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Seven home-made teacher lecture-demonstrations in physics.

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Boston University
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Thesis

SEVEN HOME-MADE TEACHER LECTURE-Demonstrations
in Physics

Submitted by

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>CHAPTER</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. INTRODUCTION</td>
<td>1</td>
</tr>
<tr>
<td>Purpose of This Thesis</td>
<td>1</td>
</tr>
<tr>
<td>Problems associated with science teaching in small schools</td>
<td>1</td>
</tr>
<tr>
<td>The simple design and construction</td>
<td>1</td>
</tr>
<tr>
<td>Low cost of materials needed</td>
<td>2</td>
</tr>
<tr>
<td>Other purposes</td>
<td>2</td>
</tr>
<tr>
<td>Description of the following chapters</td>
<td>3</td>
</tr>
<tr>
<td>II. THE NEED FOR A SURVEY OF THE LITERATURE</td>
<td>4</td>
</tr>
<tr>
<td>THE NEED FOR LECTURE-DEMONSTRATIONS</td>
<td>4</td>
</tr>
<tr>
<td>Learning and Demonstrations</td>
<td>5</td>
</tr>
<tr>
<td>Applicability of Demonstrations</td>
<td>6</td>
</tr>
<tr>
<td>Student Acquiring Knowledge from the Demonstration</td>
<td>8</td>
</tr>
<tr>
<td>Uses of the Demonstration: A Guide to Meaningful Experiences</td>
<td>10</td>
</tr>
<tr>
<td>Uses of the Demonstration: A Guide to Reflective Thinking</td>
<td>12</td>
</tr>
<tr>
<td>Criteria of an Effective Presentation</td>
<td>14</td>
</tr>
<tr>
<td>Criteria of a Good Demonstration</td>
<td>15</td>
</tr>
<tr>
<td>Specific Functions of the Demonstration</td>
<td>16</td>
</tr>
<tr>
<td>Interdependence of Experimentation to Demonstration</td>
<td>17</td>
</tr>
<tr>
<td>Expected Outcomes of the Demonstration</td>
<td>19</td>
</tr>
<tr>
<td>Evaluation of Outcomes Used as a Guide</td>
<td>20</td>
</tr>
<tr>
<td>CHAPTER</td>
<td>Page</td>
</tr>
<tr>
<td>----------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>III. SEVEN DEMONSTRATIONS: APPARATUS</td>
<td>22</td>
</tr>
<tr>
<td>Introduction</td>
<td>22</td>
</tr>
<tr>
<td>Teacher's Guide</td>
<td>22</td>
</tr>
<tr>
<td>Student's Guide</td>
<td>22</td>
</tr>
<tr>
<td>Pressure-Density Gauge</td>
<td>24</td>
</tr>
<tr>
<td>Cartesian Diver</td>
<td>32</td>
</tr>
<tr>
<td>Explosion Can</td>
<td>49</td>
</tr>
<tr>
<td>Spectroscope</td>
<td>48</td>
</tr>
<tr>
<td>Adjustable J-Tube</td>
<td>58</td>
</tr>
<tr>
<td>Sound-Resonance Tube</td>
<td>67</td>
</tr>
<tr>
<td>Light-Ray Table</td>
<td>74</td>
</tr>
<tr>
<td>IV. CONCLUSION</td>
<td>82</td>
</tr>
<tr>
<td>Limitations</td>
<td>83</td>
</tr>
<tr>
<td>Recommendations</td>
<td>84</td>
</tr>
<tr>
<td>BIBLIOGRAPHY</td>
<td>86</td>
</tr>
</tbody>
</table>
# LIST OF DIAGRAMS

<table>
<thead>
<tr>
<th>DIAGRAM</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pressure-Density Gauge</td>
<td>23</td>
</tr>
<tr>
<td>Cartesian Diver</td>
<td>31</td>
</tr>
<tr>
<td>Explosion Can</td>
<td>39</td>
</tr>
<tr>
<td>Spectroscope</td>
<td>47</td>
</tr>
<tr>
<td>Adjustable J-Tube</td>
<td>57</td>
</tr>
<tr>
<td>Sound-Resonance Tube</td>
<td>66</td>
</tr>
<tr>
<td>Light-Ray Table</td>
<td>73</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

PURPOSE OF THIS THESIS

The purpose of this thesis, as suggested by the title, is to outline seven demonstrations suitable for teaching particular phases of physics in secondary schools. In the discussion the pieces of equipment are a few apparatus needed in physics in a secondary school. A small school, constructing and using this type of equipment, can raise the standard or quality of the physics course offered so that it would be comparable to a similar course offered by a larger school with extensive equipment facilities.

Problems associated with science teaching in small schools.-- Budgets in small schools are usually limited to the extent that they are unable to provide the commercially available equipment which is necessary to teach an adequate course in physics. In this discussion the pieces of equipment referred to represent only a few samples of the equipment necessary for an adequate course in High School physics. In addition, home-made equipment represents a possible solution for schools which are inadequately equipped.

The simple design and construction.-- In this discussion the pieces of apparatus presented are of necessity simple in construction and design, but nevertheless illustrate the principles of physics adequately.
Similar devices can be built by the teacher or the student with a little initiative and imagination.

Low cost of materials needed.-- The low cost of materials needed to build the devices outlined in this discussion enables schools with limited budgets to build these particular kinds of demonstration apparatus or other similar devices leading to good teaching. The most expensive device discussed in this thesis is the Spectroscope, which was built for less than five dollars. The Explosion Can was built from scrap materials.

Other purposes.-- The devices discussed in this thesis can be used to promote students' comprehension of the principles of physics. The apparatus can be used for demonstration by the teacher or by the student, and can also be used for individual student experimentation, investigation, and projects.

Constructing and using this type of equipment also provides an opportunity for the teacher to accentuate his in-service training. This is an essential factor in good teaching. When these services are not accessible in smaller areas, there is no better way to provide for in-service training than to make the equipment and use the necessary search of the literature which applies. The teacher can perform the experiment and do the basic research necessary to perfect the equipment. It will be difficult to provide up-to-date information to his students unless the teacher makes some effort to keep up with the process himself. Current information on the material taught will be provided him, if he makes some basic, simple demonstration equipment
that is inexpensive yet up-to-date.

Furthermore, the lecture-demonstration guides the student in his effort to comprehend the principles illustrated by the equipment and renders his own experimentation more meaningful.

In large schools the teacher can make these types of apparatus and use them as samples for students' projects. The making and using of these different kinds of apparatus by the teacher will sometimes encourage the student to reproduce them or some other devices of his choice. The value of the equipment is certainly worth the effort of the student.

**Description of the following chapters.**—Chapter II is based on historical evidence as viewed by certain individuals that support the validity of the demonstration to serve as a teaching device for particular science concepts. By necessity, the determinant of the validity of the demonstration was not derived by the writer, but accepted from individuals cited in this work.

Chapter III outlines the procedures of the classroom presentation and usage of the demonstration apparatus. The devices discussed represent only samples of the many pieces of equipment needed to teach a course in the secondary school physics class. Chapter III outlines the actual tools the teacher may need in order to encourage and help develop critical thoughts in the mind of the student.

Chapter IV includes the conclusion to the study presented, the limitation of the study, and the recommendations by the writer.
CHAPTER II

THE NEED FOR A SURVEY OF THE LITERATURE

THE NEED FOR LECTURE-DEMONSTRATIONS

As pointed out in *Science Education in American Schools*, there is a great need for the development in science classes of adequate series of demonstrations for building up scientific understanding of particular principles and concepts. This need seems most acute in smaller schools because of limited funds available for the purchase of equipment which is made commercially and which is necessary for an adequate series of demonstrations. Burnett maintains:

"...there is a place--and usually it is a neglected place--for teacher demonstrations. Verbal descriptions of scientific phenomena and statements of scientific principles need to be supported by realistic experiences if the learner is to appreciate them fully."

Today, perhaps more than ever, is found the need for such realistic experiences to aid in science teaching in the classrooms.


LEARNING AND DEMONSTRATIONS

The demonstration method is undoubtedly the best method for directed teaching and learning, since it provides the student with directions that are greatly needed for more advanced studies. The demonstration method allows the student to see for himself what is occurring, and thus adds meaning to the printed word. It also allows the student to use all pertinent senses for learning, which gives him a more thorough conception and a higher degree of retention. Burnett tells us:

"Students vary in their abilities to learn from words, which are abstractions of reality.... The teacher can assist students by providing considerable opportunities for the learners to observe the realities behind the words. As for some students, the visual approach is almost a necessity if they are to gain much from science instruction. The demonstration method has certain advantages over the individual laboratory method in this respect."

Demonstrations therefore lend themselves well to directed teaching and concrete understanding by all students.

Demonstrations are auxiliary devices necessary for broader understanding of the principles of science. On this point Zim maintains:

"...[Types of equipment] are auxiliary devices.... An experiment does no more than control some of the environment so that observations can be more accurate and can be more easily verified.... They extend man's senses in all directions, making it possible for him to observe directly or indirectly phenomena of which he might otherwise remain ignorant."

1/Burnett, op. cit., pp. 199-200.

The demonstration method provides the student with situations from which he can observe and deduce useful knowledge. Zim, in support of this view, adds:

"The basic method of science is that of observation; a method that clearly implies turning to nature and studying things firsthand. Facts or conclusions come from things which can be observed and measured. Firsthand experience is at the core of science."

