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ABSTRACT

This publication has been prepared as a leadership guide for science teachers, secondary school administrators, and teacher educators who desire to produce competent science teachers. Science taught as inquiry is the central theme, and the "processes of science" are recommended as the proper content for all courses. The guide is organized into these chapters: Science and Scientific Inquiry, An Overview of Science Taught As Process, Recommended Science Program--Grades 7-12, Organizing a Science Program in Your School, Recommendations Concerning the Preparation of Secondary Science Teachers, Inquiry Program Model Lessons, and Inquiry Program Bibliography. More than half of the publication is devoted to the chapter on model lessons in which nine representative lessons taken from the recommended curriculum programs are presented. The recommended science programs include the curriculum projects developed during the last decade through federal government sponsorship. (Author/PR)

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Recommendations of
The State Science Committee
of
The Oklahoma Curriculum
Improvement Commission

DEPARTMENT OF EDUCATION
horn, Superintendent
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The Improvement of Science Instruction

in

Oklahoma

Grades 7-12

Recommendations of the State Science Committee

Earl A. Reynolds, Chairman

of

THE OKLAHOMA CURRICULUM IMPROVEMENT COMMISSION

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1970

FOREWORD

With the explosion of the discoveries in new areas of scientific knowledge and the rapidity of progress in recent materials and innovative teaching methods employing diversified techniques, the State Science Committee felt an imperative need to publish a Science Guide 7-12. The success of the recent Oklahoma Science Guide K-6 provided the emphasis for the secondary guide to aid in coordinating the science program K-12.

The Oklahoma Curriculum Improvement Commission under the auspices of the State Department of Education has been instrumental in encouraging the publication of these modern guides. The commission, the members of the steering and editing committee, and the hundreds of teachers who contributed and participated in the preparation of the guide are to be commended.

It is hoped that teachers will find the guide useful in providing the kind of science program that will be most beneficial for the young people in Oklahoma.

Scott Tuxhorn
State Superintendent of
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CONTENTS

INTRODUCTION

This guide is a departure from the traditional publications resulting from state curriculum committee studies. The science teachers in the State of Oklahoma, long recognized as somewhat avant-garde, have sought to tell-it-like-it-is or better, like-it-should-be!

There are no tried listings in this guide of "topics to be covered in typical science courses." Instead, this publication has been prepared as a *leadership* guide for the science teacher, the secondary school administrator, and for colleges who desire to train competent science teachers.

Science, taught as inquiry, is the central theme and in this guide there is *no compromise* to this approach. The "process of science" are recommended as the proper content for all science courses. Only those courses using the laboratory as the point of emphasis are considered as courses containing science content.

The synthesis of content and method, long time antagonists, has been regarded as complete. The teachers of Oklahoma have demanded this synthesis.

Oklahoma's teachers do not feel this guide is ahead of its time. They want to set the goals of science education in proper perspective *now.* Many science teachers presently teach inquiry-centered courses under traditional titles; therefore, with the availability of research and classroom tested materials, a modern science program can be implemented within a school system with a minimum of delay. Recently, State adopted textbooks have included materials directly related to or growing out of CHEM-Study, IPS, PSSC, ESCP, BSSC and other proven experimental programs with national reputations.

Among many daring innovations in this guide is an unashamed orientation that "it is better to present materials to students based on their levels of ability rather than based on the levels of the material." The guide clearly points out that it is more important to have meaningful learning experiences than to have the veneer of excellence. Often, underneath the veneer, we find the disadvantaged students who are further engulfed in their disadvantages, and perhaps worse, become convinced that they are of less worth as a person and, finally, accept their disadvantages as a "proper lot-in-life"! Educational excellence in science at all levels and for all young Oklahomans is within reach following the realistic guidelines in this publication.

Scheduled meetings were held with teachers at central locations throughout the State of Oklahoma. The names of these teachers appear in this guide. The guide's contents were discussed in detail with them. At these meetings every teacher was asked to present his ideas in writing for inclusion in the guide. Certainly, every teacher will not agree with the final draft. But every teacher will agree with the final writing committee's orientation to provide a contemporary program that is academically, sociologically, and psychologically oriented for young people in today's society.

Colleges are challenged to train teachers who will possess both an appropriate background in science and skills in science teaching. Some teachers have pointed out that the statement, "The materials are too difficult for the students" is often an incorrect statement when the fact is that there was lack of professionalism in providing a proper learning environment stemming, not from a shortage in teacher skill but often from the lack of proper teaching materials. Science cannot be learned without a realistic environment that can be manipulated and studied. This guide will be controversial for those who believe that science is best studied as an individual discipline rather than interdisciplinary; and who feel, incorrectly, that the nationally developed experimental programs are for the gifted students only. Studies indicate these national programs are better suited to the needs of all students than are the traditional text oriented programs.

In summary this guide proposes that the "processes of science", not its products, are of fundamental importance, that the nationally recognized experimental programs produced by millions of the taxpayers' dollars are, presently, the best vehicle to experience this process. It should be noted that many commercially available materials are "inquiry" oriented; more will be in the future.

This guide represents a consensus viewpoint. It is written as the composite voice of all teachers who participated in the State science seminars and contributed to the guide's contents. Only the final chapter was written exclusively by the editing committee.

Is this a guide unique among state guides? Those who wrote the guide know it will be out-of-date someday; but that day will follow the days when other guides have been forgotten.

CHAPTER I

SCIENCE AND SCIENTIFIC INQUIRY

BASIC PHILOSOPHY FOR A SECONDARY SCHOOL SCIENCE PROGRAM

We, the Secondary Science Teachers of Oklahoma, were asked to explain how we view science and scientific inquiry. Also, we were asked how those topics influence our teaching and how the topics should affect the secondary school science program in Oklahoma. Here are the principal ideas we expressed . . . .

. . . .the heart of all science is inquiry and inquiry is a process by which an individual explores the unknown.

. . . .the principal purpose of education is to teach students to think.

. . . .science, if taught by inquiry, is perhaps one of the best vehicles to use in leading students to develop the ability to think.

. . . .teaching science through inquiry, then, not only leads the student to understand the structure of the discipline and develop scientific literacy but also leads him to achieve the central purpose of the school.

. . . .students must be involved in inquiry to develop an understanding of it.

. . . .involvement means observing, performing experiments, collecting and interpreting data, and drawing conclusions.

. . . .emphasis must shift from using the laboratory as a place to verify an answer to an opportunity to find first-hand information to determine an answer.

. . . .answers found by students in the laboratory must be accepted by the teacher for discussion.

. . . .experiencing the processes by which learning takes place is at least as important a learning outcome to the individual as what he learns.

. . . .the goal of teaching the student to think should govern the teacher's choice of curriculum.

. . . .the word, science, should suggest an activity or a "happening."

. . . .the modern science teacher is a "stage setter," provider of materials, motivator, giver of clues and not the central figure in the classroom who professes to know all the answers and gives the conclusions.

. . . .the objectives of science education must be consistent at the elementary and junior and senior high school levels.

. . . .student evaluation must move away from just giving formal pencil and paper tests.

. . . .there is an obvious requirement for a continuous science program in grades K-12.

The sections of this chapter which follow use the foregoing ideas to develop a philosophy of science teachi for the secondary schools of Oklahoma.

TEACHING THE STRUCTURE OF SCIENCE

Science, man's attempt to explain natural phenomena, has a dual nature. It is, on the one hand, those explanations of natural phenomena (facts, laws, theories, etc., called the products of science), and on the other hand, it is the ways of thinking and skills used by scientists to produce the explanations. Science teaching which helps the learner grasp the structure of science must include both the product and process aspects of the subject, but it should focus on the processes by which the scientist "finds out" about or explain his environment. For the heart or essence of all science is the search for understanding of natural phenomena using logical strategies of inquiry.

In all science, regardless of the aspect of the environment being explored, the scientist makes *his own* observations, asks *his own* questions, performs *his own* experiments and draws *his own* conclusions. This approach (rational inquiry) remains the basic significant characteristic of all science, not the body of facts or explanations obtained. However, it is through such an approach that the accumulation of knowledge (products of science) in each area of science is achieved.

THE NATURE OF INQUIRY

The term "inquiry" can be most succinctly defined as a search for information and understanding. This, of course, implies that the person conducting the search has a general notion of the problem he is attempting to solve. There are many instances in the history of science, however, where the scientist had *no more* than a general notion of what he was searching for and, as a result, all the data gathered were carefully evaluated before the specific problem being investigated was solved, or, in many cases, even defined. Pasteur, for example, began his scientific career as a chemist and, as the result of attempting to solve the problem of beer and wine fermentation, was launched on an inquiry which led to the development of a new field of bacteriology. The nature of the processes of inquiry demands that situations be analyzed, investigations conducted, information evaluated, hypotheses synthesized and tested, generalizations formed and, ultimately, predictions made. Developing the ability to inquire demands that the learner (the investigator) have an *active role* in an investigation; he will not develop his powers of inquiry if he assumes only a passive (or listening) role.

PURPOSES OF SCIENCE EDUCATION

The purposes of science education which we, the junior and senior high school teachers of Oklahoma, propose fall into two categories:

1. The achieving of scientific literacy.
2. Intellectual development.

In order to develop scientific literacy, science education must ultimately help the learner achieve a conceptual knowledge of his environment. In addition, and equally if not more important, science education must promote the spirit of rational inquiry that is the spirit of science. The values associated with the spirit of science are:[1]

1. Longing to know and understand.
2. Questioning of all things.

1 Educational Policies Commission, **Education and the Spirit of Science**, Washington, D.C., 1966, p. 15.

3. Search for data and their meaning.
4. Demand for verification.
5. Respect for logic.
6. Consideration of premises.
7. Consideration of consequences.

One of our colleagues wrote, "Individual involvement is essential in the learning of scientific concepts." One can readily see that individual involvement, (collecting, organizing, and interpreting information) is also essential to the development of the spirit of science and the ability to inquire rationally.

Science, taught through inquiry, can contribute to the intellectual development of the junior and senior high school student in two very important ways. First, it can provide the student with the opportunity to use his rational powers,[2] (recalling, imagining, classifying, generalizing, comparing, evaluating, analyzing, synthesizing, deducing, and inferring), which are essential to logical thinking. It is only through use of the rational powers that they can develop and that a very important goal of education, the ability to use logical thought processes, can be accomplished.

The second way in which science taught through inquiry can contribute to the intellectual development of the junior and senior high school student is in the area of cognitive development as described by the Swiss psychologist, Jean Piaget. According to Piaget, most students entering the seventh grade will be in a state of transition between two stages of cognitive development labeled "concrete operational" and "formal operational."

The concrete operational learner can use simple logic in the collection, organization and interpretation of information. He, the concrete operational learner, has great difficulty in structuring information into abstract models, such as the atom, for the purpose of information storage or retrieval. He finds it practically (if not actually) impossible to reason from one abstract model to another. He has great trouble for example in relating atomic structure to energy of reaction between atoms. This inability to deal with the hypothetical or highly abstract model places severe limitations on the junior high school learner not only in science but in other areas as well.

Much of the 7-12 curriculum in all areas requires the student, if he is to learn satisfactorily, to be capable of reasoning with abstract or hypothetical ideas, i.e., to use formal logic or be formal operational. The formal operational stage of development does not occur spontaneously nor does it occur without effort. *It must be nurtured!* In order to nurture the ability of the learner to use formal logic which provides him with very powerful intellectual tools that enable him to structure information for interpretation, for efficient retrieval, and to search for meaningful relationships among abstract ideas, the learner must be provided certain kinds of experiences. These experiences, in general, are those which allow the learner to collect information, to search for patterns or regularities in the information, and to draw and test deductions or conclusions based on the regularities observed.[3] Science, properly taught through inquiry, is a natural vehicle to nurture the formal operational state of development. Since the ability to use formal

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2 Educational Policies Commission, **The Central Purpose of American Education,** Washington, D.C., 1961, p. 5.

3 Willard Jacobson and Allan Kondo, **SCIS Elementary Science Sourcebook,** (University of California, Berkeley, 1968) Chapter 5, pp. 34-39.

logic *can* continue to develop even into adult life, the junior and senior high school science programs must focus on this aspect of intellectual development in order to facilitate adult development.

THE NEED FOR A CONTINUOUS K-12 PROGRAM

The development of the spirit of science and the modes of inquiry will be well underway by the time students enter the seventh grade if the inquiry-program outlined in the K-6 guide have been implemented. Much that has been gained in the elementary science program will be lost if the student encounters a fact-centered program in junior high school where science is only "talked about." It is, therefore, imperative that the junior high school program continue the development of both the spirit of science and the strategies of rational inquiry. If the elementary program has not begun these developments, the junior high school must initiate them both for the purpose of developing these aspects of science and for continuity in intellectual development.

Students entering the senior high school program who have been in an inquiry science program in junior high school will be in a position to interrelate the abstract concepts of science within and across artificial discipline boundaries and truly grasp the structure of science within the framework of broad conceptual schemes.

OBJECTIVES OF THE SCIENCE EDUCATION PROGRAM

Secondary school science programs must reflect the objectives of education in general and the specific contributions that science education can make toward the accomplishment of those objectives. Therefore, the objectives of science education must be stated relative to educational goals rather than specific content goals.

The objectives of the science program in grades 7-9 must include the following as guiding principles:

1. To provide many opportunities to use and develop the rational powers, i.e., the ability to think.
2. To allow the student to actively engage in the collection of information, the development of generalizations based on his organization of the information, the formulation of deductions from these generalizations, and the testing of these deductions through actual experimentation. In so doing, the student will actuate and enhance his ability to use hypothetical reasoning.
3. To continue to develop and refine strategies of inquiry.
4. To continue the development of scientific literacy and the spirit of rational inquiry (the spirit of science).

The objectives of science education in grades 10-12 must include those of grades 7-9. In addition, due to the broad general background of scientific knowledge gained in previous science courses, and to the increased ability of the senior high school student to use hypothetical reasoning (assuming that it has been actuated in previous science programs), the 10-12 student can, through rational inquiry, interrelate the simple laws of nature into abstract comprehensive theories or conceptual schemes.

ROLE OF THE TEACHER IN THE MODERN SCIENCE PROGRAM

In preparing this guide we did not intend to recognize any of our colleagues for the contributions they made. However, when reading what the Oklahoma science teachers believed their role in teaching is, we came upon the contribution made by Naomi Pederson of Tulsa Edison. She not only summarized this entire section with her statement but these statements reflected in detail the feelings of our colleagues. Her statement follows:

> "The teacher in a modern science program no longer dispenses knowledge, as a mother spoon-feeds her children, to be regurgitated later on tests. He does not profess to know all the answers, but serves as a guide and consultant to his students helping them find answers through research and experimentation . . . Instead of telling how seeds grow, he provides seeds and lets the student discover from first hand observations . . . He encourages the student to inquire and not to expect 'pat' answers."

