-one of the openended experiments have been prepared for use in the high school by the Manufacturing Chemists' Association and are published by Henry Holt Company. In these the student reports on his experiment in his own manner and includes evidence for conclusions. Evidence is based upon observations. In no case is the student asked to supply a word in a prefabricated sentence.

After a study of the results of openended experiments in a biology class Simmons reports.

> A high level of academic performance in a specialized skill results when the biology class is up-graded by a set of openended investigations in which students utilize new techniques, develop their own format and record their own observations and findings.[35]

He found that in this type experience there was time for more individual attention for each student. The students were benefited because each worked at his own rate and was not compared to the other students in length of time spent in investigation.

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35. Maitland P. Simmons, "Revitalize Your Biology Course", *The Science Teacher*, Vol. XXVIII, No. 8, December, 1961, pp. 50-54.

CHAPTER V

CONCLUSION

The effectiveness of the high school laboratory depends to a great extent upon the way that the laboratory is used, the preparation of both students and teachers, and the careful planning of laboratory exercises to further the objectives of the laboratory. The teacher should use the objectives for his course of study as a guide to both the type of laboratory work and the procedures.

The interest of the students is paramount in any teaching situation. The problems should provide for the growth of interest and the stimulation of new interests. A part of this interest arousal is the method of presenting facts and concepts. The facts that are a discovery of the student have more inherent interest than those that are presented as an assertion by teacher or textbook.

Successful science students have acquired the habits of thought known as scientific attitudes. The teacher should strive to create an atmosphere that will foster the growth and use of scientific attitudes. At all times the student should have some part in the posing of questions and planning of procedures for answering those questions. The practice of expecting identical answers from all students or of always having an entire class work on identical problems is detrimental to the development of scientific attitudes.

The student should expect a certain measure of success in his work. This can be attained if he has acquired the habit of using scientific methods in his laboratory work and if he has ample opportunity to develop the necessary laboratory skills. Student failures can be minimized by careful planning of the work and by presenting the concept that failures are a part of success because they should lead to more and better efforts.

The scheduling of laboratory exercises is of importance to the success of the laboratory experience. When possible, the fixed laboratory schedule that may become routine and meaningless should be avoided. The preparation and planning for the laboratory period become even more important if the fixed schedule is necessary. In scheduling, the instructor should be sure to allow enough time for the problems to be solved satisfactorily.

Individual research needs to be fostered. When the students have the interest and necessary skills, they should be encouraged to attempt a project outside the classroom. The guidance from the teacher should be kept to a minimum, but should be present when necessary.

Openended experiments are of substantial value to the laboratory instructor. They provide the student the opportunity to have individual planning and the experience of drawing valid conclusions from what he has observed. The openended experiment is an aid in overcoming the automation type laboratory experiments that are often presented in laboratory manuals. The need to provide experiences for students with different levels of achievement, different interests, skills, and working speed are easily met through the use of different problem solving situations for each as provided by partially perpared openended experiments. These experiments are suggestions for problem solving that leave much of the actual planning to the individual student.

The success or failure of the laboratory is largely the responsibility of the instructor. The following check test has been devised as a guide for the instructor to use, with any personal modifications, to help insure the success of a laboratory experience.

A CHECK TEST FOR EFFECTIVENESS

1. Does it illustrate a principle?
2. Does it conform to scientific methods?
3. Does it arouse interest?
4. Does it answer the students' questions?
5. Does it cause other questions to be raised?
6. Is it related to the current work?
7. Has the necessary preparation been made?
8. Is it safe for students?
9. Does it insure some measure of student success?
10. Is the alloted time sufficient?
11. Will it cause students to develop skills?
12. Does it provide for individual differences?
13. Does it provide sufficient pupil participation?
14. Does it call for accurate reports?
15. Has an effective follow-up been prepared?

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VITA

Carl Arthur Dwyer

Candidate for the Degree of

Master of Natural Science

Report: EFFECTIVENESS OF HIGH SCHOOL LABORATORIES AND SUGGESTIONS FOR IMPROVEMENT

Major Field: Science

Biographical:

Personal Data: Born near McLean, Texas, April 17, 1927, the son of John W. and Drucilla Dwyer.

Education: Attended grade school in McLean, Texas; graduated from McLean High School in 1944; received the Bachelor of Science degree from Texas Technological College, with a major in Animal Husbandry, in August, 1948

Professional Experience: Taught science in McLean High School, McLean, Texas, from September, 1957 to May, 1961.