In a subject such as physics firsthand observation is essential, but it is not always possible to observe the physical phenomena in their natural surroundings. Nevertheless, meaning can be added to the printed word by firsthand observation using the demonstration method. The relation between the printed word and the student's experience is well-provided for by the lecture-demonstration. Thus, if the student is expected to understand the sciences and be able to apply his knowledge in a scientific way, this new material must have some personal meaning. It must be in association with his common, everyday experiences. In order to accomplish this, the teacher must use means of explanation related to, or closely associated with, the student's everyday experiences. The lecture-demonstration is undoubtedly the best means to correlate the printed word with common experience, and with the principles of physics.

**APPLICATION OF DEMONSTRATIONS**

Demonstrations can be very flexible and they can be adapted to fit a variety of situations. They enrich small as well as large classes.

1/Zim, *op. cit.*, p. 4.
As pointed out by Richardson, "The demonstration is a versatile method, with several functions and some clearly defined advantages, but the variety of ways that the demonstration can be used has not always been explored by the science teacher." One reference supports the point of view that lecture-demonstration techniques presented by the teacher are best-suited for heterogeneous secondary school classes. In addition, the writer wishes to point out that the lecture-demonstration technique also lends itself well to the teaching of homogeneous groups. Consequently, the conclusion drawn by the report mentioned above may be superficial because, as noted by a study at Boston University, little attempt had been made prior to 1950 to develop demonstrations devoted solely to the presentation of principles in a functional manner.

Richardson points out that demonstrations need not be done necessarily by the teacher; they can be performed by the student as well, or they can be performed as a "cooperative enterprise that involves the teacher and one or more students." He further states, "This position seems to take into account more adequately the idea of learning through doing." In other words, this statement implies that the student learns best by doing, implying the student will learn best by experi-


2/Science Education in American Schools, op. cit., p. 2.

3/Murray, op. cit., p. 5.

mentation. Brameld does not agree with Richardson; in fact, he maintains, "Educators return always...to the key principle—learning is ultimately not doing but reasoning—and hence to the supreme importance of education of the mind and spirit." Hence, learning must be a process which involves discipline of the mind. Demonstrations contribute to this discipline in that they allow the teacher to help guide the student through some of the steps of logical reasoning in order to attain a desired goal. Experiments alone are frequently not enough for the student to comprehend particular principles, because they do not provide the incentive, the guidance, the directions, or the discipline which are needed. Explanations and textbook reading are seldom totally effective in making material meaningful and comprehensible to the student. The demonstration, on the other hand, helps the student best to understand the meaning of the printed word and enables him to comprehend the need and the purpose of the experimentation. The writer maintains that the student learns best from the experimentation when he has been previously introduced to the problem he is to solve. Oftentimes he can be provoked to experiment by a demonstration.

STUDENT ACQUIRING KNOWLEDGE FROM THE DEMONSTRATION

The demonstrations, as mentioned previously, have a particular value for a teaching technique, and this value helps to lead to acquisition of knowledge by the student. This value can be assumed to be greater than that achieved by lecturing and experimentation either

individually or combined. Demonstrations stimulate competitive attitudes on the part of the students, inasmuch as the students participate both as individuals and as members of a class, Klausmeier points out: "In science classes, demonstrating an experiment which makes use of materials in the students' environment captures their attention." To capture the attention of the student is to stimulate his interest in the subject matter.

Demonstrations lend themselves well to concrete understanding, since the student not only acquires knowledge by reading but also by seeing, feeling, hearing, and even by smelling and tasting. According to Goldstein, to observe is not limited to physiological senses but includes also all the scientific instruments and apparatus which make it possible for us to observe and to learn. He continues:

"One of the most important methods of obtaining information is by observation. The word observe means 'to see,' but observation includes more than seeing, it includes the use of all the scientific instruments to learn what is occurring.... Observation can be made by seeing, hearing, tasting, smelling, feeling, counting, weighing, measuring...."

He further asserts that it includes all other processes making it possible for us to learn.

Other accepted views concerning learning in relation to science teaching have been pointed out by Wittich. He states that "one

\[\text{1/Herbert J. Klausmeier, Teaching in the Secondary Schools, Harper and Brothers, New York, 1958, p. 175.}\]

\[\text{2/Philip Goldstein, How to Do an Experiment, Harcourt, Brace and Company, New York, 1957, p. 28.}\]

learns better when all pertinent senses are employed...." One learns best from any situation when most senses are used. In addition, 
1/
Brameld points out that "effective education is, above all else, the scientific method at work in every area of experience."

USES OF THE DEMONSTRATION:
A GUIDE TO MEANINGFUL EXPERIENCES

Physics is generally considered difficult to teach to young adults and it is also difficult for them to learn, but perhaps this problem can be partially solved by a change in the teaching and learning environment. The writer maintains that the major problem at hand is one of comprehension. What is the best teaching method leading to good comprehension? If the individual seeking knowledge is expected to understand the sciences and to be able to apply his knowledge in a scientific way, his academic preparation should have the realistic orientation to equip him to deal with practical situations. Zim writes: "Everyone who deserves an education can learn how to think and act scientifically.... Laws of science are no longer ends to be finally defined but means to be used in further scientific study...."

In addition, he emphasizes that this is in association with common, everyday experiences. The demonstration method gives the student understanding of science by an association with reality, which he cannot master from printed ideas alone. The demonstration further provides

1/Brameld, op. cit., p. 90.
2/Zim, op. cit., pp. 4-6.
experience for the student to be able to use vital phases of his acquired knowledge effectively in actual life.

Science teaching, to be of any value to the student, must be taught with the definite understanding by the teacher that the student must be able to use the acquired knowledge. It must be of value to him. Consequently, remembering a physics formula is indeed a very poor indication that the student understands the law it represents.

Conant points out that it is not enough to be able to recall a formula or that "being well informed about science is not the same as understanding science, though the two propositions are not antithetical."

"No one can become a scientist by the mere mastery of science content," writes Zim. This implies that to acquire useful knowledge one must be able to observe, and to use the facts learned from the observation with facility. The demonstration, in addition, brings the student into contact with things which are more real to him than the printed page. As pointed out by Sternig:

"Learning from the printed page is only one method to learn. It teaches best when related to something real in the actual environment which can be seen and handled and to which the printed ideas apply. All ideas are more easily gained and more securely held when learned through association with real things. This is a fundamental principle of education! It can hardly be considered a modern discovery but it is too often overlooked by teachers."


2/Zim, op. cit., p. 5.

In classroom situations, if the student can see and touch the device, the printed explanation makes much more sense to him. It is not abstract like the printed word, rather it is more meaningful to the student.

USES OF THE DEMONSTRATION:
A GUIDE TO REFLECTIVE THINKING

Only through logical, reflective, and deductive reasoning can the student acquire meaning or comprehension of the printed material. 1/ Richardson tells us that science, "an attitude of mind, a method of study and investigation, a body of organized knowledge--owes its existence to reflective thought." Considering that science is a logical process, and to understand science, one has to think reflectively. 2/
Whitehead maintains:

"Without deductive logic science would be entirely useless.... In the teaching of science, the art of thought should be taught: namely, the art of forming clear conceptions applying to firsthand experiences, the art of divining the general truths which apply, the art of utilizing general truths by reasoning to more particular cases of some peculiar importance...."

Learning to reason is consequently at the very foundation of science learning and comprehension. According to Brameld, "Learning to reason, in the strict sense, becomes a major objective of secondary and college education...." How many teachers teach the student how

1/Richardson, op. cit., p. 107.
3/Brameld, op. cit., p. 323.
to reason? Modern trends in education demand the fulfillment of this responsibility placed on the teachers. Physics, for instance, cannot be really taught as a rote memory course. If this is attempted, it will have very little value to the student because he will not be able to transfer his acquired knowledge to any new situation with which he will be confronted. In other words, being well-informed does not mean that understanding has taken place.

Only experiences which are real to the student will give him understanding. Brameld writes:

"Man's mind...exists within the flow of experience—not at all outside of it. Mind is not some mysterious entity that defies scientific explanation in the mental realm. As a matter of fact, it is not an entity, a distinct organ or object, at all.... Mind is, in essence, an especially important way of experiencing."

Experiencing is in essence an entity not independent of the mind; on the contrary, it is a part of the mind. All physical laws are logical; therefore, if the mind is to experience knowledge from those laws, it must be through the use of logical, reflective, and deductive reasoning.

This short discussion of the philosophy of science education is only a small part of the entire field of the philosophy of education, but it cannot be regarded as unimportant and irrelevant because it is a part inseparable from the total discussion presented in this thesis. Brameld writes, "All of us philosophize whenever we try to express the things we believe about our lives and about our relations to the rest of life."

1/Brameld, op. cit., p. 102.

2/Ibid., p. 84.
CRITERIA OF AN EFFECTIVE PRESENTATION

One of the major assets available to the teacher of science as a medium of instruction, as discussed previously, is the demonstration. A demonstration, regardless of how elaborate, will be just as effective as the teacher makes it. It is imperative that the teacher devote a great deal of time to the preparation of the demonstration if it is to be effective. Demonstrations should be accompanied by a lecture-

discussion. Richardson emphasizes this point when he says:

"...the science teacher may accompany a demonstration with his own comments or description....this procedure /1/ such that it may be called more properly a demonstration-discussion. /2/ geared toward/ such appropriate functions as creating problems, or solving them...."