ROLE OF THE STUDENT IN THE MODERN SCIENCE PROGRAM

The role of the student is that of an investigator. As an investigator (or inquirer), he must be an active participant both mentally and physically. It is unlikely that any two students will investigate a particular problem in exactly the same manner. One student might choose to begin with exploratory experimentation, another might begin with a review of the literature, and another might choose to simply sit and ponder for a time. Our secondary school science programs must be flexible enough to allow for such individual differences in students.

THE PLACE OF THE LABORATORY

The laboratory is a place in which a science student (or scientist) observes, explores, collects information, and experiments to verify or reject hypotheses. The laboratory can be a room formally designated with that title, but it can also be the classroom, the home, or in many cases, the out-of-doors.

Information which is collected in the laboratory should provide the basis for student-student and student-teacher discussions in the classroom. The generalizations made by the students from the information collected in the laboratory and the inferences or deductions drawn from those generalizations should provide the guidelines for both classroom discussion and subsequent laboratory experiences.

CHAPTER II

AN OVERVIEW OF SCIENCE TAUGHT AS PROCESS

A LEARNING SITUATION

In order to teach any curriculum or to apply any pedagogical method, one must understand the philosophy on which it is based. The following science learning situation will exemplify some of the characteristics of the process approach to teaching and learning science, and the philosophy on which it is based.

Teacher: "Can we discuss your insect collections which you have developed? I believe you decided to collect only those insects which are most commonly called bugs. Does anyone want to share any interesting features of their collection?"

Jill: "A couple of my insects are fierce looking. One has a horn growing from its head."

Mark: "All of mine have a hard body covering."

John: "Some of mine have different colors."

Jill: "Two of mine look like they could bite."

Teacher: "Why do you think that, Jill?"

Jill: "The sides of their head around their mouths are jagged-looking. They can move these in and out. It would be just like pinching something."

Carl: "One of mine is quite large and is white with black spots."

Jill: "I have several June bugs, but they aren't the same color."

Teacher: "Can you group your insects?"

The students proceed to group (classify) their insects according to some property or attribute which they select. The teacher moves from student to student, observing the various schemes and asking individual questions.

Teacher: "Carl, on what basis did you group yours?"

Carl: "I used antenna lengths with one group less than one centimeter, another group between one and one-half centimeter, and another group over one and one-half centimeters."

Teacher: "Jill, what characteristic did you use?"

Jill: "I used body color. Look, I've discovered all June bugs don't have the same body color."

Steve: "I also have several June bugs and they aren't all the same size. Why aren't they all the same?"

Teacher: "Does everyone have a June bug? Good. Check, are they all the same size?"

The teacher's question about size initiates considerable student-student interaction as they compare June bugs. The interaction leads to the conclusion that not all are the same size.

Teacher: "How large is the typical June bug?"

Carl: "Do you mean in weight, length, width or what?"

Teacher: "Let's decide. What dimensions do you want to include in determining the June bug's size?"

Jill: "Shouldn't we include all three; weight, length, and width?"

Mark: "I believe all should be included."

Teacher: "All right, if everyone agrees, how much does the typical June bug weigh and how long and wide is it? How about determining these for the June bugs you have and recording them on the board."

Each student measures and weighs his own June bug and records the dimensions on the board.

Teacher: "Now that these observations have been recorded, can you say what the size of the typical bug is?"

Mark: "Maybe we can if we average all the dimensions."

Jill: "We could rearrange the dimensions in either increasing or decreasing order."

Carl: "Why couldn't we make a histogram of the data?"

After a discussion, the class decides that the histogram is the best method for ordering their data. Each student then constructs his own graph.

Teacher: "Now from your histograms, what is the size of the typical June bug?"

Jill: "I think it is one and one-half centimeters long, three-fourths centimeters wide, and weighs fourteen grams."

Teacher: "Does everyone agree with Jill's observation?"

Carl: "I don't. I think the typical June bug weighs 12 grams."

Jill: "Oh, yes, I made a mistake. It does weigh twelve grams."

Illustrated here is a significant tactic employed by the teacher. Note that the teacher posed a question which Jill answered but apperently incorrectly. The teacher did not reject her response. However, Jill was corrected by Carl. This particular move by the teacher is another attempt to remove the "authoritarian" characteristic common to the conventional teacher role. Inquiry teachers must not be looked upon as classroom authorities if inquiry learning is to be successful.

Ultimately, the scientist is confronted with the necessity for designing an operation which will permit him to attempt a logical solution to a problem. This kind of operation has appropriately been called an experiment. Because experimentation is fundamental to the success of the secondary science program, students must have experience in designing experiments. The typical "cook-book" laboratory approach will not suffice for this experience.

A continuation of the previous learning situation will illustrate the kind of experimentation one should expect in a process approach.

Jill: "Will heat or light make the June bug larvae grow faster?"

Teacher: "Class, what do you think? Will heat or light accelerate the growth rate of the larvae?"

Mark: "I don't think light will, because the larvae are always underground."

Carl: "Heat might make them grow faster since the ground is usually warmer than the air."

Teacher: "Is there some way you can determine whether heat or light will accelerate the growth rate?"

In the ensuing discussion, the class decides that this problem can be solved through experimentation. Each student is to collect some larvae and to design and conduct an experiment in an attempt to answer the question.

A week later the teacher opens the discussion based on the student designed experiments.

Teacher: "What did you determine? Will heat or light accelerate growth rate in the June bug larvae?"

Jill: "Yes."

Teacher: "Jill, will you tell us how you determined this?"

Jill: "I placed all my larvae in a jar and placed them close to the hot water tank's burner. Also, I suspended a light bulb over the jar. Each larvae was measured each day for the seven days. All larvae increased in size."

Carl: "I don't believe Jill's experiment is very good. She doesn't have a control."

Teacher: "Carl, will you tell us how you designed your experiment?"

Carl: "I placed some larvae in a jar, put a lid on it and placed it on my desk at home. In another jar which I painted black, larvae were placed and a lid was put on it. This jar was placed close to the burner on the hot water tank. Larvae were placed in another jar which was not painted. This jar was lighted at all times but not heated. Another jar with larvae wasn't painted black but was placed close to the burner of the hot water tank."

"A record was kept of the daily growth. As the result of my experiment, I believe heat causes the larvae to grow faster; but light didn't influence the growth rate. I used two controls to assure accuracy."

The experimental design of Carl's is much superior to Jill's design. Jill's conclusion was based on too many uncontrolled variables. In contrast, Carl designed into his experiment a control which was the jar placed on his desk and left untouched. The larvae in this jar represented the normal growth rate. Likewise, Carl constructed the variable situations, one at a time, which could possibly influence the outcome of the experiment. Thus, any well designed experiment will have a control and variables will be identified and isolated for comparative study.

The reader will recognize the absence of the major emphasis on factual content in the learning situation. The attainment of factual content is only superficial and it is usually soon forgotten whereas the process approach emphasizes the development of attitudes and operations which allow the learner to function in any intellectual environment. Facts learned in this situation will have a better retention period and contribute to an overall conceptual pattern.

Reflection on the previous activities will illustrate the functioning of the following processes:

Observation — One should note the observations offered by the students were unrestricted in that all were accepted by the teacher. Each student stated simply what he had seen or understood relative to the insects collected. It is not necessary that a series of observations be related. Observation is a means to gather data.

Inference — Jill based her belief that two of her insects could bite on her observation of the mouth parts of these insects. This was an inference. Inferences are made through logical reasoning based on observations or experiences.

Classification — Each student had collected a number of insects. However, until a collection is ordered, it is of little value to the collector. It is significant that the teacher gave no predetermined basis for the student classifications. Classified observations are ordered observations.

Data Interpretation — Data can be logically interpretated only after they have been ordered. In the preceding activity, the data were meaningless until the students ordered them in a histogram. Only then could the data yield the dimensions of the typical June bug.

Conceptual Invention — Inquiry-centered science teaching differs from the conventional approach in the manner by which a student is confronted with a new concept. In inquiry learning, the student is involved in activities designed to provide experiences normal to the development of a specific science concept. Of course, these activities are based on science processes. It is only after these initial activities have provided a structural comprehension for the conceptual relationships that the concept is isolated and identified by the teacher; in essence, this is the conceptual invention; an illustration will be helpful. Suppose a student has had many experiences relating to the concept of photosynthesis. However, all these combined experiences will never allow the student to say, "Ah, this is photosynthesis." The teacher has to do this. This is the actual invention of the concept which was developed through a series of experiences.

Contrasted to this is the conventional approach where the concept is first defined and then, maybe, an activity is provided in support of this definition in an attempt to develop comprehension. The difference is quite distinguishable as illustrated by the following:

Inquiry Learning Format $\xrightarrow{\text{leads to}}$ Comprehension Activity $\xrightarrow{\text{leads to}}$ Conceptual Invention,

Conventional Learning Format $\xrightarrow{\text{leads to}}$ Concept Definition $\xrightarrow{\text{leads to}}$ Supportive Activity.

One must understand the philosophical basis of the tactics employed by the teacher in this learning situation if the true meaning of "process" is to be understood.

Basic to the process philosophy is the manner in which concepts are developed. The broad concept of taxonomy originally was developed through the various ways in which the students grouped their insects. Certainly, the classifications chosen by the students were not the same as those an entomologist would choose in grouping the insects. The teacher, stressing inquiry, recognized the significance in making the concept of taxonomy applicable to all situations, even though insects were selected to develop the concept.

The teacher permitted the students to develop the direction of the class proceedings. In essence, the student activities were student designed with key moves by the teacher. These key moves consisted of questions and designs which sustained the emphasis on process and still kept the integrity of science within the framework of the activity.

A question often asked is, "How are inquiry situations developed in the classroom?" The following discussion will provide assistance in answering that question.

HOW DOES A TEACHER EMPLOY INQUIRY TEACHING METHODS IN THE CLASSROOM?

There are two roles in any classroom — the teacher and the learner. In an inquiry-centered classroom each of these roles must have an active participant because the actions of one will be greatly influenced by the actions of the other. In the discussion which follows the assumption is made that learners are free to investigate.

Inquiry-Centered Teaching and Learning Responsibilities

TEACHER	*LEARNER*
1. If the learners do not have a topic to investigate, the first responsibility of the teacher is to provide a topic to investigate.	1. The learner does the investigation; in other words he designs the procedures necessary for the investigation and collects information.
2. The teacher asks the learners for the information collected from the investigation.	2. The young investigators describe what has been found.
3. This teacher responsibility cannot be stressed too strongly: *the teacher accepts the findings which the learner describes.* In addition, the teacher urges the learner to search for a pattern in the information collected. Usually the learners will need to be asked questions to keep the search going. The teacher may need to provide clues.	3. The learner searches the information for some type of a pattern and, usually under the guidance of the teacher, finds a pattern. Do not expect all the learners to find the same patterns; if several interpretations of the information are made, and if these interpretations are valid, the inquiry process is being especially productive.
4. The teacher next questions about the relationship of the pattern found to the topic being investigated. Is the pattern relevant to the topic or has some new idea been uncovered? Perhaps the teacher will need to	4. The learner is now led to generalize from the interpretation he has made of the collected information. He is now in the position to form a new concept for himself or the teacher can now invent the concept; that

invent[1] an new concept.	invention, however, must be based upon the information collected.
5. Questions can now be raised about the relationship of the new concept just formed to concepts which were based upon previous investigations. The inquiry-centered teacher will raise the questions and allow the learners to discover such relationships by exchanging ideas, not by telling them what that relationship (if any) is. These questions should always be asked and not only when a relationship exists.	5. The learners are now, by using the process of inquiry, accomplishing something that every teacher wants his students to accomplish, i.e., they are broadening their understanding of a scientific principle. This broadened understanding, however, is possible because the learners have been involved in developing the information which led to the invention of the concept. They are not "broadening" their understanding by simply being told that this new concept applies in many different situations.
6. For a teacher who truly believes in inquiry and who also believes that any new idea must be subjected to the arena of disproof, this phase of inquiry teaching is the most stimulating and pedagogically worthwhile. The teacher raises questions about v a l u e, meaning and/or validity of the concept which has been developed. The teacher must keep firmly in mind that he must accept the pro and con student arguments relative to the concept's value, meaning and/or validity.	6. The learners now must defend not only the concept which has been developed but also their procedures and thinking processes which were used in arriving at the concept. They are having to apply the inquiry process to the results of an inquiry process. As understanding of an idea deepens through inquiry, one is truly learning how to learn as he clinically inspects and evaluates the results of his own thinking. The learners are now in the position of suggesting other investigations which will either confirm or deny the exactness of the concept. If they are in need of assistance, the teacher has one additional responsibility.
7. The teacher may need to suggest additional investigations to test the concept's validity.[2]	

1 For a complete discussion of concept invention, see J. Myron Atkin and Robert Karplus, "Discovery or Invention?" **The Science Teacher,** September, 1962, p. 51.

2 Renner, John W., "Using Inquiry in the Science Classroom," **Educators Guide to Progress Service,** Randolph, Wisconsin, 1969, p. XX-XXII.

MATHEMATICS, ESSENTIAL TO A SCIENCE PROGRAM

Just as the hammer is a basic tool for the carpenter, mathematics is a necessary and vital tool used by the scientist. One would not expect the carpenter's work to progress far without the aid of the hammer. Likewise, scientific activity would be severly restricted without the aid of mathematics. At best, scientific observations could only be of a qualitative nature. The utilization of mathematics permits the investigator to quantitate his observations.

The secondary science curriculum must reflect this mathematical emphasis if the course structure is to parallel the work of the scientist. Far too often, the secondary science program suffers when mathematics is omitted. This has resulted in descriptive science courses. There is no reason why the artificial boundaries can't be removed so that secondary science and secondary mathematics can be fused by the learner. A science program can only be valid in its processes if it is supported by an adequate usage of mathematics.

RELATIONSHIP OF THE SCIENTIFIC PROCESS TO SCIENTIFIC PRODUCTS

An inquiry-oriented science curriculum is based on the development of the processes of science. The processes are those things which the scientist does in attempting to solve problems and these successes lead to the development of our understanding of natural phenomena.

In contrast, a science curriculum emphasizing the scientific product is concerned only with attaining the knowledge which is known about natural phenomena. At the secondary level, this emphasis has resulted in curricula being centered in knowledge-filled textbooks, sometimes accompanied by a laboratory consisting of "cook-book" attempts at process. These types of curricula should not actually be referred to as "science" since the pedagogical method employed with it is basically reading. There is no actual involvement of the learner in the kind of activity which the scientist experienced in developing the knowledge of science. These traditional approaches must change if the spirit of science is to be captured in the teaching and learning of this discipline.

The products of science can be used in the process-centered approach. Products or simple factual content of science will serve as the vehicle for developing the process. In this manner, the products become the means to the development of science processes.

EVALUATION IN THE PROCESS APPROACH

One of the most frequent questions asked by educators relative to the process approach is how evaluation is achieved. Since the process philosophy differs from that of conventional teaching, it is logical that evaluation must also differ. There is no simple solution to the problem of evaluation in the process approach. As you think about goals in science, you also need to consider how you will evaluate progress toward them. There are several current fresh ideas on evaluation; Dr. John W. Renner, in an article, describes a broadly useful plan for evaluating the changes that occur in student's behavior as they engage in the activities of science.

EVALUATION WITHOUT TESTS:[3]

Planning Ways to Evaluate Progress

The Nineteenth-Century German chemist Justus von Liebig described the beginning of a new field of science as ". . . nothing more than a series of observations and experiments which had no obvious connection with one another."

Professor von Liebig was also describing how science expands, progresses, and forces man to use and develop his intellectual capabilities. He was clearly stating that two of the activities which comprise science are *observing* and *experimenting*. In addition to these, *measurement, data interpretation,* and *prediction* are also part of the fabric of science.

These five basic activities of science are all behavior oriented. If, then, a learner is provided experiences with these five activities and is evaluated in terms of how well he functions with them, teachers will have clearly demonstrated that their primary objective in teaching science is changing the learner's behavior. Behavioral change is a primary purpose of all educational experience.

Let's Agree

How does one evaluate how well a student has learned to observe, measure, experiment, interpret, and predict? Before answering that question, there are three points about teaching, learning, and evaluating which must be agreed upon. They are:

1. *Teaching is not telling.* Exclusive use of the lecture represents ineffective teaching.

2. *Memorization is not learning.* Asking students to memorize material is probably not developing their ability to learn.

3. *Being able to repeat is not evidence of understanding.* Recall test items probably measure very little behavioral change.

Since "tell'em-show'em-ask'em" procedures do not make use of the five basic activities of science in teaching, such procedures will not allow you to determine if the activities have changed the learner's behavior. Therefore, what follows assumes that science is taught as investigation, not as fact-accumulative process.

Now let's look briefly at the five activities mentioned above to see the general approach to evaluation.

What is observation? It can be defined as looking at an event, object, or situation and being able to describe and understand what is seen. In studying science, the opportunity to develop this ability is provided in many ways. An adequate statement of the problem being investigated reflects that observations on prior experiments

3 Renner, John W., "Evaluation Without Tests", Science/Junior High School Edition, Advance Planning Issue, 1968-1969 Croft Educational Services, New London, Connecticut.

or on the work of others have been carefully made. Recording the results of an experiment (and not what the learner thought the results should be) is evidence of careful observation. Direct experiences in observing must be provided the learner, but the teacher must evaluate *indirectly* if the student has learned how to observe.

The same situation exists with the other four basic activities.

What is being evaluated in experimentation is whether or not a learner is willing to put together all the information he has and take a step into the unknown. How do you evaluate this type of behavioral change? A paper and pencil test, essay or objective, will not do it because there the learner need only talk about experimentation; he need not demonstrate his willingness to behave in a specific manner. What the learner *does* when meeting an experiment determines if the experiences provided have changed his behavior.

Specific Criteria

The following five questions can be used as criteria to determine if the five activities of science have changed student behavior.

1. *Does the student state the problem being investigated clearly enough to enable him to devise an experiment for it?*

If the student can imagine, design, and conduct an experiment from his statement of the problem, he has made careful observations and interpretations of other experiments or information from other sources.

2. *Does the student record all the data from the investigation and not just what he thinks the data should be?*

If you can say *yes* to this question, you can be sure that the student is learning to observe and measure, and that these activities are affecting his behavior.

3. *In interpreting his data, does the student state only those interpretations which the data will support?*

Applying this question honestly, objectively, and regularly will give you information about how the interpretation experiences you are providing are changing behavior. Not infrequently, what a student interprets from an experiment depends on what he believes the teacher will accept.

4. *Were the conclusions the student drew based upon actual findings and not upon his preconceived notion of what should be found?*

Here, of course, you are evaluating how observation, measurement, experimental results, and interpretation have influenced the learner.

5. *Does the student approach the next investigation using the results of the last one?*

In addition to being evidence of a true behavior change, an affirmative answer here is evidence that the learner has internalized the meaning of prediction. He has evidenced faith in his findings by being willing to base future actions upon them.

Practical Suggestions

How do you use the foregoing criteria? How much of a student's grade should be based on them? These questions deserve practical answers.

You need to keep records, so prepare a sheet (use the ditto machine) for each student which lists the five questions, and put the sheets together in a looseleaf notebook. Record evidences on each student as they occur. Some weeks you may have several items to enter, other weeks nothing will appear. Remember you are looking for evidences of true behavioral change or lack of it.

Is this procedure subjective? Certainly. So are other evaluation procedures. Any pencil-and-paper test is based on the teacher's subjective opinion on which questions to ask. In this new situation you must rely on your day-by-day experiences with students for information on which to make judgments.

Does this procedure require additional work? Probably. But keeping the records suggested is simply keeping an expanded gradebook. When the time to prepare the final grades arrives, the information you have on each student will make the effort worthwhile..

How much weight should your records on behavioral progress have in computing the student's final grade? Ideally, this information should determine that grade. However, in most communities, the public is not ready for such a move — parents expect schools to use fact-centered examinations and teachers to use numbers (not logic) in determining final grades.

You will note that the five evaluative criteria suggested must be applied during investigations. Since the laboratory is normally an integral part of science, fifty per cent of the final grade coming from the five criteria seems reasonable. Be sure to inform the students of the criteria you are going to use in determining this significant portion of their grades.

In Summary

The evaluation of student progress in science can be done in many ways besides paper-and-pencil tests. To utilize other methods of evaluation, the teacher must be sure of his purpose at the beginning of the year and select that content and those teaching procedures which will allow the learners to work toward the achievement of those purposes. The five basic activities of science have been suggested as constituting behavioral objectives that can be used as the basis for student evaluation.

As you teach toward changing student behavior through the activities of science, you will need to examine your teaching approach.

The following questions are referred to as checkpoints by the author.

Do you listen to students?

Listen to what students have to say about an investigation or problem and utilize their contributions in carrying forward the classroom activities. This does more than establish rapport; it tells the students that they, as well as you, have a responsibility in carrying out the learning activities. A teacher who listens tells the learners that what they have to say is a valuable part of the investigation being conducted. *Be a good listener.*

Do you accept the results which the students get in an investigation?

Too many times teachers will accept only experimental results that constitute the "right" answers. When a learner has honestly done an experiment, you have the responsibility to accept his results.

What do you do if the results are unacceptable to science? Suggest other investigations which represent different ways of solving the same problem. The second investigation will probably produce results contradictory to the first. Now the student must decide which set of results to accept, and he will see that one of the investigations (perhaps both) must be done again. If you reject his first set of results, he will put his future investigative efforts into guessing what results you will accept. *Be an acceptor.*

Do you ask questions which focus the student's attention on specific points in the investigation?

Ask many questions to find out what the students are thinking; few of the "can-you-guess-what-I'm-thinking" type. When the learner gives you an honest reply, accept it; and if that response is one which could lead him astray, ask him another question which will demand and/or allow him to refocus his attention. *Ask questions.*

Are you a guide for students during an investigation?

Ask questions, provide cues to those frustrated and/or on dead center, recommend other investigations to perform, suggest alternate ways of thinking about a problem, challenge results, and provide materials needed. *Be a guide, but do not lead by the hand.*

For a year's work, are you more concerned with the type and quality of investigations than with the number completed?

The "we-must-finish-the-book" attitude has no place in a classroom which is concerned with changing student behavior through utilizing the five basic experiences of science (sic; observation, experimentation, measurements, data interpretation, and prediction.

CHAPTER III
RECOMMENDED SCIENCE PROGRAM GRADES 7-12

"Science is a basic and important aspect of man's intellectual endeavor. It is also the basis underlying our technology as well as our increasingly frequent biological manipulations. Education in science cannot, therfore, be apart from the social and cultural turbulences which seem certain to be the characteristics of the next few decades. Accomodations with these forces and the continuing self-development of science programs will demand new designs for progress in science education."[1]

We, the science teachers of Oklahoma, have indicated our acceptance of the philosophy of inquiry in both the K-6 science curriculum guide and in the suggestions received for this guide. It would seem reasonable that any science program for grades 7-12 would seek to make use of the experience, skills, and knowledge gained by the students in grades K-6. The purpose of the grades 7-12 science program should then be to continue the development and refinement of the rational powers and the continued development of scientific literacy.

During the period of elementary school learning, the student has developed the concept of the "verb" nature of science, inquiry. He should have been exposed thoroughly to the interrelatedness of all branches of science. Secondary school is not a place to destroy this concept concerning the common elements by reverting to our contrived system of compartmentalization of subject matter. Scientific inquiry is the heart of biology, chemistry and physics in the same way that matter and energy are the underlying theme of all three.

Although schools will offer courses in biology, chemistry and physics, we, the teachers, see our role as something more than describing these branches of science to the student. We will constantly strive to accomplish these two goals:

1. To cause the student to experience science as a practitioner of the discipline.
2. To constantly stress the common threads (concepts) which link all science.

THE NATURE OF THE LEARNER

The learner entering grade seven is probably between eleven and one-half and thirteen years old. This age range is significant in that it represents a period of transition from one stage of intelletual development to another. Piaget indicates that during this time the learner is progressing from what he calls the concrete operational stage of intellectual development to that which he calls the formal operational stage.[2]

The concrete operational stage of development is, as the name implies, characterized by the childs' tendency to reason in the realm of the concrete. His thoughts are, to a very large degree, controlled by his actual experiences with the physical objects in his environment.

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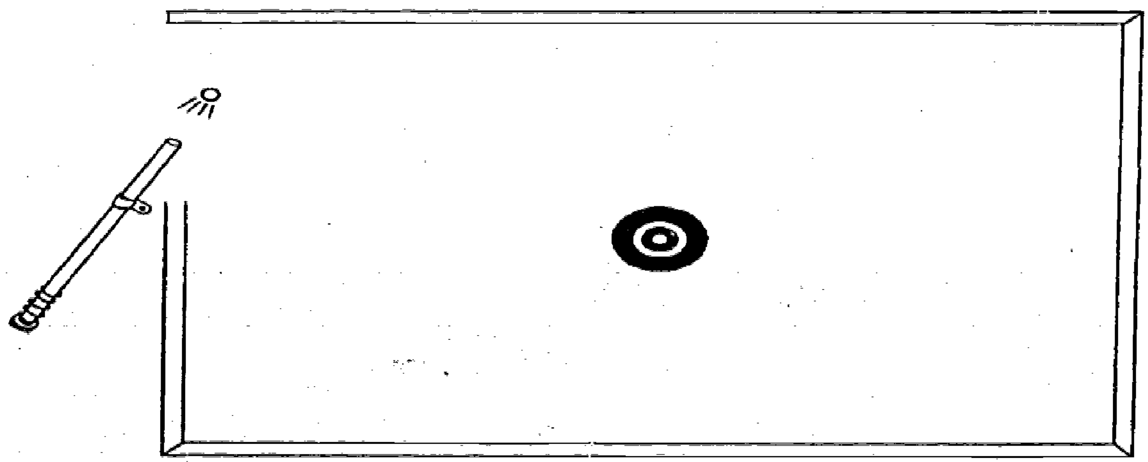
1 National Science Teachers Association, **Designs For Progress In Science Education,** Washington, D.C., 1969, Introduction, p. XI

2 Phillips, John L. **The Origins of Intellect: Piaget's Theory,** (W. H. Freeman and Company, San Francisco, 1969).

The formal operational child, on the other hand, is developing the ability to deal in thoughts and concepts that are in the realm of the abstract. He is not *totally* limited by his experiences and environment but can create a mental world of ideas to complement his environmental world of phenomena.

These stages can probably be best understood by sharing an example from a book by Inhelder and Piaget.[3] The experiment makes use of a billiard table type device. (See illustration) Balls are propelled from a spring loaded tubular "gun" that can be pivoted around a fixed point. The ball rebounds from a wall into the interior of the table where a movable target is located. Subjects are asked to try to hit the target with the ball and afterwards asked to report their observations.



The child to about age six has a distorted concept of the trajectory of the ball. "He succeeds occasionally but describes the trajectories with his finger only in the form of curves not touching the walls of the apparatus; he considers only the goal as if there were no rebounds."[4]

As older subjects are used they will begin to see the trajectory of the ball as two straight lines with a rebound joining them but are still, even at age 9-12, unable to develop the concept of equal angles. "Thus we see that the subjects succeed in isolating all the elements needed to discover the law of the equality of the angles of incidence and reflection, and yet they can neither construct the law *a fortiori* nor formulate it verbally. They proceed with simple concrete operations of serial ordering and correspondences between the inclinations of two trajectory segments (before and after the rebound), but they do not look for the reasons for the relationships they have discovered. And they do not consider the segments except from the standpoint of the directions taken; thus the idea of dividing the total angle made up of the two segments into two equal angles (incidence and reflection) fails to occur to them."[5]

3 Inhelder, Barbel and Piaget, Jean. **The Growth of Logical Thinking from Childhood to Adolescence,** Basic Books, Inc., Publishers, 1958.

4 **Ibid.,** pp. 5-6.

5 **Ibid.,** p. 8.

An older child, in the formal operational stage, can take the observed paths and from these observations formulate the law of reflection even taking into consideration imperfections in the ball or reflecting surface. The learner at this stage of development can take the observations and transform them into a satisfactory mental generalization.

As has been stated earlier, in this guide, the transition from concrete to formal operations is not spontaneous. It is *caused* and must be *nurtured. Certain experiences may even cause acceleration of this transition.*

Since some evidence[6] has been gathered, in Oklahoma, to indicate that the development of formal operations may occur somewhat later than age 13, we, the science teachers of Oklahoma strongly recommend that during grades 7-9, the child receive inquiry experiences which will aid in his transition from concrete to formal operations. We also recommend, since many learners in grades 10-12 are formal operational, that these students receive those inquiry experiences which will refine their rational powers and further develop their ability to deal with ideas in the abstract framework.