In this respect the lecture-discussion will help the student as he studies to comprehend the principle illustrated by the demonstration. To render the demonstration more meaningful to the student, it should be accompanied by informational materials produced by the teacher. These include such items as the diagram, statement of principle, description of apparatus, directions for the student's experimentation, and statement of the historical background. The responsibility of producing the informational materials should be that of the teacher, but they can be produced as a cooperative enterprise with one or more students.

As maintained by Burnett, "The effective teacher of science must make use of a vast array of teaching materials. He must spend time in


2/Burnett, op. cit., p. 354.
devising, assembling, and using demonstrations and laboratory experiences...." The verbal introduction to the demonstration is, of course, only one of the media the teacher can use in order to present the demonstration effectively. For instance, some particular demonstration may require the presentation by certain specific audio-visual material used as an introduction. An effective demonstration demands an exploration of all the possible methods of presentation, and the teacher is to choose the most appropriate technique to fit the particular need.

CRITERIA OF A GOOD DEMONSTRATION

The presentation can be improved greatly when the following criteria for a good demonstration are followed, according to Richardson. They are:

"(1) The demonstration should be tried in advance.
(2) The purpose of the demonstration should be clear.
(3) The demonstration should be visible to everyone in the room.
(4) The apparatus used should be as simple as possible.
(5) The demonstration should be utilized as fully as possible in the light of its purposes.... Many demonstrations introduce ideas and possible relationship for further study."

Richardson continues by saying that at times it may be necessary to attempt a demonstration on the spur of the moment. Advance trial of the demonstration should not hinder the trial-and-error method of presentation, which is also all-important. Quite often spontaneous situations arise in the classroom when it is necessary to explain a scientific principle to the student. This may necessitate, on the

1/Richardson, op. cit., pp. 80, 81, 82.
spur of the moment, the use of demonstration apparatus for which previous preparation has not been made. Richardson states further that the apparatus should be simple in construction and in nature.

A sixth criterion that should also be met, according to the writer, is that the demonstration should not be the *finale* of the principle it exemplifies. Adequate follow-up, such as discussion and formal or informal testing, should be provided to insure thorough understanding.

Other related criteria which should be met, according to a group study in 1950 at Boston University, are as follows:

"(1) It must demonstrate a principle.
(2) It should work and be as infallible as possible.
(3) Apparatus should be on a large scale.
(4) It should be simple and speedy.
(5) It should be of easily available and inexpensive materials."

These are only a few but essential criteria the demonstration should meet in order to be effective. Other criteria may need to be met to fit some particular situations or conditions, which the teacher may explore in order to meet certain specific situations.

**SPECIFIC FUNCTIONS OF THE DEMONSTRATION**

Some of the specific functions of the demonstration, according to Richardson, are:

"(1) to solve a problem
(2) to explain, to make clear by analysis
(3) to verify, substantiate, and review
(4) to supply an application

1/Murray, op. cit., p. 6.

2/Richardson, op. cit., pp. 78-79.
(5) to evaluate student achievement
(6) to create a problem
(7) to show methods and techniques
(8) to display objects and specimens."

This passage seems to imply specific processes of learning concurrent with the demonstration. These functions seem geared toward specific goals of accomplishment, but these goals are not noted by Richardson.

Above all, the writer believes, before the demonstration can be effectively used, a problem must be stated. The demonstration is then geared toward the solving of that problem by: (1) making clear by analysis; (2) showing methods and techniques, especially emphasized to show the logic of problem solving; (3) solving the problem; (4) supplying an application of the problem and the solution; and (5) supplying meaning to the student's subsequent experimentation.

INTERDEPENDENCE OF EXPERIMENTATION TO DEMONSTRATION

Often in the secondary school physics class the success of the student's experimentation is a result of the success of the demonstration. Directions furnished by the "cookbook" procedures of the conventional laboratory manual are not always effective as a method leading to reflective and critical thought. Admitting that critical thinking is an essential factor contributing to the development of the physics student's mind, the demonstration is by far one of the most important contributors to the aim of critical thinking. It has been mentioned previously in this work that experiments alone are frequently not enough to teach particular principles because they do not provide the incentive, the guidance, the directions, nor the discipline which are
necessary to develop critical thinking. The experimentation becomes meaningful to the student only when he is provided with the purpose for the experiment. The student's results will be more meaningful to him and he will learn best from an experiment when he understands the principles implicit in and the procedures necessary to a demonstration. In support of this statement, Breckenridge can be cited:

"The problem of education becomes...the problem of helping...[students] to learn to use their imaginations constructively.... This involves acquainting...[students] with as wide a set of scientifically accurate facts as possible. It means training [students] in the habit of using facts rather than wishes as a basis for thinking."

The above discussion applies to teaching students in secondary schools how to reason critically by analogy. The student sees the demonstration, he can question the authenticity of what he saw, and finally, he can prove or disprove his doubts by experimentation. In relation to this statement, Brameld writes, as cited previously, that "learning is ultimately not doing but reasoning...." In contrast to this view, Richardson maintains that learning is primarily a function of doing. Granted that doing is an intermediate step in the process of learning, doing must have some purpose and, like some ultimate objective, it must not be a goal in itself. The use of conventional laboratory manuals with the formal type of procedures outlined does not always influence attitudes leading to critical thinking. Demonstration may not be the


2/Brameld, op. cit., p. 323.

complete solution to the problem, but it can be said to be a step in the right direction, leading to a meaningful analysis of the problem being solved.

EXPECTED OUTCOMES OF THE DEMONSTRATION

It is expected that the demonstration will give the student measurable acquisition of understanding and ability to transfer his knowledge to lifelike situations, experiences, and materials. It is expected that the student will gain experience in discipline of his own mind and spirit so essential to the development of critical thinking. Critical thinking, as mentioned previously, should be an objective. In the light of this objective, the preliminary discipline necessary is the ability to reason logically, reflectively, and deductively.

The results or aims of these achievements are determined by the objectives outlined and established in mutual agreement between the teacher and his students. On this point Richardson \(^1\) states that "ultimately...[the plan] represents the combined efforts of the students and the teacher."

In addition, the teacher should always be alert to recognize immediate goals that the pupils set up intermittently. These goals are associated with the pupil's peculiar needs, experiences, and daily associations. When this occurs, the pupil is guided into the over-all classroom objectives as he responds individually to his particular objective. For example, in a physics class a boy might be particularly

\(^1\)Richardson, op. cit., p. 170.
interested in repairing television sets. He studies a demonstration outlined by the teacher on the electronic tube. His peculiar interest and goal are derived from his individual experience. At this point, the teacher guides him to reach the over-all class objectives by acknowledging his peculiar goal in the planning of the presentation.

Numerous opportunities result from the demonstration method for guidance of the pupil by the teacher into competitive activities and group work. The teacher should always be alert to recognize the pupil's expanding interest in technological advances, the use of the scientific method, and his possible choice of a vocation that was inspired by his classroom studies.

EVALUATION OF OUTCOMES USED AS A GUIDE

Important factors to be considered in the evaluation of outcomes, according to Richardson, are as follows:

"Ability to think reflectively. Ability to retain content-facts, principles, and generalizations. Understanding of and skill with quantitative relationships. Ability to work effectively in the laboratory. Ability to develop, organize, and express ideas."

Evaluation of the outcomes of the demonstration can be used as a guide to determine what, how much, and of what quality is the knowledge the student acquired from the demonstration. One major advantage of the demonstration resides in the possibility of repetition of parts of the demonstration; it allows also improvement in the technique of presentation with the needs of the student. In other words, what the student

1/Richardson, op. cit., p. 147.
did not understand the first time can be repeated when necessary until understanding is achieved.

The demonstration method affords one of the best opportunities for the teacher to make random direct observations of pupils' reactions to a presentation. For example, after a demonstration has been introduced, the teacher can observe how pupils handle the apparatus and how they interpret data in relation to mechanical equipment designed to show a scientific problem.

Anecdotal records, conferences with pupils, individual laboratory reports (reports of students' findings), and individual pupil reactions during classroom discussions are some of the means of evaluation. These and other channels aid the teacher in arriving at a systematic evaluation of the students' understanding of scientific principles.
CHAPTER III

SEVEN DEMONSTRATIONS: APPARATUS

INTRODUCTION

This chapter includes an outline of seven demonstrations that serve as typical examples of the demonstration technique discussed in this thesis. The organization of each individual section is the same. The presentation of the material in each section is introduced by a diagram which is followed by a guide for the procedures of presentation.

Teacher's Guide.-- The teacher's guide for the presentation of the demonstration is outlined as follows: (1) the diagram, which introduces the section; (2) a statement of the principle; (3) description of the apparatus; (4) suggestions for the procedure of presentation including demonstration, observation, and suggestions for students' experimentation.

Student's Guide.-- The student's guide is made up of reproduced informational materials which are given to the student. The informational material is outlined as follows: (1) the diagram introducing the section; (2) a statement of the principle; (3) description of the apparatus including a material list, procedures, and directions for construction; (4) a directive for the student's experimentation (made by the teacher using the suggestions presented here); (5) an outline of the historical background and principle; and (6) a student's report of findings (laboratory report sheet).
PRESSURE-DENSITY GAUGE

GLASS TUBE

METER-STICK

RUBBER TUBE

TWO-HOLE STOPPER

Y-TUBE

FLORENCE FLASKS

UNKNOWN

WATER

PINCH CLAMP

J. ALPHEE DESJARDINS
1959
PRESSURE-DENSITY GAUGE

I. Principle:
Under a given pressure a confined liquid will rise in a tube to a height which is inversely proportional to its density.