Since science, as much as any body of subject matter, provides such a vast reservoir of materials with which to develop the rational powers *we further recommend that every child in the public schools of Oklahoma experience programs of inquiry in science in each of the grades 7 through 12.*

RECOMMENDED SCIENCE CURRICULUM The recommended science curricula for the secondary schools of Oklahoma are given in figure 1. It should be noted that the programs listed represent, what we feel, are good examples of inquiry science. Other good programs are available and should be considered within the scope of these recommendations.

The programs recommended for Example I and Example II, represent the programs which will apply to the *majority* of students. Example I represents programs with an annual division along subject matter lines while Example II represents an interdisciplinary or integrated program. The local school systems choice of Example I or Example II would be determined by the background of the teachers available, the space and equipment provided, the total philosophy of the system and the needs and desires of the students.

Example III programs represent inquiry science for that portion of the students who have had limited success and/or experiences in science. Vertical mobility is indicated in the recommendations in that the Example I and/or Example II programs for grades 7-9 may become the Example III program for grades 10-12.

No specific grade level recommendations have been made for the programs at grades 10-12. We feel that the grade at which these courses are offered will depend upon the mathematical level and degree of level of scientific literacy that each student has. One group of students might be ready, for example, for chemistry at grade 10 while another group might not benefit from chemistry until grade 12. These decisions can only be made locally.

6 Unpublished research by Elizabeth Friot, University High School, College of Education, University of Oklahoma.

Since we have recommended experiences in inquiry science in each grade, 7-12, a much broader range of courses has been listed than currently exists in most secondary schools. *We feel that these offerings are essential in order to meet the needs and future goals for every student in the school system.*

THE LABORATORY IN HIGH SCHOOL SCIENCE

In an article dated July 7, 1962, in the *Saturday Review of Literature*, Dr. Warren Weaver, Vice President of the Sloan Foundation in New York said:

> "It seems to me absolutely essential that the student do something more than listen to lectures, look at demonstration experiments, study a textbook, and recite lessons. All these things are good, but they are not enough. In addition the students simply must do something on their own, with their own minds and with their own hands. They must have a 'scientific experience' even if it is so simple as swinging a bunch of keys hanging on a string and timing this pendulum with their pulse."

Any science course that the student has without the benefit of concurrent laboratory experiences is not science but is simply *about science*.

The experiences that the students have in the laboratory should be inquiry oriented. They should aid development of the rational powers. The trend today is toward open-ended activities. This type activity is not designed to verify but instead to lead the student to new avenues of investigation. The student not only gains understanding of natural laws, i. e., $F=MA$, $V=IR$, etc., but sees these natural laws not as final results but simply bits of data which will lead to further inquiry and further science competencies.

Two statements made regularly by students in a science laboratory should bring tears to the eyes of the modern science teacher. They are:

1. "I've done the lab."
2. "Did this do what it was supposed to?"

The first statement is usually heard at the end of a laboratory period and the translation means "I have followed the lab manual step by step. All the blanks are filled in and the percent of error is within the —5% which you will accept. I would like to turn in my paper now . . . and take a nap." The student sees the laboratory not as a place to explore but rather as an exercise room in which he must do a prescribed number of "science push-ups." He never realizes that an investigation can be judged by the number of questions uncovered as well as by the number answered. This student never experiences the desire to continue after the last blank is filled in.

The second statement is often heard during the last half of the laboratory period. Translated it means, "Here is what I have in the blanks. Is it acceptable to you?" This student really doesn't think that a pendulum bob, or a strip of litmus paper, or a pickled perch can do other than what it is "supposed" to do. He simply wants to know, before committing himself, if the teacher will accept his findings.

Either statement should tell the alert science teacher that something is wrong with his course or his students. Budding young scientists as well as seasoned old veterans must realize that the "lab" is never done. Any experiment worth its salt will open new avenues of investigation. He should know that his instruments may lack precision, his measurements may be in error, and his observations biased, but nonetheless he continues. Conclusions must be completed, but the vehicle of inquiry which carried this experiment, like ole man river just keeps rolling along.

One of the best examples of the "open-ended" experiment is one which has been christened the "black box" experiment. This particular activity is excellent for use early in the school year. Each student is given a sealed box containing some object (pill boxes obtained from the drug store are excellent). The students are asked to first obtain as much information as possible about the object without opening or damaging the box. The students can shake the box and gain information about the object's size, hardness, shape, mass, and possible texture. After a sufficient time, the student is asked to "describe and/or name the object in the box." No time deadline is given for this assignment and no student may damage or open the box. This experiment may last a week or a month or several months, but almost all students will give a very good description of their object and a very high percentage of the students will correctly identify the object. The significance of this experiment, aside from the use of rational powers, is that all systems in science were originally or are still black boxes. A modern example is the atom; we must describe the atom without "seeing" it. Other examples are: gravity, magnetism, electricity, and even life. Currently, all of the recommended programs make extensive use of the "open-ended" experiments.

OUTLINE OF RECOMMENDED PROGRAM

GRADE LEVEL	EXAMPLE I	EXAMPLE II	EXAMPLE III
7	Life Science such as ERC	Integrated program such as I S C S	Selected units from programs such as ESS: Kitchen Physics, Small Things, Pendulums, Batteries and Bulbs, Micro Gardening, Daytime Astronomy, Pond Water
8	Earth Science such as TSM		
9	Physical Science such as IPS		
10 THROUGH 12	Biology such as BSCS Earth Science such as ESCP Chemistry such as CHEM-Study Physics such as PSSC and HPP Physical Science such as PS-2 Independent Studies	Integrated program developed from materials such as those in Example I for grades 10 - 12	ERC TSM IPS Patterns and Processes | I S C S

CHAPTER IV

ORGANIZING A SCIENCE PROGRAM IN YOUR SCHOOL

We, the Secondary School Science Teachers of Oklahoma, have been asked to express our views on the organization of a science program. We feel the following areas should be considered in preparing for such program:

1. Leadership responsibilities.
2. Planning for change.
3. Role of administrators, classroom teachers, the community, and outside consultants.
4. Articulation and sequence of science program.
5. Adoption of nationally developed science curriculum materials adapted to local situation.
6. In-service training.
7. Implementation and evaluation.
8. Meeting needs of all students in science.
9. Facilities, equipment, and supplies for science.
10. Time allotment for science teachers to teach and plan.

We also believe that in order to initiate a local action program, someone in the local situation must first recognize that improvement is desirable. The administrator, the classroom teacher or even an interested patron may recognize the need for improvement and seek assistance in assessing an appropriate course of action. Unless this is done, it is entirely possible that others will fail to see the problems or needs in the same perspective. Once interest is aroused, and the need for a local action program is recognized, there must be developed an organized plan to assure effective curriculum change. The formalization of a plan of action requires the combined effort of the school administrator, classroom teachers, interested patrons, curriculum supervisors, and appropriate consultants.

THE PLANNING PHASE

In order to facilitate planning, we cannot over emphasize the need for "*one*" individual to assume the responsibility for providing leadership in coordinating the organization and planning of a local action group to bring about change. We strongly recommend the following activities be completed during the planning phase:

1. The local situation must be studied to decide what action should be taken to design an appropriate science program.
   - (a) Appraise the schools' existing educational philosophy, objectives and purposes.
   - (b) Obtain a full description of the schools' existing science curriculum to identify strengths and weaknesses and to sharply define areas of concern.
   - (c) Seek out relevant information from others who have had similar problems or need.

(d) Determine the characteristics and needs of the local community and the trends of the large society in which the present population will live.

(e) Recognize the cultural, economic, and sociological differences.

(f) Determine requirements for proposed change, i.e., money, facilities, personnel, etc.

(g) Develop some type of model or pattern to demonstrate just how the proposed change will operate.

2. Study the current trends in science education and curriculum developments.

    (a) Using laboratory-centered approaches as opposed to the textbook-centered approach.

    (b) Teaching for behavioral change.

    (c) Emphasizing the conceptual schemes and processes of science rather than the products of science and topic to topic coverage.

    (d) Recognizing the teacher as the key to an effective program.

    (e) Utilizing materials to meet stated educational objectives.

    (f) Developing a sequential, well-articulated science program as opposed to adopting several science programs developed independently and oriented to a one-grade and one-discipline approach.

3. Provide an in-service program for all involved in the science program.

    (a) Education of teachers in the philosophy, rationale, and content of current science curriculums.

    (b) Special educational experiences, usually with consultant, in teaching the "inquiry approach."

    (c) Consultant visitation.

    (d) Special training in writing behavioral objectives and evaluation.

    (e) Examination of current materials.

    (f) Familiarization of teachers with the use and maintenance of laboratory equipment.

    (g) Safety in the science program.

    (h) Special training in working with individuals, small groups, and large groups.

    (i) Special training in methods of meeting individuals differences and providing individualized instruction.

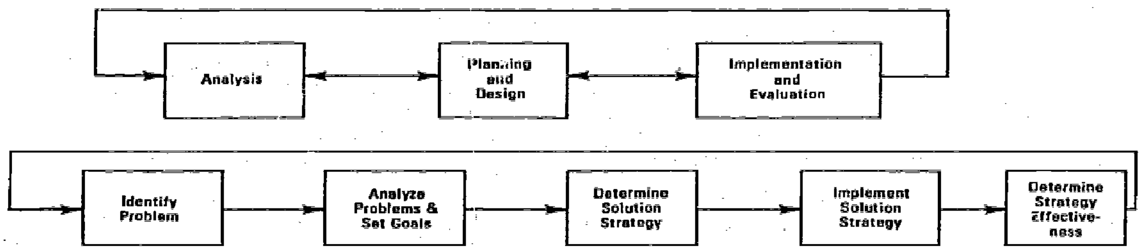
    (j) Special training for teachers in preparing evaluative instruments that evaluate the results of "inquiry teaching" and not simple recall of facts or memorization.

4. As in the elementary school, the formulation of a total action program is necessary to effect science curriculum change in the secon-

dary school. This program will be developmental and cyclical in nature and will consist of:

(a) design, (b) trial, (c) evaluation, (d) revision, (e) trial, (f) evaluation, and (g) revision.

In an attempt to assist educators to plan for change, week-long training sessions have been held for representatives from the State Departments of Education, institutions of higher learning and local school systems. The model, illustrated below, shows the concepts presented at these meetings and is included in this guide to aid educators concerned with planning and effecting educational change.



The basic phases of planning from the initial problem identification to the implementation and evaluation of the selected strategy. Upper: A simplified flow-chart of the process. Lower: A more detailed breakdown of proccess.[1]

The process illustrated is usually referred to as the system approach to planning. The system approach is merely one technique of technology to help insure good planning. This approach is helpful to define, identify, or isolate problems; and will lead to feasible strategies to bring about solutions to the problems. Notice that both include provision for continuous feedback, or order that modifications be made as necessary throughout the process.

It is important that the local action group explore several alternatives in order to be better prepared to make knowledgeable decisions relating to the adoption and implementation of their science program. In studying some of the experimental programs listed in this guide, a local group will need to clarify local objectives concerning science education and select and implement those materials which most nearly meet their particular objectives. They must decide either to accept a nationally developed program as it is, or develop the materials into a sequential articulated program designed specifically for the local situation. Progress has been real and significant at the instructional level in curriculum development. A relationship must be established among these efforts; gaps must be identified and closed, and fragmentation avoided.

A local action group can help to accomplish this by considering such problems as sequence and content of courses, grade placement, program for learner of varying levels of ability, different teaching styles, and relationships between science and other subject areas. As stated earlier, there is an increasing need to adjust nationally developed projects to fill local needs,

1 David L. Jessen, "Systematic Planning: An Answer to Educational Dilemma?" **The Science Teacher,** May, 1969, p. 33.

and to develop a local K-12 science program based on basic principles and concepts organized into a sequential, well articulated, format.

THE ROLE OF THE TEACHER

We, the classroom teachers more than anyone else, realize that we are the key to the success of any program. Realizing this, we must continually experiment with new material and approaches and desire to do so. We should innovate and modify materials to fit our own teaching situation. We should seek in-service training sessions that stress inquiry, concepts, philosophy and rationale of the new science programs; and we want to participate in discussion groups with others engaged in similar experimentation.

We must maintain the spirit and approach of inquiry, the spirit of discovery, and above all provide for student involvement. A committment to developing the student's ability to inquire will force the teacher to get out of the way in order to give students room to explore ideas. Then, we must remember that the "finish-the-book" attitude has no place in a classroom concerned with developing a student's ability to inquire.

We, the classroom teachers, must create a classroom environment conducive to inquiry learning. The materials we provide plus our attitude toward the materials is a central force in shaping the classroom environment. Teachers who accept all honest replies and leave the decision to reject an idea or theory to the students will aid in establishing the proper environment. It will be a place where students can express ideas and try them out on each other, without fear of failure or embarrassment.

As stated earlier, the teacher must also assume a new role in the laboratory, one of "director of research." Students are viewed as the primary investigators, and we, the teachers, are there only to help, challenge, and oversee. We believe the primary responsibility of the teacher is to ask leading questions that require students to exert their own initiative to solve problems.

THE ROLE OF THE ADMINISTRATOR

The administrator may be the superintendent, the principal, or the science supervisor, depending on the school system. In any case, the administrator must be the curriculum leader for effective change and must accept this responsibility from the start. The principal must not vacate his leadership role with the rationale that he isn't a science major, but must involve himself during all the phases of the action program for change. A vital function of the administrator is to ask "searching" questions that call for reappraisal of the present program. He may do this in many ways: (1) use of the faculty meetings as a form of large-group instruction in which films, consultants, and other presentations provide teachers with information not readily accessible elsewhere, (2) review findings of the latest North Central Evaluation on science programs, (3) organize faculty discussion groups to consider educational objectives of the school in relation to what they are doing in their classroom, (4) provide materials on educational innovations and encourage staff to make use of these materials, (5) provide an opportunity for members of his staff to observe science programs in other schools and school systems, and (6) encourage attendance at professional meetings, both local and national, by providing financial assistance and released time.

The science program in a school is largely the reflection of what the administrator believes, encourages or neglects. To obtain desired goals, the administrator must create and maintain a favorable climate for teaching and learning. The administrator who permits curriculum to be governed by convenience or expedience defeats the goals of a good curriculum. Policies and procedures can do much to enhance the learning that goes on in every classroom. A teacher in the classroom may innovate, but the administrator's reaction will limit the effectiveness if he opposes change. Administrators may stimulate the development of a quality science program by the changes he makes in scheduling, facilities, evaluation, and other instructional matters.

WE, THE SECONDARY SCHOOL SCIENCE TEACHERS OF OKLAHOMA, CANNOT OVER EMPHASIZE THE IMPORTANCE OF ADMINISTRATORS IN PROVIDING THE PSYCHOLOGICAL, PROFESSIONAL AND MONETARY SUPPORT SO NECESSARY IN UPGRADING AND IMPROVING A SCIENCE PROGRAM.

Effective open lines of communication involving teachers, supervisors, and the public must be established and used by the administrator to insure a continuous study and revision of the science curriculum.

Balance in the school curriculum must be maintained by the administrator to ensure that science is not over or under emphasized but *forms an integral part of the students total educational experiences.*

Above all, the school administrator must play the role of a facilitator, one who makes it possible for every teacher to achieve the goals for which the curriculum is designed.

THE ROLE OF THE SCIENCE CONSULTANT Science consultants from within and from without the school should be contacted to aid the local action group. Science educators from the State Department of Education, universities and colleges may be contacted to secure consultive help.* Consultants, if they are to be effective, will work with administrators and teachers in determining means that provide for school needs as these needs are identified by the local school district and community.

A consultant does not dictate the approach nor the curriculum, but works closely with interested professional personnel to develop a program that is current and above all, meets the need of the local school district. Consultants may provide services within the framework of conferences, workshops, in-service institutes and classroom visitations, they can provide current material on science curriculum development, counsel on the accuracy of curriculum materials, conduct demonstration inquiry teaching, and present the latest research findings on learning and evaluation, etc. The consultant's role is that of a co-worker in curriculum planning and in-service education.

Consultant service, to be of value, must be available over a long period of time in order to provide for follow-up and provide for adequate discussions on problems that develop.

* Names and addresses of consultants available in the state may be obtained by writing or calling Dr. Clifford Wright, Director of Curriculum Division, State Department of Education, Oklahoma City, Oklahoma 73105, Telephone 521-3341.

THE IMPLEMENTATION PHASE

New materials should be used experimentally on a limited basis, to provide an opportunity to try a variety of materials and approaches in situations where they will be used. This will assist detection of any "bugs" in the program, and give teachers an active part in the selection of techniques and procedures to be retained.

An adequate science room should provide for the learning areas which will accommodate each of the different types of learning activities the selected program requires. Each area should contain the equipment, supplies, and facilities necessary to support the science program. The objectives of the program should be used to formulate the learning activities, which in turn will serve to define the science facilities essential to the realization of the objectives. The construction of adequate science facilities and the intelligent purchase of material and laboratory apparatus are dependent upon clearly conceived and clearly stated objectives.

The relative importance of science to the total curriculum and its relationship to other subjects, should be considered at all stages of planning and implementation. Many subject disciplines are inextricably related to science in actual practice, but have been arbitrarily separated in the school curriculum. The many relationships that do exist should be explored and strengthened so that students will be familiar with the relationship of science to other aspects of life.

FOLLOW-UP, EVALUATION AND REVISION

Follow-up has its value in establishing lines of communication between teacher, administrator, and consultants. The sharing of experience and the interchange of ideas encourages and gives the teacher a feeling of security in working with the new material and the inquiry method of teaching.

Evaluation is continuous. It must begin with the initial phase of the program. Individual student achievement, implementation of the science program within the school, and the effectiveness of the program on a system-wide basis are three major levels to be considered in evaluation. The criteria for evaluation should be based on the objectives of the science curriculum. Emphasis for evaluation should be placed on (1) conceptual learning, (2) behavioral change, (3) ability to see interrelationships and (4) ability to apply knowledge to new situations. This type of evaluation is more difficult than objective testing of factual recall; nevertheless, teachers must continually strive to develop instruments that evaluate the previous four points. Objectives stated as behavioral patterns, (1) emphasize that teaching should lead to desirable changes in the learners behavior in social and scientific skills, (2) provide guides as to what the behavior should be, and (3) give a basis for evaluating the effectiveness of the teaching and learning. (See Robert F. Magers book *Preparing Instructional Objectives*, Fearon Publisher - 1962, for further information on this subject.)

Revision must be continuous. Evaluative feedback is used to help in the teaching methods and in the selection of science materials current and pertinent to the objective of the science program.

NATIONAL SCIENCE CURRICULUM ORIENTATION

The following excerpts are reproduced from THEORY INTO ACTION . . . IN SCIENCE CURRICULUM DEVELOPMENT, National Science Teachers Association, Washington, D.C., 1964.

"The National Science Teachers Association takes the position that to be fully adequate the school science program:

1. Must start as early as kindergarten or first grade;
2. Must be articulated from one level to the next through grade twelve or higher.
3. Must encompass a full range of the contemporary knowledge and ideas which scientists employ;
4. Must result in understanding the nature of the scientific enterprise through direct student involvement in the processes of scientific inquiry;
5. Must involve the best that is known about child growth and development and the psychology of learning; and
6. Must be supported by first-rate staff, facilities, and instructional materials.

"With regard to evaluation . . . This process should be closely tied to the stated objectives of a given curriculum . . . where the evaluation of a given set of goals turns out to be difficult, this should not be taken as indicating a weakness in the goals, but rather as a weakness in our knowledge of evaluation . . . No single program can or should be designed for use in all or even a majority of the school districts of the nation. Multiple efforts in curriculum development should be encouraged which involves creative and diverse approaches."

CHAPTER V

RECOMMENDATIONS CONCERNING THE PREPARATION OF SECONDARY SCIENCE TEACHERS

We feel there is a definite need for college and university teachers to take a critical look at the instructional procedures within their courses as well as the total course organization and content. If secondary teachers are to be expected to teach science by the method of inquiry with any real understanding, they must experience inquiry in the science courses they take in their professional science training in college; it is impossible to accomplish this point of view in a methods course alone.

The processes of scientific inquiry are of the same order of importance as the conceptual information desired. Ability to use inquiry can only be developed by experiencing satisfaction with it. This process includes: investigating, observing and reporting results of investigations, isolating and testing variables, stating hypotheses, designing and conducting investigations, using various measuring devices, classifying materials, organizing and interpreting data, and making generalizations.

The education of secondary science teachers must be viewed as a continuous process — both pre-service and in-service. The preparation needed, in most instances, differs in both scope and emphasis from that typically available in most introductory college courses.

The scope must be much broader with emphasis on the underlying concepts, scientific principles, and the nature of scientific inquiry. The elements must be obtained by providing:

1. Learning experiences which lead to increased understanding, knowledge, and skills in science and mathematics.
2. Opportunities to increase understanding of science and mathematics problem solving, critical thinking, and methods of inquiry.
3. Learning experiences which lead to understanding the relationships between branches of science and mathematics and between these areas and other branches of learning.
4. Opportunity for the study of the historical development and philosophy of science.
5. Awareness and appreciation of the expansion of knowledge and changing emphasis in science and mathematics.
6. Awareness on contemporary scientific developments.
7. Experiences of many kinds, in working with children, especially laboratory and field experiences, which illustrate the methods of science.

Science courses pursued by the secondary teacher in college must be organized and taught using the philosophy of inquiry with emphasis on: the nature of evidence, the process of measurement and instrumentation, the interrelationship of all areas of science and mathematics, and the ability to understand abstract relationships. These courses must be taught by professors who are interested in and understand the philosophy of inquiry and who are provided time to plan and prepare for the classroom.

In developing courses for secondary teachers, consideration should be given to the notion that they need not be organized according to traditional disciplines. The inquiry approach to teaching science is not concerned with science as a distinct discipline but as a composite unit. *The nature of the science programs advocated in this guide requires that colleges and universities develop interdisciplinary courses in order to provide the teacher with the experiences necessary to deal with the philosophy of the courses advocated. This will require new courses designed to meet the special needs of the new curricula.*

Separating the various scientific disciplines and to separate the sciences from their social implications is becoming increasingly difficult. There should be provision for individual and group laboratory experiments. Demonstrations performed by the instructor are not adequate substitutes for students' laboratory work; they can and should be utilized for illustrative techniques and stimulative scientific thought. Opportunities, however, must also be provided for students to develop their ability to inquire through designing and conducting their own laboratory investigations.

During the pre-service preparation for secondary teachers, in addition to the required science course, there should be a laboratory course in experimental procedures and scientific techniques as they apply in the presentation of science to the secondary school child. The preparation program should emphasize the teaching of science processes through inquiry.

There should be provision for gradual induction into teaching through a planned sequence of experiences including observation of secondary school programs in science culminating in a period of full time supervised student teaching. This entire experience should be accomplished over a period of three or four semesters and not just for a few weeks during one semester. The professional courses specifically designed to develop skill in science teaching for the secondary schools should include:

1. Systematic consideration of purposes, methods, materials, and evaluation procedures appropriate to the teaching of science.
2. Attention to the identification and development of teaching procedures appropriate to the abilities of the individual.
3. Study of a number of different approaches to teaching science, research in science, and current trends and developments.
4. Provision of opportunities for the development of individual creativity in conducting experiments, planning other types of learning activities, developing teaching resources and procedures.
5. Study of the psychological characteristics of learner.
6. Experiences in analysis, study, and development of curricula.

In addition to the pre-service preparation program in science for the secondary teacher, serious thought must be given to the teacher already on the job who needs help.

In-service programs designed to facilitate the implementation of an inquiry-centered science program at the local school level must be provided by the State Department of Education, colleges and universities, and local administration units. These programs must be so planned that scientists, science educators, supervisors, and others work as a team to help the teachers understand the nature of the inquiry approach; develop the needed materials; secure suggestions for program development and implementation; adapt to local needs; and provide procedures for evaluation.

It is recognized that improvement in science instruction in the Oklahoma schools inevitably requires improvement in the preparation of the teachers of science. This is the responsibility of the colleges and universities; however, the teacher education programs in the colleges and universities are greatly influenced by the certification requirements established and enforced by the State Department of Education.

The committee makes the following recommendations:

1. All teachers of courses designated as science courses in the secondary schools, should have a Natural Science Teaching Certificate. This would include teachers of 7th and 8th grade science courses.
2. Before receiving the highest level of professional certification, the committee recommends that teachers be required to have a master's degree with specialization in science.

CHAPTER VI

INQUIRY PROGRAM MODEL LESSONS

Inquiry science programs supported by carefully prepared curricula and materials have received strong acceptance throughout the United States and some foreign nations. Support for most of the programs is obtained from government agencies and private organizations interested in the improvement of science instruction in the junior and senior high schools. The National Science Foundation has supported the major part of these program developments.

The model lessons contained in this section emphasize inquiry and discovery learning through laboratory investigations. The materials have as a common goal "doing" science to increase the students awareness and understanding of his environment through development of his rational powers. It is strongly recommended that teachers use these model lessons with their classes. If a teacher is to implement an inquiry program, he must indeed discover inquiry himself. For additional information concerning materials and programs refer to the bibliography.

WANT TO SAVE YOURSELF SOME WORK?

Model Lesson — Junior High School

INTERMEDIATE SCIENCE CURRICULUM STUDY

Introduction

The Intermediate Science Curriculum Study (ISCS) materials are designed for individual study. The student in using the test does an experiment, answers questions, and under guidance from the teacher asks questions of the materials. In essence, the student inquires on an individual basis. The activities are designed so that they build upon one another. The text, in one way, may be compared to a programmed text. Yet, the student requires guidance from the teacher and a discussion of the question asked is necessary.

The student is asked to secure his equipment, provided by the teacher, work through the exercise at his own rate. The teacher is *not* to lecture, but rather move around the classroom giving assistance as needed. The teacher should make the materials readily available to the student so that he may proceed at his own rate.

Accompanying the test are "Excursions." These activities are extensions of the text lesson and the student is encouraged to do an excursion whenever he would like or whenever he feels the need to do so. The teacher may also want to suggest the student do an "Excursion" exercise.

The activity used here does not include one of these excursions, however, the teacher is encouraged to have students extend their work to understand the concept of "work."

Student Activity

Do you want to save yourself some work? People save it all the time. They save work in various ways and use it later in some other place. For example, when you wind a watch you are doing work that is then saved for you and given back slowly. Similarly, you get back part of the work that you do climbing a hill when you ski or slide back down.

Of course, you can't get something for nothing. The only way you can save work is by storing it. To get work out, someone must put work in.

● 1-1. List two other things that store work. (Toys often contain ways to store work.)

Every car has something that stores work — the battery. You can build your own battery with a few simple materials. After it is built, you can find out how much work it can store.

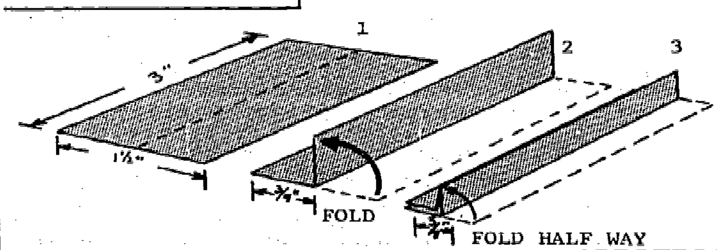
The parts you will need to start are:

1 plastic cup about 2 inches in diameter with cover
2 sheets of lead, each 16 inches long by 1½ inches wide
2 strips of lead, each 3 inches long by 1½ inches wide
2 pieces of cardboard, each 18 inches long by 2 inches wide
1 large rubber band

Place everything on the table in front of you. Then put the two long lead sheets on a piece of paper. Because each sheet should be wrinkle free, smooth them with your hands until they are flat. Set them aside for the moment. Spread out the two smaller strips of lead, flatten them, too, and go ahead as shown in the activity frames on the following pages.

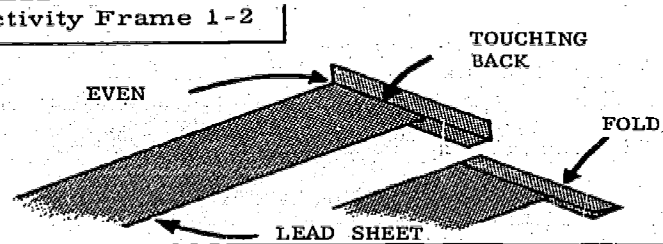
MAKING THE TABS

Activity Frame 1-1



Fold one of the small lead strips down the middle as shown (steps 1 and 2). Fold the same strip again, leaving it open (step 3). *This is your tab.* Do the same thing with the other small strip.