II. Description of apparatus:
A. Materials needed for the construction:
   1. One meter-stick
   2. One wooden board 1 meter long for the back board
   3. One square board for the base
   4. One piece of wood 2 inches by 2 inches
   5. Four two-inch wood screws
   6. Two Florence flasks
   7. Two 2-hole stoppers
   8. Two glass tubes, about 2 inches long
   9. One Y-tube
   10. Two rubber tubes, about 6 inches long
   11. One rubber tube, about 15 inches long
   12. One pinch clamp
   13. Two glass tubes, preferably one meter long and small-size diameter
   14. Two 1/2-inch wood screws
   15. Two clamp holders (wire can be used).

B. Construction: (Refer to diagram)
   1. Cut the back board to the required size.
2. Fasten the meter stick to the back board with screws (or use glue).

3. Make a suitable base with a piece of plywood and fasten to the back board with screws, using the 2-inch by 2-inch to give it strength.

4. Assemble the tubing and the Florence flasks as shown in the diagram.

5. Fasten the Florence flasks to either the base or the back board with clamps or by any other suitable method.

III. Procedure:

A. Demonstration:

This demonstration is used to show and calculate the density of any unknown liquid, provided the density of the companion liquid used is known. The demonstration shows that at a given pressure confined liquids of different densities will rise unequally in the tubes. To demonstrate this, place each of the two liquids, one of known and one of unknown density, in Florence flasks. Place the stoppers in the flasks, making certain that there are no leaks and that the long glass tubes reach below the level of the liquids. Blowing into the rubber tube will cause the two confined liquids to rise in the tubes unequally.

B. Calculating the density of an unknown:

Place a known-density liquid in one of the Florence flasks, and a liquid of unknown density in the other flask. Water is recommended for the known liquid.
The principle states that at a given pressure a confined liquid will rise in a tube to a height which is inversely proportional to its density. Another way of stating the principle is that the pressure exerted by a column of liquid is directly proportional to the product of its height and density. This can be expressed by the formula

\[ P = dh \]

where \( P \) is the pressure, \( d \) is the density, and \( h \) is the height.

Letting this formula represent the known-density liquid in one of the Florence flasks, the pressure caused by the unknown density liquid in the other flask can be expressed by the formula

\[ P_1 = d_1 h_1 \]

where \( P_1 \) is the pressure, \( d_1 \) is the density, and \( h_1 \) is the height of the unknown.

As the pressures in both flasks are the same, equalized by the Y-tube,

\[ P = P_1 \]

Substituting in the formula:

\[ dh = d_1 h_1 \]

Solving for the density of the unknown:

\[ d_1 = \frac{dh}{h_1} \]

C. Student's experimentation:

Having seen the demonstration, the student should be able to experiment with the piece of apparatus. The usual procedure
is to give the student about three samples of unknown liquid to identify. Following the same procedures as explained in the demonstration, the heights to which the two liquids will rise in the tubes can be determined. Using these figures, the student can calculate the density of the unknown liquid. With the calculated density (for each unknown) the identification of the unknown can be found by consulting the density tables in the textbook or library reference books.
Historical Background and Principle--Student's Information

The historical background of this piece of apparatus is related to a number of devices which work on a similar principle. The ancients were aware of air pressure caused by the atmosphere. Evangelista Torricelli, some three hundred years ago, first attempted to measure it. Torricelli is credited with the invention of the mercury barometer. The barometer measures atmospheric pressure, or in other words, the weight of a column of air of unit size extending the full "depth" of the atmosphere. The lift pump, which works on a similar principle, was invented long before Torricelli's time. In fact, Torricelli invented the barometer because the Duke of Tuscany had asked him why his well pump did not work. Torricelli did not know the answer, so he decided to experiment. He discovered that atmospheric pressure could not force the water high enough in the pipe for the pump to lift it to the surface. Once it was known that atmospheric pressure caused a column of water to rise to some height (34 feet), Torricelli substituted water with a denser liquid (mercury) and made a practical barometer.

The next invention to be mentioned is the force pump. This pump, rather than lifting, forces liquids into a tube. This pump is placed at the bottom of a well and pushes the liquid up the pipe. This type of pump is used today to pump oil from deep wells. The principle of operation of the force pump is that it furnishes enough pressure to overcome the pressure caused by the column of liquid above it. When the column of liquid is more dense, it requires more pressure to lift
it. The height a liquid of a given density will rise in a tube is limited to the pressure exerted by the pump. This is essentially how the Pressure-Density Gauge works.

All the devices discussed here have one thing in common: liquid is displaced because of differential pressure at the ends of the tube. This is to say that by connecting a vacuum pump to a Y-tube connected to the top of the tubes of the Pressure-Density Gauge, the same results can be obtained as previously described.
PRESSURE-DENSITY GAUGE

Student's Report of Findings

By a diagram clearly drawn and labeled, illustrate the principle you have investigated.

In what aspect of reality does this principle apply? Name three applications, and discuss one fully.

1.
2.
3.

Give your comments on the instrument: Explain how it helped you understand more clearly the principle. If it did not help, suggest how it could be improved.

Identification of "unknowns"

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Density of known liquid</th>
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How does the Pressure-Density Gauge resemble a barometer?
CARTESIAN DIVER

CORK

AIR PRESSURE

RUBBER TUBE

WATER LEVEL

TEST TUBE

OLD CONDENSER

TUBE

GLASS PLUG

CORK

J. ALPHEE DESJARDINS
1959
CARTESIAN DIVER

I. Principle:

When the weight of a body placed in water is greater than the weight of the volume of water it displaces, the body will sink.

II. Description of apparatus:

A. Materials needed for construction:

1. One cold-water jacket from an old condenser
2. Two corks to fit the ends
3. One rubber tube about 3 feet long
4. One test tube
5. One rubber tube 2 inches long
6. One glass rod 1 inch long
7. One air pump
8. Water to fill the condenser
9. Food coloring (optional)
10. Two burette clamps
11. One ringstand
12. One air pressure gauge.

B. Construction:

1. Close one end of the condenser with a cork. This end will be the bottom. Assemble the stand and attach the condenser to it with clamps.
2. Plug the side bottom opening using the short rubber tube and glass plug.
3. Pour water into the container to 3/4 full.
4. Fill the test tube with water.
5. Place one finger over the mouth of the test tube, then invert the tube, holding it directly above the opening of the condenser.
6. Simultaneously remove the finger from the mouth of the test tube and drop the test tube in the container. If this is well done, there will be just about the right amount of water left in the test tube. The test tube should now be buoyant; about 1/2 inch of the test tube should be above the water level.
7. Close the top opening with the other cork.
8. Connect one end of the long rubber tube to the side top opening and connect the other end to the pump.

III. Procedure:

A. Demonstration:

This demonstration is to show that if the weight of a body is more than the weight of the volume of liquid it displaces, it will sink; if less, it will float.

Increased pressure in the closed container causes the water to rise inside the test tube by compressing the captive air. As the captive air decreases in volume, the test tube and air displace less water to the point where the test tube and air weigh more than the water displaced. A release of pressure will lower
the water level in the test tube and cause it to rise.

This is an excellent demonstration of the Cartesian Diver as the variation of the water level in the test tube can be as much as 1 1/2 inches. Coloring the water will add to the visual demonstration.

B. Calculating the pressure in the test tube at depth:

The pressure on the Cartesian Diver can be calculated for each demonstration by the depth at which it will be buoyed. At that point the weight of the Cartesian Diver is exactly equal to the weight of the water it displaces; or, the "density of the test tube" is exactly equal to the density of the water at that depth. According to Archimedes' principle, the test tube is buoyed up by a force \( F \) equal to the weight of the water displaced. Using the mean distance the test tube sinks, measured from the level of the water to the middle of the test tube, the average pressure acting on the test tube can be calculated. Expressed by a formula the pressure is:

\[
P = P_w + P_a
\]

where \( P \) is the total pressure, \( P_w \) is the pressure caused by the water above, and \( P_a \) is the air pressure in the confined container. Pressure \( P_w \) equals the product of the height \( h \) and the density \( d \) of the water. Using an air pressure gauge (reading in pounds per square inch), the pressure of the air in the confined container can be substituted directly in the formula. The pressure causing the test tube to be buoyed is, as expressed by a formula:

\[
P = d \cdot h + P_a
\]
C. Student's experimentation:

Variations from the demonstration can be used for the student's experimentation. By connecting an air pressure gauge on either the pump or the rubber tube, the student can determine the pressure in the enclosed container. With the readings obtained, the student can calculate the pressure in the test tube.

Another variation is using a liquid other than water in the condenser tube. A less dense liquid will require less pressure for the same effect. A denser liquid, like salt water, will require a greater pressure.
Historical Background and Principle--Student's Information

A body floating or submerged in a liquid is buoyed up by a force equal to the weight of the liquid displaced. This principle was discovered by the Greek mathematician and inventor, Archimedes, in the third century B.C. Archimedes did not invent the principle of the boat buoyed on water, but he explained it by a mathematical formula. In ancient Greece mathematics was considered as a sort of mythical study for the higher class of people. As a result, there were no correlations between realia and mathematical formulae. Archimedes, although belonging to the upper class, was intrigued and eager to investigate some of the natural phenomena and explain them in terms of mathematics, but he was reluctant to make public his discoveries. Archimedes, as a result, did not leave records of all of his many discoveries.