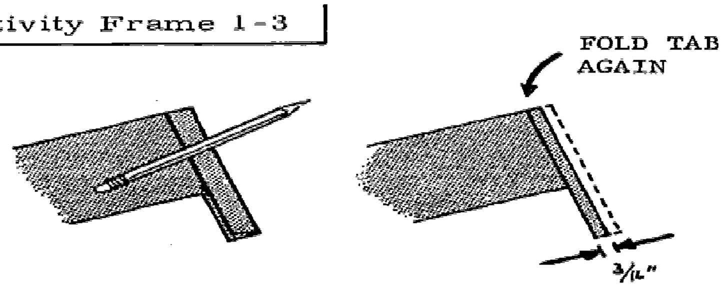
Activity Frame 1-2



Next, place one end of a long lead sheet against the back of a tab. Fold the tab down over the end of the long lead sheet.

Repeat with the other tab and sheet.

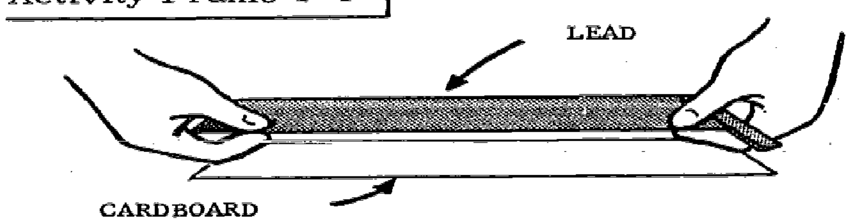
Activity Frame 1-3



Run your pencil along one tab to smooth it. Push the lead sheet into the tab as far as you can. Fold the tab once more and smooth it again.

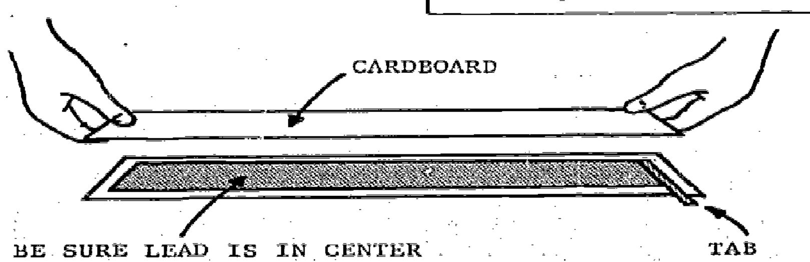
Repeat this with the other tab and sheet.

Activity Frame 1-4



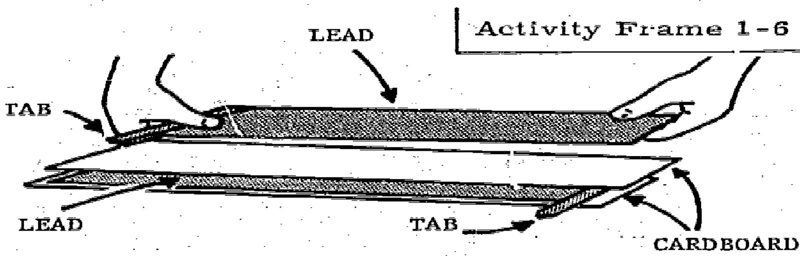
Place a long lead sheet on one of the pieces of cardboard. *Be sure* the lead is in the *center* of the cardboard. The tab will be near one end of the cardboard, sticking out along the side.

Activity Frame 1-5

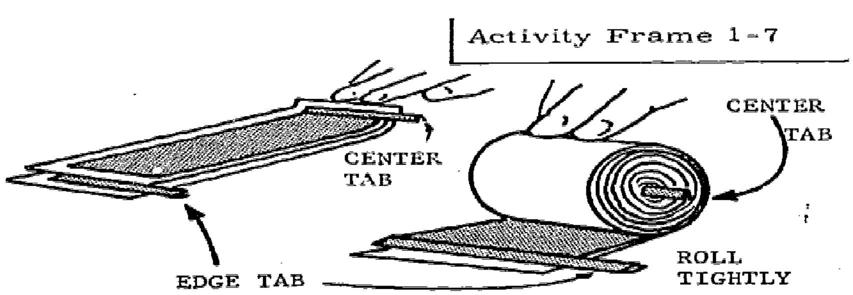


Cover the lead with the second piece of cardboard to form a lead "sandwich."

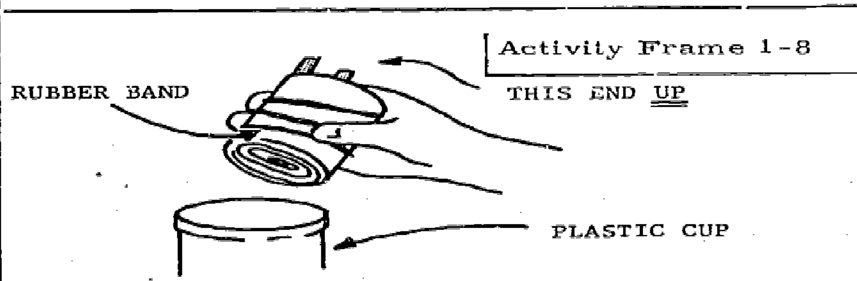
Activity Frame 1-6



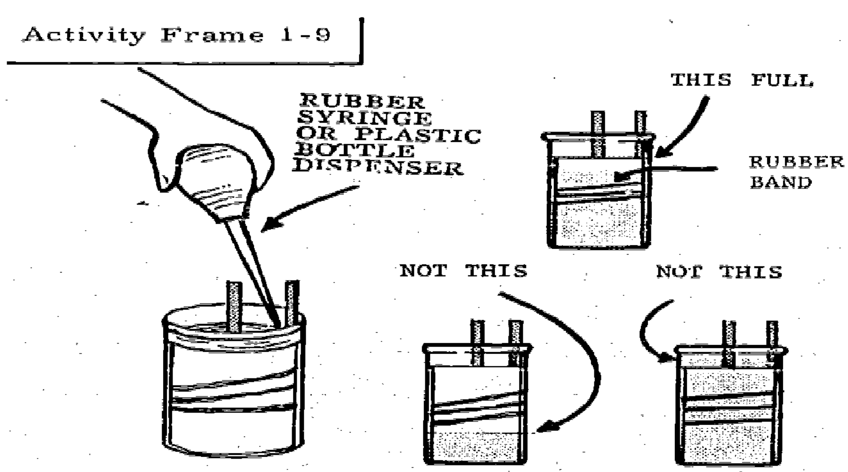
Place the other long lead sheet on top of the sandwich. *Be sure the cardboard keeps the two sheets of lead from touching.* Notice where the tabs are.



Roll the sandwich up into a tight roll. When you are through, the roll should be small enough to fit in the plastic cup. One tab should stick out from the center of the roll. The other tab should be on the edge.



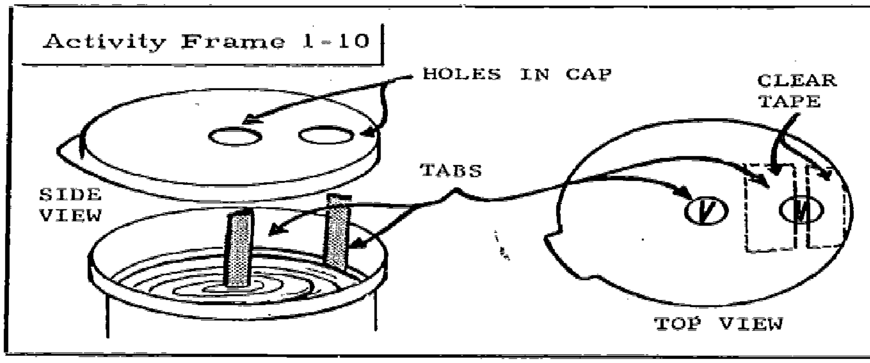
Wrap a rubber band tightly around the roll, and place it in the plastic cup. The two tabs should point up.



You will find a bottle of "sodium sulfate" solution on the supply table. Use some of this to almost fill your cup. Squeeze out just enough of the solution to cover the roll. The cardboard may soak up a little liquid. If it does, add more. The roll should be barely covered with liquid at all times.

Sodium sulfate is dangerous when swallowed. It is a good idea to think of all chemicals as being harmful if not used properly. (Lead is poisonous. Babies have died from eating lead paint on their cribs.) *Never* taste *any* chemical, and avoid getting them on yourself. *Always* wipe up spills *immediately*. Wash yourself quickly if any chemical spills on you. When you use chemicals, be neat and keep your work area clean.

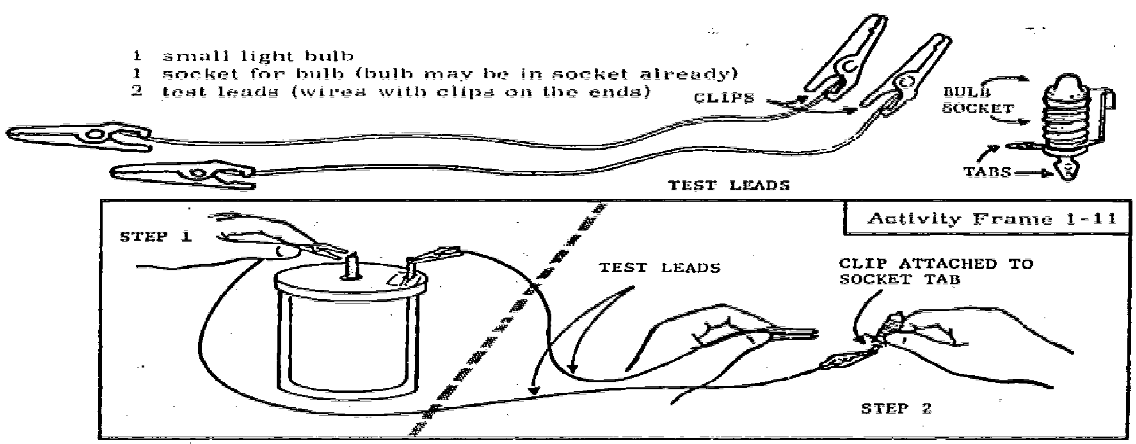
Activity Frame 1-10



Punch two holes in the cap, one in the center, the other near the edge. Put the cap on the cup. The folded strips should stick out through the holes in the cap. Cover the open part of the outside hole with clear tape. You want the top to be fairly airtight to cut down evaporation.

What you have built is a chemical cell or battery. The next problem is: "Does your battery work?" On the supply table you will find testing materials. Pick up the following items and connect them as shown in Activity Frame 1-11:

1 small light bulb
1 socket for bulb (bulb may be in socket already)
2 test leads (wires with clips on the ends)



Activity Frame 1-11

● 1-2 Does the bulb light? ______

● 1-3. List all the reasons you can think of for what you have just observed. (Consider your materials, your methods, your own work.)

If you had trouble, several things may be to blame. Let's try getting rid of them one at a time.

● 1-4. How can you use a flashlight battery to test whether or not the test leads and light bulb work? Describe your method, try it, and write your conclusion.

Perhaps you didn't follow directions carefully while building your battery. As you can see, it is very important that you understand what you read and that you follow all directions carefully. You will have a lot of freedom in this course, but freedom means responsibility. If something you read confuses you, read it again. If something you make won't work, check the steps you followed in making it. If you are still confused, get help from a classmate or your teacher. Go on with your work once you understand what you are doing.

Your classmates have been building batteries also. Their batteries may look like yours, but the batteries may not be exactly the same.

● 1-5. Do you have any evidence that your battery doesn't work because of some mistake that only you have made? Why do you think so?

Of course, in building your battery you may have made a mistake that no one else made. Remember, though, that the battery you have built is supposed to be a *storage* battery. Have you stored anything in it?

You will find a "charging system" somewhere in the room. Notice that it contains a "charger" plugged into the wall, a car battery, and two wires attached to a piece of wood (the charger harness).

Connect your battery to the charger harness as shown in Figure 1-1. Be careful about overloading the charger. It can charge up to six batteries at one time. If you have already charged your battery, you goofed. You were following your classmates rather than this book. Keep your own pace. Read; then do.

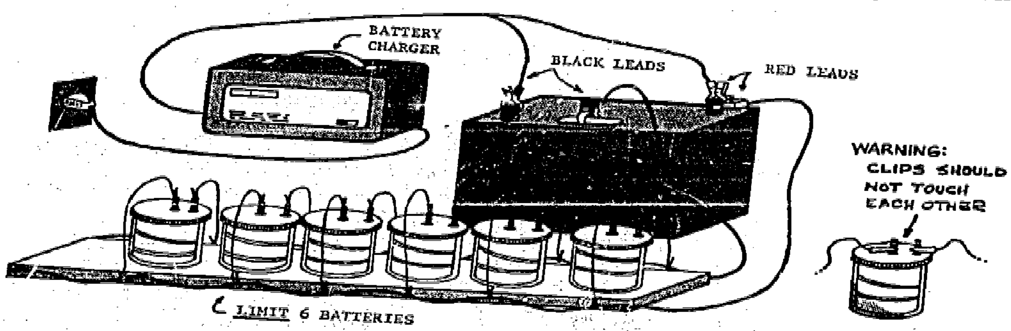


Figure 1-1

Watch the liquid in your battery as it charges.

● 1-6. What do you see happening? (If you don't see anything, ask your teacher for help before you give an answer.)

When your battery has charged for about four minutes, unhook it. Now test your battery with a light bulb.

● 1-7. Does the bulb light this time?

If your answer was "no," something is wrong. Find out what it is. Some possibilities are: You built the battery incorrectly; you connected it to the charger incorrectly; or, you connected it to the bulb incorrectly. Do not go on until you can light a bulb with your battery.

● 1-8. For how many seconds can your battery keep the bulb lighted? ______ seconds.

Your battery will work better each time you charge and discharge it. When it will keep the bulb burning for at least 60 seconds, you are ready to go on. If it is not charged enough, put it back in the charging system another two minutes and then try again. Keep recharging until you get the bulb to burn for 60 seconds or more.

By now you should be getting a feel for how this course will work. The book will guide you through the things that you will *do*. For the most part, you will work on your own and at whatever speed is best for you. Your teacher will help you when you get stuck, but try hard to solve problems yourself before asking your teacher or classmates for help.

Remember these points when answering questions:

1) The questions help you see what is happening.

2) It is important to answer each question as you come to it.

3) Give complete answers. You may need the information later.

4) You may repeat your activity before answering.

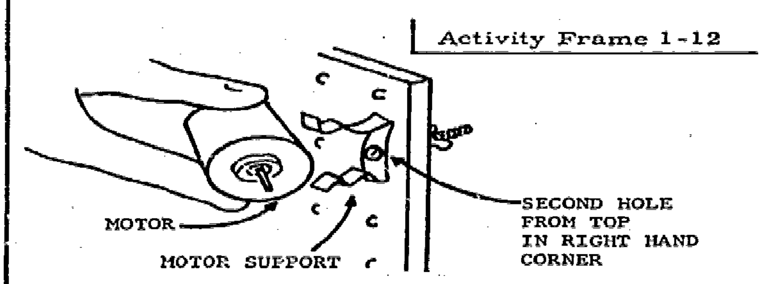
5) You may look back at other answers.

6) Answer all questions before you go on.

Can you get any work out of your battery? Of course, it lights the bulb, but you can also make it lift things. You will need help for the next part. Find someone near you who is at about the same place in the book as you are. Work with him or her for the next few minutes. One of you should collect the following equipment from the supply area:

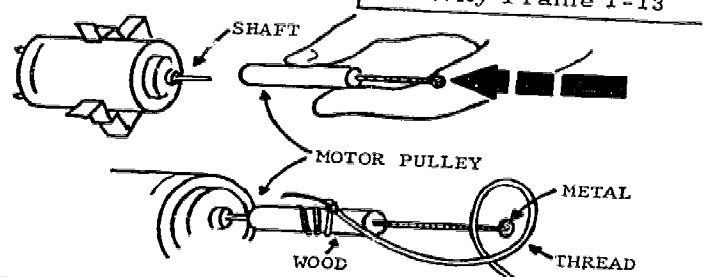
1 electric motor	2 sinkers
1 motor support	1 piece of thread about a meter long
1 motor pulley	2 test leads
1 pegboard stand	1 paper clip

When you have all the equipment, including the battery you made yourself, you are ready to go ahead with the following activity frames.



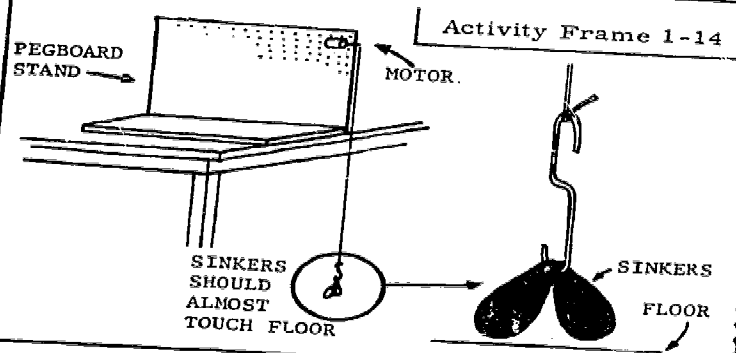
Place the pegboard stand so that its solid base is flat on the table and nearest you, as shown in Activity Frame 1-14. The side with the holes should be upright. Bolt the motor support to the pegboard stand and clamp the motor in place.

Activity Frame 1-13



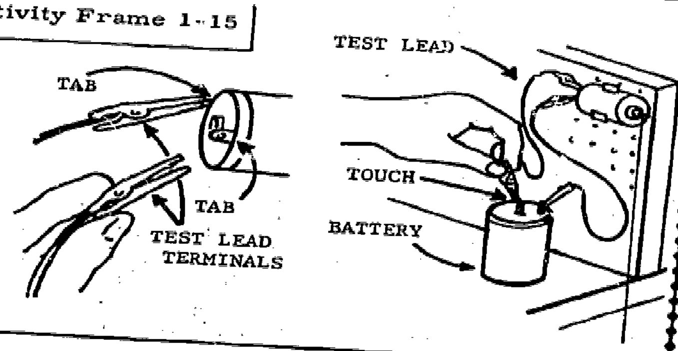
Push the motor pulley firmly onto the motor shaft. Tie the thread tightly to the wooden part, and then loop it over the metal part. You may need to tape the end of the thread to the wooden part of the pulley if it slips.

Activity Frame 1-14



Move the pegboard stand to the edge of the table. Bend a paper clip into a hook. Tie the hook to the thread so that when the two sinkers are attached to the hook they will hang just above the floor.

Activity Frame 1-15



Connect the clip of one lead to one tab of the motor. Attach the other end to a tab on your freshly charged battery. Attach one clip of the other lead to the remaining motor tab. Touch the loose clip to the other tab of the battery.
Repeat the same steps with your classmate's battery.

IT WORKS! At least, if you did everything right, your battery and motor ought to do work. If not, check everything carefully to see what is wrong. Perhaps one of the connections is not tight, or the battery was not properly charged.

At the beginning of this chapter, you started out to save some work. Apparently you have done so.

- 1- 9. What work did your apparatus (battery and motor) do?
- 1-10. Where was the work stored?
- 1-11. Where did the work come from in the first place?
- 1-12. Finally, here is a tough question, partly because it looks easy. We have talked about doing work and about saving work — but what is work?

In the next chapter, you will do some more work in order to find out more about work. Many chapters later, we will ask again for a definition of work. At that time, you will need to think about your answer again to Question 1-12. Maybe by then you will have changed your mind.

The above material came from **Probing the Material World,** Vol. I, 1968. Intermediate Science Curriculum Study, Florida State University, Tallahassee, Florida. Reprinted by permission, copyright 1968 by Ernest Burkman, Director, Intermediate Science Study.

WHAT IS POLLUTION?

Model Lesson — Junior High School

EDUCATION RESEARCH COUNCIL

The assumption behind the design of this problem is that although students have had vicarious exposure to the idea that man pollutes his environment, they do not have a feeling that they are a part of this polluting population. The student activities are designed to provide these kinds of experiences. The goals are not to frighten children by this realization, but rather to evoke an awareness and responsibility for the character of their deeds. Carrying out one or more of the recommended activities and sharing in the results of other students should result in the student demonstrating a more cautious attitude when he is asked to evaluate the effectiveness of a hypothetical program for controlling nuisance plants in a city park.

Guidelines for the Problem

In this problem, the student is asked to investigate the effects of common household products on living things. These should be products that eventually find their way into our water supplies. The list provided in the *Student Investigations* is only meant as a beginning. Since there is such a wide array of these products, perhaps a short class discussion listing personal suggestions on the blackboard would be a stimulating way to begin the problem.

It is assumed that by this stage of the course, the individual, or at least groups, will be able to perceive at least a skeleton outline of a problem design. But it is also probable that teacher guidance will be necessary for working out the details of the investigation. To promote the maximum impact, as many separate investigations should be encouraged as the storage space of the room will permit. The possibility of conducting some of these investigations at home should be encouraged wherever the design fits the facilities that are available there.

The following chart, (Suggestion for Investigating the Effects of Household Products), is reprinted from the *Student Investigations*. This chart suggests a variety of possible experimental organisms, sources where they may be obtained and appropriate areas to study with each organism. In addition, the chart, Common Household Products, which also is in the student material, suggests some household products whose effects on living things might be tested.

Detergents	Window cleaner
Auto Polish	Insect poison
Soap	Water from septic tank
Water soluble paint	Disinfectants
Fertilizer	Toothpaste
Crab grass killer	Hair spray
Slug killer	

Common Household Products.

It may not be possible to ensure that each problem investigated is equally meaningful. There are obvious differences in students' abilities to design and carry out investigations. However, by carefully playing your role as a consultant, you can increase the probability of each student having a meaningful experience.

When each individual or group has decided on the organism, the product and the effect they wish to test, they should be required to explain to you their experimental procedure. The following list represents a minimal group of requirements which should be present in most of these plans:

1. The design should include some way of comparing the experimental organisms with normal organisms.
2. The quantity of the material used should be specified. For example, if a serial dilution technique is suggested, the method for doing this should be clearly stated.
3. Where measuring dimensions or rate of activity is required, the method of measurement and recording the measurement should be specified by the student. When the life history of the organism to be used is not well understood by the student, perhaps he should be asked to do a brief library study of the organism so that he can work with it effectively.
4. If the student is to acquire his organisms from some part of his environment, such as a lake or a pond, you should be reasonably certain it is available. (Frogs are difficult to collect in the winter.)
5. When phenomena such as growth rate require observations over a period of time, a reasonable estimate of the time required should be obtained before the student begins the investigation.

Materials

There are no lists of materials for these problems. Since such a wide variety of options is open to students, trying to collect all of the organisms beforehand might result in a waste of time. The greatest demand will probably be for a supply of conditioned water. That is, tap water which has been allowed to sit for several days so that the chlorine will escape. If unpolluted pond water is available, this might be used for many investigations that might not be influenced by the presence of some micro-organisms. Since the organisms with which many children will be working will be relatively unknown to them, two or three class days at the beginning of the problem may be necessary for them to become familiar with their beasts. This time could also be used for procuring the test pollutants and experimental organisms.

The following references would be helpful in enabling the students to do the necessary background work for their experiments:

Berrill, Jacqueline. *Wonders of the Fields and Ponds at Night.* Dodd Mead Company, 432 Park Ave., South, New York, N.Y. 10022; 1962. (80 pp.).

Buck, Margaret W. *In Woods and Fields.* Abingdon Press, 201 8th Ave., South, Nashville, Tennessee 37202; 1950. (96 pp., paperbound).

Buck, Margaret W. *In Ponds and Streams*. Abingdon Press; 1955. (72 pp., paper).

Hillcourt, William. *Field Book of Nature Activities and Conservation*. G. P. Putnam and Sons: 1961. (432 pp.),

Hylander, Clarence J. *Sea and Shore*. The Macmillan Co., 60 Fifth Ave., New York, N.Y. 10018; 1950. (242 pp.).

Klots, Elsie B. *The New Field Book of Fresh Water Life*. G. P. Putnam and Sons, 200 Madison Avenue, New York, N.Y. 10016; 1966.

Malkus, Alida. *Meadows in the Sea*. World Publishing Co., 119 W. 57th St., New York, N.Y. 10019; 1960. (71 pp.).

Needham, P. G. and P. R. Needham. *A Guide to the Study of Fresh Water Biology*. Holden-Day, San Francisco; 1962.

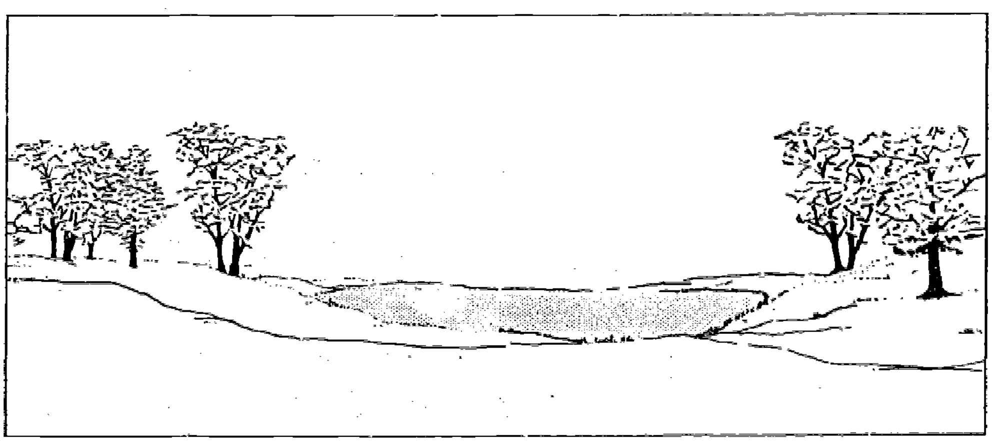
Pels, Gertrude. *The Care of Water Pets*. T. Y. Crowell Company, 201 Park Avenue, New York, N.Y. 10003; 1955.

Reid, G. K. *Pond Life*. The Golden Press, affiliated Publishers, One West 39th Street, New York, N.Y. 10018; 1967. (160 pp.)

Selsam, Millicent E. *Underwater Zoos*. William Morrow and Company, Inc., 425 Park Avenue, South; New York, N.Y. 10016; 1961.

Checkpoint

In the city parks in Plainville, Ohio, there is a small attractive lake which supports populations of frogs, turtles and birds. The hills around the lake have areas which are shaded by trees and also a large amount of grassy picnic area.



The park is heavily used in the summer as a picnic and recreation area. The chart, Plainville Park and Lake, shows the relationship of the lake to the land area in the park.

One of the most common complaints of the people using the park is that the grassy spots around the lake contain large numbers of broad-leaved plants like dandelions and knotweeds. These plants are not as attractive as grass. They also seem to do best where there is bare earth around them. These kinds of plants make the picnic areas much less desirable.

A survey was made to determine what should be done to improve the problem caused by these plants. From this survey, any of the following plans seems possible. Pick one of the three and state your reasons for your choice.

1. Apply a cheap very efficient broad-leaved plant killer that will destroy all of the undesirable plants in one year. This would allow the more desirable grasses to fill the spots occupied by the broad-leaved plants. This plan would take the least time and best satisfy the requests of the people using the park.
2. Get the large numbers of young people, such as the Boy Scouts and Girl Scouts, to dig up the plants and plant more grass in the bare spots. This would be less expensive than the weed killer and allow young people to participate in a worthwhile activity. This process would have to be repeated every year or two.
3. Leave the area pretty much as it is. There may be a reason for the broad-leaved plants among the grasses that is not understood; removing these plants by either method could have effects that would be more serious than the weeds themselves.

There is an obvious hierarchy of replies to this checkpoint. Plan 1 should cause the most hesitation on the part of the students, Plan 2 the next, and then Plan 3.

A recommended procedure for using this checkpoint would be to have each student choose a plan, then write a defense for his selection. If a majority of the responses show an awareness of the possible effects of a poison in a park or of widespread but ineffective digging program, then the goals of the problem have been achieved.

Student Activity

Do large populations of people tend to pollute their water supply? Does that include you? Are you partly responsible for the "No Swimming" sign at the lakeside beach? Do you add to the mess that destroys living things and makes "bad smelling" water?

In this problem you will be able to test these questions for yourself. You will be able to test directly the effects of some of the things that you personally add to your own water supply. Think about some of the common activities that occur in your house over a period of time, such as, doing the laundry, washing the car, painting the house (inside or outside), taking a bath, washing the dishes, showering, brushing your teeth, salting the sidewalks, fertilizing your lawn or garden, killing insects, or even cleaning windows. Most of these activities require water plus some other kind of product which is eventually put down a sewer. These materials, in some form or another, end up in a river, in a lake or an ocean. What effect do these common, everyday, household products have on the living things in that lake or river? You may not be able to answer these questions directly, but you can get data on a similar one.