The operation of the Cartesian Diver is based on Archimedes' Principle. When the level of the water in the test tube rises, the weight of the test tube is increased. This is because the volume-air which is trapped in the test tube is reduced. Some of the buoyancy of the test tube is provided by the entrapped air in the tube. This is to say that the air in the test tube weighs less than the water it displaces. Part of the volume occupied by the air is replaced by water which is denser than air. The remaining smaller volume of air in the tube is not large enough to provide the necessary buoyancy to lift the test tube. As a result, the test tube will sink.
Another very important principle making it possible to increase the weight of the test tube was first stated and demonstrated by Blaise Pascal (1623-1662). Pascal discovered that any change of pressure in an enclosed fluid is transmitted undiminished to all parts of the fluid. A practical application of this principle is to be found in hydraulic systems where a force is applied on one part of the liquid and some load is moved at another. An increase in pressure in the condenser tube means an equal increase in pressure in the smaller test tube, or anywhere else within the closed container.
CARTESIAN DIVER

Student's Report of Findings

By a diagram clearly drawn and labeled, illustrate the principle of operation of the Cartesian Diver.

At a given depth a submarine is moving at a given rate of speed. Does the submarine weigh more, less, or the same as the volume of water it displaces? Explain your answer.

A large ocean liner sank to the bottom of the ocean (depth is 70 feet). Experts claim it can be lifted back to the surface. Demonstrate with a device of your own making how this will be done, using Archimedes' and Pascal's Principles.
EXPLOSION CAN

CAUTION: DO NOT USE WITH LESS THAN 36 INCH TUBE.

TOBACCO CAN

RUBBER WASHERS

NUT

DETAILED VIEW

SCREW BOTTLE CAP

BICYCLE VALVE

RUBBER TUBE

(1/4" X 36")

J. ALPHEE DESJARDINS
1959
EXPLOSION CAN

I. Principle:

When combustible dust is dispersed in air inside a closed container, the dust and the oxygen in the air combine explosively when ignited.

II. Description of apparatus:

A. Materials needed for the construction:

1. A one-pound size tobacco can (or any similar can with a friction lid)
2. A complete stem and valve from a bicycle tire, or auto, inner tube
3. Two rubber washers to fit over the stem (may be made from sheet rubber)
4. One screw cap from a catsup bottle
5. One short wax candle
6. One rubber tube 1/4-inch inside diameter, minimum length 36 inches for safety. (This is important!)
7. Matches
8. Lycopodium powder, or any other combustible, dry, fine powder.

B. Construction:

1. Use a tobacco can about one-pound size (or any other can of similar size which has a friction cover).
2. Cut a hole on the side of the can about 1/3 the height of the
can from the bottom to fit snugly over the valve stem.

3. Using a screw cap, from a catsup bottle or any other cap of comparable size, cut a hole to fit over the stem as close to the bottom of the cap as possible. This bottle cap will serve as a funnel to hold the powder.

4. A support for the candle can be made from sheet metal. Location of the support is not essential as the candle can be placed anywhere. Light the candle and place a few drops of wax at the bottom of the can to mount the candle upright.

5. Assemble as shown in the diagram.

III. Procedure:

A. Demonstration:

This piece of apparatus is designed to demonstrate in safe miniature the danger of dust explosions in mines, grain elevators, or where the air is contaminated with dust, mostly because of poor ventilation or low humidity. This experiment is more than instruction in physics--it is a lesson in safety.

Place one teaspoonful of lycopodium powder in the funnel (the bottle cap). Light the candle and close the cover of the can quickly. Place the open end of the long tube in the mouth and blow hard.

CAUTION: Do not stand close to, or over the can. Be as far away as possible. As the strength of the can is unknown, if the cover fits too snugly, the can may blow up.
B. **Investigations:**

Lycepodium powder is the most commonly used dust for this experiment. Actually, *any* combustible powder can be used. Some of the dusts used were wheat, oats, tobacco, paper (well-washed and dried), hay, and a number of minerals.

C. **Student's experimentation:**

The Explosion Can was designed for students' use. The bicycle valve provides safety for the student. Nevertheless, the student must be carefully instructed of the dangers in using the can.

The usual procedure is to give the student a selection of powder samples for him to determine their relative explosive powers by using always the same amount of powder for each experiment. It is also recommended that the student perform some experiments on non-explosive powders so that he may experience the difference. The list of powders mentioned in *investigations* will provide a good selection of powders.
**Historical Background and Principle--Student's Information**

All combustible materials need oxygen to "burn." Burning is simply a chemical process called **oxidation**. In oxidation the atoms of the fuel combine chemically with atoms of oxygen and form a new substance. The general chemical reaction is not too important to us at this time; what is most important is **how fast** does this combustion take place?

A kindling wood fire consumes oxygen at a relatively slow rate as contrasted to a gasoline fire. If the same piece of wood is broken into many parts, a larger area of wood is exposed to oxygen and thus the wood will burn faster. The carburetor of an automobile mixes air with the vaporized gasoline, and the two are compressed into the cylinder. The droplets of gasoline are all surrounded with oxygen. The result is that the gasoline burns "so fast" that it produces an **explosion**. This is to say that the rate of oxidation is very fast. For better explosions in the cylinder of the internal combustion engine it was found that gasoline needs to be mixed with air at the ratio of 1:16. What happens when an automobile's engine is "flooded" is that the ratio of the gasoline to air is more than 1:16, perhaps 1:8. Although gasoline is plentiful in the cylinder, the spark from the spark-plug will not ignite it. Gasoline companies have spent a great deal of money in research in an effort to reduce the rate of combustion of gasoline. The principle is to make the explosion last as long as possible without sacrificing power.

Consequently, with different rates of combustion of the different
fuels, it is possible to use combustible materials for different purposes.

Explosives, in the form of black powder (potassium nitrate mixed with carbon and sulphur), were known long ago by the Chinese. Roger Bacon, in the thirteenth century, independently discovered black powder. Black powder was first used for war at the Battle of Crécy in 1346.

Nitroglycerin (a combination of glycerin and nitric acid) was first discovered by Ascanio Sobrero, an Italian, in 1846. Nitroglycerin is a very powerful detonator, but it is also very difficult and dangerous to handle and transport.

Alfred Nobel of Sweden perfected dynamite in 1864. He discovered that nitroglycerin retains most of its explosive quality when mixed with a fine absorbent mineral substance. What Nobel discovered was that he could slow down the rate of combustion by exposing less of the surface area of the nitroglycerin to oxygen.

For the Explosion Can, the reverse is true: combustible dusts are exposed to more oxygen. Hence the rate of combustion is increased high enough to be explosive. A normally harmless combustible material has become a dangerous explosive. Imagine this to be a grain elevator.... Explosives are harmless if controlled, but they are very destructive and dangerous when not controlled.
EXPLOSION CAN

Student's Report of Findings

In what aspect of reality does the principle of the Explosion Can apply? Explain one of the following: How can a grain elevator, or a coal mine, explode?

Compare the Explosion Can with an automobile carburetor.

Describe some of the necessary precautions which must be followed to prevent explosions in coal mines.
SPECTROSCOPE

EXPLODED VIEW

BOLT & NUT

FROSTED GLASS

BRIDGE

ADJUSTMENT SCREW

LIGHT SLIT

LENSES

DIFFRACTION GRATING REPLICA

LENSES

EF 6

J. ALPHEE DESJARDINS
1939
SPECTROSCOPE

I. Principle:

Each chemical element in the periodic table, when raised to a high temperature and vaporized, emits its own characteristic light with its characteristic "lines" (with definite wave lengths) which are observed as "spectral lines."

II. Description of apparatus:

A. Materials needed for construction:

1. Two double convex lenses (55 mm by 88 mm focal length)
2. One sheet of diffraction grating replica, cut to needed size
3. One piece of frosted glass
4. An old drafting compass with a center-wheel adjustment
5. A piece of galvanized sheet metal for the light slit
6. About two dozen brass wood screws, 1/2 inch long
7. Two brass bolts with nuts
8. One bottle of India ink
9. Varnish, shellac, black paint, and glue
10. Common hand tools
11. Two inches of platinum wire
12. Bunsen burner or blow torch
13. Selection of chemical compounds, such as salt
14. The wood required will be listed in construction, as any dimensions will do

15. A pair of tweezers.

B. Construction:

1. Select the two double-convex lenses to be used.

2. Dimensions for the box:
   
a. The distance from the outer edge of the light slit to the center of lens (1) equals the focal length.

b. The distance between lens (1) and the center of the diffraction grating equals 11/7 of the focal length.

c. The distance between the center of the diffraction grating and the center of lens (2) equals 2/7 of the focal length of lens (1).

d. The distance between the center of lens (2) and the outer surface of the frosted glass equals the focal length of lens (2). The frosted side of the glass is toward the outside.

e. The cross-sectional dimensions of the inside of the box are to fit the lenses used. Cut the diffraction grating replica to fit.

3. Remove the angle-adjustment screw from the old drafting compass.

4. Cut the parts for the light slit from galvanized sheet metal.
   
The bottom part is cut to a height half the height of the box.

   The top part is high enough so that it is higher than the box by 1 inch when in place over the bottom part.
5. Roll the top edge of the top piece of the light slit around a nail. After rolling, remove the nail and drill a hole large enough to fit the adjustment screw downward through the "tubular" section.

6. Make a bridge from hardwood, as shown in the diagram. By drilling one hole across the top, and one downward through it so that the holes cross, the necessary holes for the adjustment screw and the threaded cross bar are provided.

7. Assemble the bridge, adjustment screw, and the parts for the light slit, as shown in the diagram.

8. The remainder of the box can be assembled by following the diagram. The dimensions are not important except for the length, which must be correlated with the focal lengths of lenses (1) and (2).

9. Paint the inside of the box with India ink.

10. Paint, varnish, or shellac the outside of the box.

III. Procedure:

A. Demonstration:

This piece of apparatus is designed to demonstrate that elements can be identified by spectroscopic methods. Using a sample such as common table salt in solution, the element sodium can be identified by its characteristic yellow color emitted at high temperature. Holding the platinum wire with tweezers, wet the wire with the salt solution. Place the wire over a Bunsen
burner and observe the flame with the spectroscope. The spectroscope will show a bright yellow line across the viewing screen. This is the characteristic wave length emitted by sodium. Similar observations can be made of any element in the periodic table.

B. Observations:

This piece of apparatus is not designed to measure wave lengths, but for a visual relative "measurement" of the wave lengths. The longer wave lengths visible are the red, and the shorter ones are violet. The longest wave lengths to the shortest are progressively red, orange, yellow, green, blue, indigo, and violet. Observation of a regular tungsten-filament light bulb with the spectroscope will show all colors of the spectrum. The four most prominent and defined colors are red, yellow, blue, and violet. Red, yellow, and blue are primary colors, while violet is prominent because it is located at the end of the scale. The remaining colors seem to blend with the others, thus do not appear too well-defined.

Any element can be identified by comparative analysis. For instance, sodium will show two strong yellow lines only, while hydrogen emits lines of red, greenish-blue, indigo-violet, and violet. Thus there is no reasonable doubt as to the identities of these two elements, or those of any others similarly compared.

C. Student's experimentation:

Given various samples of chemical compounds and metals,
the student can identify them by the comparative method described previously. The spectroscope can be used by more than one student at a time. While one student is preparing his samples for observation, another can be observing his with the spectroscope.

A good selection of samples to be analyzed includes about two gases, such as a hydrogen tube, and two metals. As the average time allowed in actual classroom situations is limited, to analyze these four samples in one class period seems adequate.

The student must be required to keep records of his observations. These records can be kept on file for future reference. Records well kept can be used as an index file, thus eliminating the necessity of making comparative analysis each time. In the future, to determine the identity of a given element, one has only to refer to the index file.
Historical Background of Spectroscopic Studies--

Student's Information

There are three distinct types of spectra which can be observed with this spectroscope: continuous, bright-line, and dark-line (or absorptive).

Continuous spectrum. An unbroken band of seven colors indicates a continuous spectrum. This band of colors is produced by incandescent substances. For instance, when a platinum wire is placed in the colorless portion of a Bunsen burner flame, a continuous spectrum will be observed.

Bright-line spectrum. Gases or vapors under atmospheric pressure raised to a high temperature will emit bright-line spectra. For example, if the spectroscope is turned toward a high-voltage, gas-discharge tube such as a neon sign, a series of bright horizontal lines of various colors on a black background will be observed. In fact, the colors observed will be predominantly red for neon. Red is the characteristic color for neon because several of the bright lines emitted by neon are in the red region. Observation of a sodium highway light with the spectroscope will reveal only a pair of bright yellow lines close together.

The same observation of sodium can be made by using table salt. Dip a short platinum wire in salt solution and place in a Bunsen burner flame and observe with the spectroscope. Two bright yellow lines close together are always characteristic of sodium.
Dark-line or absorptive spectrum. A glowing gas or vapor is able to remove or absorb from a continuous spectrum the lines of color it emits at a high temperature. For instance, using the spectroscope, observe white light passing through sodium vapor: A continuous or rainbow background will be seen crossed by two horizontal black lines at exactly the location of the yellow lines described above for sodium bright-line emission.

Studies of the sun's spectrum: The continuous spectrum emitted by the sun was first studied in 1802 by Wollaston, who also observed the black lines which were interspersed throughout the solar spectrum.

A few years later, in 1817, Joseph von Fraunhofer independently discovered and studied the black lines which are emitted in the solar spectrum. Fraunhofer mapped and studied some seven hundred of these lines. He labeled eight of the most prominent ones by the first letters of the alphabet. These eight lines, in honor of the discoverer, are called the Fraunhofer lines.

Reasons for the dark-lines. The omission of parts of the solar spectrum is attributed to absorption of the missing bands by the solar atmosphere. High temperature causes the sun to emit a continuous spectrum. As light passes through the sun's cooler atmosphere, certain wave lengths are absorbed. Not all the wave lengths are absorbed, but only the wave lengths this gaseous atmosphere would emit if heated to a high temperature. In other words, the atoms of a chemical element will absorb only the wave lengths which are characteristic of its own frequencies, while other atoms will absorb only certain other characteristic wave lengths.
A simple explanation is that the vibration of atomic electrons of an element at a high temperature is the cause of the light emitted by those atoms. The motion of the electrons gives rise to electromagnetic waves which have exactly the same frequencies as the excited electrons.

Conversely, when the atoms of an element are in a gaseous state, they will absorb only the wave lengths (or electromagnetic waves) which are characteristic of the frequencies of their own electrons. This can be compared to the resonance of two tuning forks. The second fork will resonate only when it is at exactly the same frequency as the first.

The light wave frequencies removed or absorbed from white light passing through a vapor will be at exactly the natural frequencies as the atoms in the gas. The atoms set in motion because of the absorbed energy re-emit this extra energy an extraordinarily short fraction of a second after absorbing it. The chances of emitting the absorbed energy in any one direction are equally probable for all directions. Therefore, very little of the absorbed light waves are emitted parallel to the ray of incidence. In the spectroscope, the portions absorbed will appear black.
SPECTROSCOPE

Student’s Report of Findings

By the use of the graph below, make a relative comparison of the spectrum lines observed with the spectroscope for each element studied.

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<tr>
<th>Sample No.</th>
<th>Spectrum lines</th>
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Explain how scientists can identify elements in far-away stars.

Do you think that a spectroscope has a practical implication in the industry? Explain one application which it may have in any industries (e.g., steel industry, copper industry, etc.), such as quality analysis.
I. Principle:

The volume of a confined gas at constant temperature varies inversely as the pressure.

II. Description of apparatus:

A. Materials needed for construction:

1. One meter stick
2. One glass tube with a small faucet, preferably built as shown in the diagram
3. One glass tube with a funnel, preferably built as shown in the diagram

(Both glass tubes above can be purchased from any supply house.)
4. One heavy gauge or plied rubber tube 20 inches long
5. Markers or indicators, and the clamps, can be made from scrap sheet metal. See the diagram.
6. Three bolts with nuts to fasten the clamps to the support boards
7. Two stove bolts 2 inches long, and two washers to fit the bolts
8. Wood needed: Hardwood is recommended:
   a. One board one meter long, for the back board
   b. One board, 1/4 inch thick, cut to dimension to cover the top of the back board
c. Two boards, 1/4 by 1 1/2 by 15 inches long, for the supports for the glass tubes

d. One board, 1 inch by 12 inches square, for the base board

9. Glue, nails, screws, sandpaper, and varnish

10. Common hand tools and a table saw, if available

11. Two pounds of mercury.

B. **Construction:** Refer to the diagram.

1. **The back board:**

   Make the back board from hardwood. The grooves, as shown, can be made with a table saw. The grooves on both sides must be 1/4 inch deep and wider at the bottom than at the surface. The middle groove is cut deep enough and wide enough to hold a meter stick. Lastly, cut the board to length, one meter long.

2. **The base:**

   Fashion the base board from hardwood or plywood to the given dimensions. Drill the necessary holes and fasten to the back board with screws.

3. **The supports for the glass tubes:**

   Cut the two support pieces from hardwood to fit the outside grooves on the back board so that they slide up and down easily. Cut to length (about 15 inches long). Drill the hole for the clamps only after making the clamps.

4. **The clamps, for the glass tubes:**

   Fashion the clamps from old sheet metal, as shown in
the diagram. Drill the holes in the clamps for the bolts.
Drill the holes to fit the clamps in the support boards.

5. **Adjustment screws:**
   
The adjustment screws are fashioned from two stove bolts, with the holes of the washers filed square to fit over the square collar of the bolt. Drive the washers snugly over the square collar against the inside of the head. Rivet the square collar against the washers.

6. **The nuts for the adjustment screws:**
   
   Countersink the nut for the adjustment from the end of the support board. See the diagram. Drill the hole for the adjustment screw. After making certain the adjustment screws work properly, glue the nuts in place.

7. Assemble as shown in the diagram. Be certain the rubber tube is well-secured on the glass tubes.

**Alternative construction:**

1. Rather than using commercial glass tubing, an old burette can be used for one of the tubes. Any comparable size tube can be used for the other.

2. The back board can be built from a flat board using glued or screwed-on guide strips for the sliding members. This method is recommended if a table saw is not available.
III. Procedure:

A. Demonstration:

This demonstration apparatus is designed to show that the greater the pressure on a confined gas, the smaller will be the volume of the gas.

Place the glass tubes at equal level, open the faucet, and fill the tube with mercury. It is important to keep the faucet dry of mercury; use the open tube to pour the mercury in. After filling the tube, close the faucet and lower the position of the closed tube a little. Take a reading, from the meter stick, of the level of the mercury in the closed tube. Leaving the closed tube at the same position, move the position of the open tube higher. Take another reading of the level of the mercury in the closed tube. Notice the decrease in volume of the gas in the closed tube, or the lower reading on the meter stick.

B. Calculating the reduced volume of gas:

The closed tube is uniform in cross-sectional area. The pressure on unit area of the confined gas is equal to the weight of a column of mercury of unit cross section. The volume of the gas in the confined tube is calculated by the difference of readings of the level of the mercury and the top of the closed tube. Letting the pressure acting on the original volume of the confined gas be standard atmospheric pressure, then the pressure acting on the second volume of the gas is atmospheric pressure plus the difference of the level of mercury in the two
tubes. Expressed as a formula and solving for the "new" volume:

\[ V_2 = \frac{P_1 \times V_1}{P_2} \]

where \( V_2 \) is the second volume, \( P_1 \) is standard atmospheric pressure, \( P_2 \) is standard atmospheric pressure plus the difference in the mercury levels of the two tubes, and \( V_1 \) is the original volume at standard atmospheric pressure. Substituting:

\[ h_2 = \frac{760\text{mm} \times h_1}{760\text{mm} + L} \]

where \( h_2 \) is the new volume, 760mm is standard atmospheric pressure, \( h_1 \) is the original volume at standard atmospheric pressure, and \( L \) is the difference of the levels of the mercury in the tubes.

C. Student's experimentation:

With an Adjustable J-Tube the student can perform a number of interesting experiments. Following the directions provided by the teacher during the demonstration, the student can repeat the same experiment. In addition, the student will perform a number of other experiments by varying the heights of the tubes. Carefully kept records of the student's findings are important for accurate calculations.

A variation of the use of the J-tube is to use it as a manometer tube to measure gas pressure of the gas supply in the laboratory. As mercury is too dense for this purpose, water has to be used in the tube rather than mercury.
Historical Background and Principle--Student's Information

After the invention of the barometer by Torricelli (1608-47), Pascal (1623-62) and Guericke (1602-86) experimented on the pressure of the atmosphere. Blaise Pascal discovered that mercury will not rise in a closed tube as high if the standard pressure of the atmosphere is reduced. He discovered that the higher the elevation of the barometer, the lower the mercury did rise. Otto von Guericke invented the first air pump by similar reasoning, and the vacuum pump.

Robert Boyle (1627-91), like the others of his time, has shown the value of experiment in studying the physical properties of gases. Boyle and his assistant Robert Hooke (1635-1703) built an improved air pump with which they were able to produce a high vacuum. With this, Boyle performed experiments that soon enabled him to find the weight of the atmosphere. Further experiments gave him the relation between the volume and pressure of a gas. He established the rule that bears his name--Boyle's law.

The principle of Boyle's law, as stated previously, is that the volume a confined gas will occupy at a given temperature is inversely proportional to the pressure confining the gas. Another way of stating the principle is that the pressure of a given quantity of gas varies inversely as its volume. Boyle's law provides an important piece of evidence for the theory that all matter is made up of tiny particles which are in constant motion. According to the kinetic molecular theory, molecules of gas in a container are in constant motion, bouncing off
each other and off the walls of the container. When the gas is compressed to half its original size, there are twice the number of molecules per cubic inch than before. Hence the pressure exerted by the vibration of the molecules will be twice as great. When the volume of that same gas is reduced to one fourth its original size, the pressure exerted by the gas will be four times as great.
By a diagram clearly drawn and labeled, illustrate the operation of a modern piece of equipment (of your choice) which makes use of the principle of physics studied in this demonstration.

Modern aircraft are built with pressurized cabins to protect the passengers. If the fuselage were punctured because of some accident while in flight, what effect could this have on the passengers (other than lack of oxygen)?

**Calculations.** Use the space below and list the findings of your experimentation.

<table>
<thead>
<tr>
<th>Reading of closed tube</th>
<th>Reading of open tube</th>
<th>Difference</th>
<th>Volume of gas</th>
<th>Pressure caused by the mercury</th>
</tr>
</thead>
</table>
SOUND-RESONANCE TUBE

TALL TRANSPARENT CYLINDER

WATER LEVEL

TALL GRADUATED TUBE
SOUND-RESONANCE TUBE

I. Principle:

An air column will reinforce a sound wave when the length of the air column is in resonance with the sound wave.

II. Description of apparatus:

A. Materials needed for the construction:

1. One tall, transparent, open-end cylinder of large diameter
2. One tall graduated cylinder
3. One Bunsen clamp
4. Water to fill the graduated cylinder
5. Tuning forks
6. One meter stick.

B. Construction:

1. Place the tall transparent cylinder inside the tall graduated cylinder.
2. Place the Bunsen clamp loosely on the tall cylinder above the graduated tube.

III. Procedure:

A. Demonstration:

This demonstration is used to show that the shortest length of an air column that can amplify a sound wave is one fourth the wave length of the sound wave. Set the tuning fork vibrating directly above the open end of the tube. Move the tube up and down, along with the fork, until the loudest sound is produced. Hold the tube at that point and tighten the clamp directly above
the graduated cylinder. Measure the length of the tube above the water level with a meter stick.

B. Calculating the wave length:

A full wave length includes two halves, one a compression and the other a rarefaction. The compression is produced when the vibrating prongs of the tuning fork are moving downward. The compression travels downward in the tube, where it is reflected by the water back to the fork again. At the instant it reaches the fork, the prongs have just completed a half cycle and are now moving upward. The compression helps the motion of the prongs and amplifies the sound as the compression and the prongs are moving in the same direction. If the length of the air column in the tube were not in resonance with the fork, the motion of the fork and the motion of the compression would oppose each other, and the vibration would be reduced. From the instant the compression wave leaves the tuning fork to the time it returns it has traveled twice the open length of the tube (up and down). This represents a half wave length, or as expressed in a formula:

\[ L = 4L \]

where \( L \) is the wave length and \( L \) is the length of the tube.

C. Student's experimentation:

This piece of apparatus was designed to be used as a resonance tube for tuning forks of various frequencies. The recommended procedure is to give the student a selection of
tuning forks of different frequencies with which he can experiment. The wave length, the frequency, and the time the sound wave requires to travel the length of the tube in each case can be calculated.

Comparing his results of the calculated frequency with rated frequency stamped on the tuning fork, he can correct his errors of measurement. After he has acquired some experience in the procedures and methods of measurement, an unmarked tuning fork will provide additional experiences for the student in an effort to establish the frequency of the "unknown" tuning fork.
The principle of operation of a resonance tube is that the air column amplifies the sound when it is in exact resonance with the tuning fork. In a closed tube (closed at one end) this occurs when the length of the tube is 1/4, 3/4, 5/4, 7/4, etc., the wave length of the sound.

The explanation is that the sound produced by the tuning fork travels down the tube, reflected by the water; it returns to the fork just as the fork is starting to move upward. Hence, the sound is amplified as both the fork and the vibrating column of air are moving in the same direction; in other words, they are in phase. The vibrating column of air assists the motion of the fork, or exerts a force on the tuning fork. The resulting amplitude of the "new" sound wave equals the algebraic sum of the two individual sound waves. The amplitude is defined as the maximum value of the displacement.

A brief mention of the historical background of the studies of sound includes first of all the velocity of sound. The earliest attempts to measure the velocity of sound in air were made in 1640 by Marin Mersenne, a French physicist. In 1656 Giovanni Borelli and Vincenzo Viviani, Italian physicists, continued the investigation. Since that time, many improvements of the methods of measurements were made. The most recent measurements were those of Dayton C. Miller, an American physicist, in 1934.

The intensity of sound, it was discovered by Hermann Helmholtz (1821-94), is characterized by its loudness and is measured scientifi-
call by the amount of energy in a given volume of space through which the sound is traveling. This is to say that sound waves constitute a flow of energy through matter. This can be demonstrated by placing a large base drum near a large funnel placed with the beak near a candle. Hitting the drum hard will set in vibration the air in front of the drum, and the funnel channels or amplifies the sound wave, which in turn blows out the candle.

Sir Isaac Newton (1642-1727) made the first attempt to express by a formula the velocity of sound in a given tube. Pierre Simon, Marquis de Laplace (1749-1827), a French scientist, modified Newton's formula. The formula states that the velocity square is directly proportional to the product of the compressibility and the pressure, and inversely proportional to the density of the material. The significance of this discovery is that sound will travel faster in denser material that is most elastic. Sound travels more than four times as fast in water, and more than fifteen times as fast in steel, as in air.
SOUND-RESONANCE TUBE

Student's Report of Findings

By a diagram clearly drawn and labeled, illustrate the principle you have investigated.

In what aspect of reality does this principle apply? Name four applications, and discuss one fully.

1.
2.
3.
4.

Arrange in a tabular form in the space provided below, the calculations for 1) wave length, 2) the frequency, and 3) the time the sound wave requires to travel the length of the tube. Assume the velocity of sound is 1090 feet/second.

Compare the frequency numbers for each fork (small numbers marked on the forks) with the calculated frequencies.
LIGHT-RAY TABLE

VARIABLE LIGHT SLITS

J. ALPHEE DESJARDINS
1953
LIGHT-RAY TABLE

I. Principle:

Light beams passing from one transparent medium to another bend according to the relative density of the two media.

II. Description of apparatus:

A. Materials needed for the construction:
   1. One piece of plywood, 1/4 by 9 by 15 inches
   2. An old wooden box, 9 inches wide, any practical height and length
   3. One piece of hardwood, 1/4 by 1 1/2 inches long, enough to surround three sides, as shown in the diagram.
   4. Four pieces of hardwood, 1/4 by 1 1/3 by 3 inches, for the legs
   5. Two pieces of hardwood, 1/4 by 1 by 3 inches, both grooved as shown in the diagram, to hold the metal light slits
   6. A selection of prisms
   7. A selection of light slits, made from old pieces of aluminum
   8. Any suitable light source, such as a slide or filmstrip projector
   9. Black India ink
   10. Dark-colored paint and varnish.

B. Construction:
   1. Cut the piece of plywood to size.
   2. Remove the two 9-inch ends from the wooden box.
3. The open sides of the box will be the bottom and the back.
   The remaining sides of the same dimensions as above, will be
   the top and front.

4. At the center and bottom of the front part cut a square hole,
   1 1/2 by 1 inch.

5. Making the light slits: The light-slit plates are made from
   scrap sheet aluminum 1/20 inch think by 2 1/2 inches square.
   Drill the round light "slits." The square light slits are
   cut with a hacksaw, as shown in the diagram. Measured from
   the edge, each slit has a depth of 1/2 inch. The round holes
   are located 1/2 inch from the edge.

6. Assemble as shown in the diagram. Place slide supports for
   the light slits so that light will not leak along the sides.

7. After the assembly, paint the top of the table around the
   light opening, and the inside of the hood, with black India
   ink.

8. Paint the remainder of the table any dark color. A non-gloss
   paint is recommended. To improve the appearance of the piece
   of equipment, the legs and sides can be varnished.

III. Procedure:

A. Demonstration:

   This piece of apparatus is used to demonstrate the be-
   havior of a light beam as it passes through one transparent
   medium into another. Using a prism, the direction of a light
beam may be controlled at will by merely changing the angle at which the light beam strikes the surface of the prism. In addition, the behavior of the light beam as it leaves the prism can also be demonstrated. Light beams can be studied in terms of reflection, refraction, critical angle, incidence, and dispersion. By the use of various prisms and lenses and reflectors, the behavior of light beams can be studied and demonstrated fully.

B. Calculations:

To calculate the path a light beam follows, it is necessary to include the definitions of the terms needed. The perpendicular to the surface of the prism is called the normal. The normal is the reference line used to calculate the angles of reflection, refraction, and incidence. Reflection refers to the light ray reflected from the surface of the prism. Refraction refers to the bending of light ray passing through the prism. Incidence refers to the light ray emitted by the source of light. According to the law of reflection, the angle of incidence equals the angle of reflection (measured from the normal). This law can be checked and verified with this piece of apparatus. One thing that will be noticed in this demonstration is that the reflective ray will not be as intense as the ray of incidence. The reason is that only a portion of the ray of incidence will be reflected, while the remaining portion will be refracted. For instance, if the angle of incidence is nearly 1° (from the normal), nearly 99 per cent of the ray of incidence
will be refracted and about 1 per cent will be reflected. If the angle of incidence is nearly 89°, then about 99 per cent will be reflected and nearly 1 per cent will be refracted. When the angle of incidence is 45°, 50 per cent will be reflected and 50 per cent will be refracted. Snell’s law, expressed in a formula,

\[
\frac{\sin i}{\sin r} = \frac{V_1}{V_2} = n
\]

states that the ratio of the natural \( \sin \) of the angle of incidence (\( i \)) to the natural \( \sin \) of the angle of refraction (\( r \)) is the same for all angles of incidence and is equal to the ratio of the velocity of the ray of incidence (\( V_1 \)) to the velocity of the ray of refraction (\( V_2 \)), and equals the refractive index (\( n \)).

C. Student’s experimentation:

The Light-Ray Table was designed primarily for the student’s use. Due to its simple construction, more than one can be made with very little effort. With a good selection of prisms and reflectors, a number of experiments can be conducted on light. The student can study refraction, reflection, and dispersion. He can see for himself that a beam of light can be controlled. For variation, focal lengths of parabolic mirrors can be studied. This can be accomplished by using two beams of light. In this method the reflector is placed in the paths of the two beams and focused to a point. The distance from the focus to the center of the reflector is the focal length.
For special projects, the student can construct prisms of various sizes and shapes. These special accessories can be made from lucite or any other plastics. "Lenses" can also be constructed. These are made from the same material and are cross sections of lenses (flat on two sides, double convex, double concave, etc.) which can be constructed.
Galileo Galilei was the investigator who, by the method of science, made a practical use of lenses. He developed the refracting telescope more than 300 years ago. This was a great achievement.

Light travels in a straight line. This basic rule has been proven a number of times since Galilei, but it can be said that it was more or less assumed before Galilei's time. According to recorded scientific history, Galilei was the first scientist who was interested enough to do a number of systematic experiments on light. What is a lens? A lens in basic principle enlarges (or reduces) the image reaching our eyes. In other words, a lens is an external extension of our sense of vision. With a lens we can control light rays. The construction of the lens determines the manner of control. Galilei never knew exactly why this was true; he simply knew the condition prevailed.

In 1621 the Dutch astronomer and mathematician, Willem Brord Snell, was the first to discover from experiment that the ratio of the ray of incidence to the ray of refraction is the same for all angles of incidence on the same material. This law is known as Snell's Law of Refraction. It is customary to express Snell's law in trigonometric terms:

\[ n = \frac{\sin i}{\sin r} \]

In the formula \( n \) is a constant, \( i \) is the angle of incidence, and \( r \) is the angle of refraction. Galilei had discovered that light bends while passing from one medium to another. Snell had discovered that
the bending of light rays followed certain rules. Like Galilei, he was not certain as to the cause. The explanation was related to a factor that Galilei had attempted to measure, but because of the crude method he had used, he had failed. It was Foucault who in 1850 repeated the experiment which unveiled the secret that Galilei had failed to discover: light travels slower in water than in air. Although his procedure was crude, it was a crucial experiment. Michelson, the first American scientist to be awarded the Nobel Prize, accurately modified and verified Foucault's experiment. Light travels slower in a medium than in a vacuum. Bending of a light ray as it travels from one medium to another is a factor dependent on the densities of the media. The velocity formula is generally expressed as:

\[
\frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in a medium}} = \text{Refractive Index}
\]

and symbolically, \( \frac{V_i}{V_r} = n \)

Combining the two formulae presented,

\[
\frac{V_i}{V_r} = \frac{\sin i}{\sin r} = n
\]
In what aspects of reality does one of the principles studied apply? Choose one and explain.

By a diagram clearly drawn and labeled, illustrate the procedure used to measure the focal length of one of the parabolic reflectors you have studied.

Give your comments on the instrument: Explain how it helped you understand more clearly the principle of the bending light rays. If it did not help, suggest how it could be improved.
CHAPTER IV
CONCLUSION

It was found that all authors in the field of science teaching are in accord that the demonstration plays a very important role in processes of learning science.

It can be inferred from the literature that the demonstration method lends itself well to small schools with limited budgets. Homemade apparatus can be made to meet fully all criteria, as outlined previously, of good demonstrations.

It was pointed out previously that the demonstration method is probably one of the best methods for directed teaching and learning, as it provides some of the necessary directions conducive to more advanced studies. The demonstration method allows the student to see for himself what is occurring and thus adds meaning to the printed word. It also allows the student to use all pertinent senses for learning, which gives him more thorough and better-retained learning.

The demonstration method gives the student understanding of science by an association with the things which are more real to him. In addition, it gives the student training in logical, reflective, and deductive reasoning.

The pieces of apparatus described in this thesis have been used for a period of one year in a secondary school physics class. Their
usefulness in teaching methods and procedures has been established on the basis of the students' comprehension of physics principles. This type of equipment was found to be versatile and thus adaptable to a variety of classroom situations. The students' interest in demonstrations appeared at a high level in all cases. The demonstrations motivated the students to perform additional experiments.

It was found that the demonstrations seemed to influence students to ask questions which perhaps would not be asked under different circumstances. An example of the type of question asked was: "May I do this experiment in the book? I do not seem to understand the principle." In a number of cases, the experiment which the student wanted to perform had little to do with the actual demonstration or principle he had seen. It became evident to the teacher that the pupil was eager at this point to revert to solving other problems by demonstrations. In most cases, these problems and/or principles had been previously studied by the pupil without any particular motivation for him to continue searching for the answers, until they had been completed. In individual experimentation he apparently found a method that enhanced his desire to continue until the problem was solved. From all indications, the demonstration method used by the teacher had served as a challenge for the student's individual initiative.

LIMITATIONS

As shown by the search of the literature, there are numerous limitations to this study. Presently, the literature showing the actual
value of the demonstration method as a teaching and learning device is decidedly limited. It can be assumed from the literature that the validity of the demonstration method has not been established by research.

As noted previously, a study at Boston University in 1950 showed that prior to that year little attempt had been made to develop demonstration devoted solely to the presentation of principles of science in a functional manner.

Lastly, it can be pointed out that the solution presented here for small schools is not the only solution. Small schools can merge into regional schools and thus be able to afford commercially made apparatus for the presentation of physics principles.

RECOMMENDATIONS

It is recommended that additional studies be made under more closely controlled conditions to determine the actual value of the demonstration method. The demonstration method should be compared statistically with other methods, such as the individual or group experimentation method.

It is also recommended that this specific topic could be a good basis for a study or dissertation. It is recommended that the teachers in all schools should be encouraged to use the demonstration method more freely and that its possibilities be pointed out to them by their professors.

1/Murray, op. cit., p. 5.
Lastly, it is recommended that teachers may be in need of a change of attitude if they are to use demonstrations to the best advantage. The value of the demonstration in educational processes may be a direct and measurable aspect of the teacher's work.
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