The chart, Common Household Products, shows a list of products that are commonly used in your community and then flushed down your drains.

You may be able to think of others. The chart, Suggestions for Investigation the Effects of Household Products, shows a list of living things, where they can be found, and some features or functions of the living things that might be affected by one of the common household products. Either by yourself or in a group, whichever is suggested by your teacher, find a product you would try on one of the organisms listed and the effect you would like to study. You may choose to use some other organism, but check with your teacher first.

Write a brief outline of your idea, then discuss it with your teacher.

If you are not well informed about how your test organism looks and acts, try to find this information in the library. You should learn something about the place where this organism lives, the kind of food it eats, something about its normal behavior, and perhaps, if necessary, how you can catch or obtain some. Then, when you are familiar with your experimental animal or plant, try to write out how you will ask your questions. For example, if you are going to test the effect of fertilizer on the growth rate of tadpoles, how much fertilizer should you use? How would you tell if the growth rate is faster or slower than if you had not added the fertilizer? How will you keep the tadpole during the experiment? In a large container? In a small container? With deep water or shallow water? What will you feed it? How often will you feed it? These may seem like simple questions, but they will require your attention if you wish to carry your experiment to the end. If it seems that your investigation will require special measuring instruments, such as thermometers or a balance, let your teacher know so she can prepare for these needs.

While the individual and group investigations on pollution are being carried out, ask your classmates or the group next to you what they are doing. Find out what questions they are asking. See if you think their experiments are really asking the questions they are asking.

In preparing the final report of your investigation, be as thorough and complete as possible. Include all the data you have gathered, not just information you think is important. If you gather data on growth or breathing rate, what is the best way to organize it? Would a graph make it more meaningful to those who read it?

The above material came from **Man's Effect on the Environment**, Topic IV, Instructional Guide, Second Experimental Edition 1967-68, Educational Research Council of America, Cleveland, Ohio, pp. 1-19.

MEASUREMENT AND PURPOSE

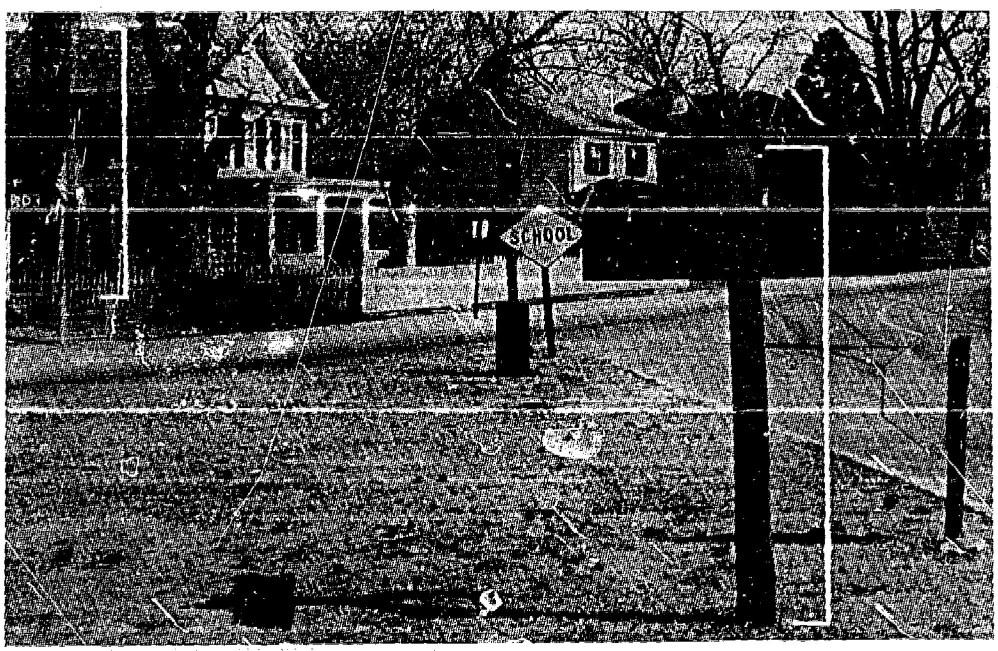
Model Lesson — Junior High School

SECONDARY SCHOOL SCIENCE PROJECT

Indirect Measurement

Instruments have proven to be invaluable to the students in the conduct of their investigations. With the balance and the calibrated vial they have been able to measure precisely the mass and volume of many objects and with these measurements to study properties such as the density of various substances. However, many objects cannot be brought into the laboratory to be compared directly with standards. For instance, the calibrated vial and the balance are of little use in measuring the size and the mass of very large objects. In these instances, indirect methods of measurement must be used.

Students should remember from Phase II that direct measurements are made by a simple comparison with some standard unit. Indirect measurement, however, frequently requires comparing the apparent size of the object with a standard unit and then adjusting for the reduction in actual size due to the object's distance from the observer. This was true of the photograph, "The House and The Signpost", where the apparent height of the white shingled house on the left side of the picture is less than the height of the signpost in the foreground. From their experience, however, students knew that the actual height of the house is certainly greater than that of the signpost. It appears to be smaller than the signpost because it is farther away. How can the actual height of the house be determined? It could be calculated if the distance to the house were known, but this information cannot be found in the picture. Perhaps some feature of known size on the house could be used as a unit of measurement. One such feature is the height of an exposed shingle.



If the exposed section of a shingle in the photograph is measured carefully, its apparent height will be found to be close to 1.5 mm; the apparent height of the house measures approximately 70 mm. The house is then $\frac{70}{1.5}$ or nearly 47 times the height of a shingle.

The actual height of the exposed section of a shingle on a house such as this is close to 7 inches. If the house is 47 times as high as a shingle, the house would be 47x7/12 feet, or about 27 feet tall.

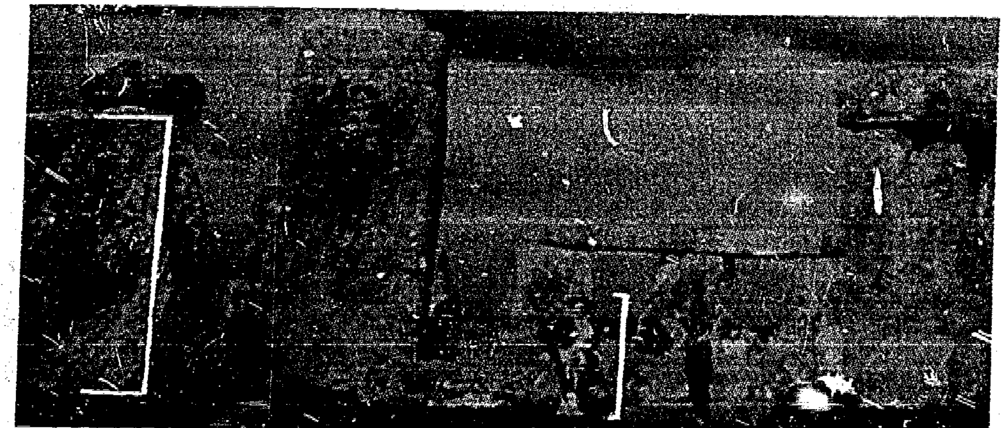
In an estimate such as this, the precision with which the results are known depends largely upon how precisely the value of the unit being used for comparison can be established. Sometimes the dimensions of such a unit are known with a great deal of precision. At other times this may not be so, and the calculated results may involve considerable uncertainty. Even so, estimating the dimensions of an object in this way may be the only available procedure in some circumstances. Estimating from photographs the size of the huge sandstone blocks and the circular area they surround at Stonehenge provides an example.

Estimations of Stonehenge

Stonehenge, which is located on Salisbury Plain in southern England, consists of a group of large monoliths set in a circular pattern. An aerial view appears on the back cover of Investigation Book 5. A closer view may be found on the front cover. Archeological evidence suggests that Stonehenge was built between 1900 and 1600 B.C. The stones are believed to have been organized so that various astronomical phenomena could be observed. A number of recent books and articles discuss the probable uses of this structure. One such book is *Stonehenge Decoded* by Gerald Hawkins and John White.

What is the height of Stonehenge blocks such as the one at the extreme left in the photograph on the front cover? What is the diameter of the circle in which they are placed? There is no standard unit of length that can be used for comparison. However, it may be suggested that the height of the woman in the front-cover picture could be used to find the height of the block in the same way the shingle was used in estimating the height of the house. No one knows how tall the woman is, but observation and experience permit a reasonable estimate of her height.

STUDENTS CAN ESTIMATE THE HEIGHT OF THE BOULDER TO THE LEFT BY COMPARING IT TO THE PROBABLE HEIGHT OF THE WOMAN



The woman appears to be short; she is only about a head taller than the boy standing nearby. In estimating her height, there is little doubt that she is less than 6 feet and more than 4 feet tall.

In fact, it would be reasonable to assume that she is about 5 feet tall with an uncertainty in this estimate of ½ foot to either side.

The apparent height of the woman in this photograph, measured with the ruler, is 3.0 cm. The height of the large boulder to the extreme left, which is about the same distance from the camera as the woman, measures 7.2 cm. In other words, it is about 2.4 times as tall as the woman. If the height of the woman is assumed to be 5 feet, the boulder would be 12 feet high (2.4 x 5 ft = 12 feet). The lower and upper limits of its height, established on the basis of the uncertainty in estimating the height of the woman, would be 11 feet and 13 feet respectively. (2.4 x 4.5 ft = 11 ft, and 2.4 x 5.5 ft = 13 ft). The height of the boulder is then reported as 12 ft + 1 ft. If the class knew the height of the woman more precisely, their estimate of the height of the block could also be more precise.

It is now possible to estimate the size of the Stonehenge circle from the photograph on the back cover of the Investigation Book, using the height of the block on the front cover as a unit of measurement. If students open their Investigation Books and place them on the table with both covers facing up, they should be able to identify this block in the circle. (See Figure 31.) Even without this identification, however, it can easily be seen that all of the blocks in the perimeter of the circle measure about 1 cm in height on the photograph. The diameter of the circle measures about 8 cm, that is, about 8 times as wide as the blocks are tall. If the blocks are approximately 12 feet high, the circle must be nearly 100 feet in diameter.

Obviously, considerable uncertainty is involved in making such estimates. For example, if it were possible to measure the diameter of the Stonehenge circle directly by placing a series of standard lengths across the circle, a more precise value would have been obtained. Nevertheless, such an estimate is adequate for many purposes.

Precision and Purpose

The precision with which an investigator makes measurements is influenced by the purpose for which the measurement is to be used. The relationship between precision and purpose can best be seen in a practical problem. Any number of problems could be used, but students might consider the problem facing a warehouse supervisor about to receive a large shipment of one million dictionaries. His responsibility is to arrange for the storage of these books in a building whose rooms are similar in size to typical classrooms. How many rooms should be set aside for the storage of these books?

The problem can be handled in a number of ways. The most direct approach is to determine the volume of the room and divide it by the volume of a single dictionary. This will provide an estimate of the number of books that will fit into such a room. The number of rooms required to store the entire shipment can then be easily calculated. In calculating the volume of a room and of a dictionary, their respective lengths, heights, and widths must first be measured.

The dimensions of a classroom can be measured with yard-sticks. Students will usually try to measure the dimensions to the nearest inch. The dimensions of one classroom were found to be:

Length = 42 ft, 8 inches = 42.7 ft
Width = 28 ft, 0 inches = 28.0 ft
Height = 8 ft, 0 inches = 8.0 ft

The dimensions of a standard dictionary can be measured with a ruler. Students normally measure the dimensions of an object of this size to the nearest eighth of an inch. The dimensions of a dictionary were found to be:

Length = 9 7/8 inches = 9.9 inches = 0.82 ft
Width = 7 inches = 7.0 inches = 0.58 ft
Height = 1 6/8 inches = 1.75 inches = 0.15 ft

The volume of the room divided by the volume of the dictionary produced the following estimate of the number of books that would fill the room:

$$N = \frac{42.7 \text{ ft} \times 28.0 \text{ ft} \times 8.0 \text{ ft}}{0.82 \text{ ft} \times 0.58 \text{ ft} \times 0.15 \text{ ft}}$$

$$N = 134{,}000 \text{ or } 1.3 \times 105 \text{ books/room}$$

This would be a good time to introduce powers of ten (standard) notation: Ten to the zero power (10^0) is equal to one; ten to the first power (10^1) is equal to ten; ten to the second power (10^2) is equal to one hundred; ten to the third power (10^3) is equal to one thousand; and so on. The exponent records the number of zeros which follow 1. Similarly, 0.1 is written as 10^{-1} and 0.01 as 10^{-2}, and so on. Negative exponents are also used to represent the reciprocal of the corresponding positive power. Thus $\frac{1}{10}$ can be represented as 10^{-1}, and $\frac{1}{10^{-5}}$ as 10^{-5}.

When numbers in exponential notation are multiplied, their exponents are added. For example: $100 \times 10 \times 10 = 10^2 \times 10^1 \times 10^1 = 10^4$. When such numbers are divided, their exponents are subtracted. For example:

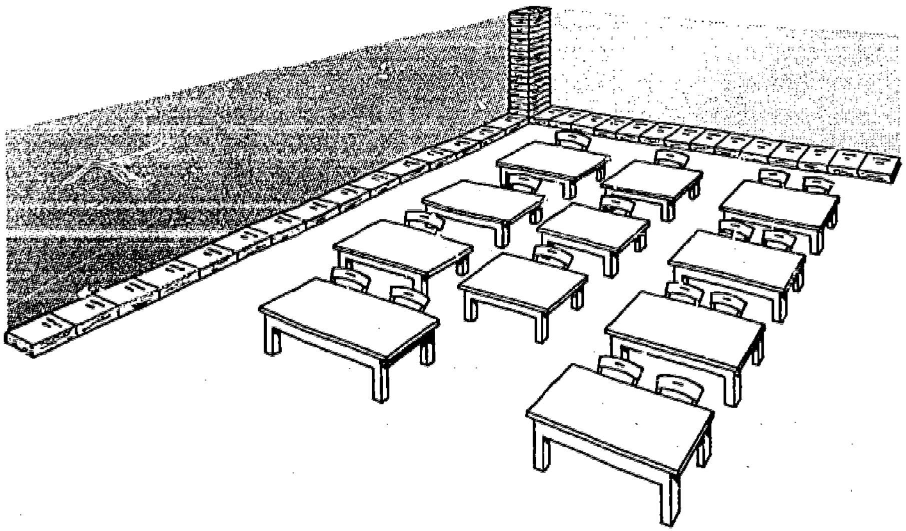
$$\frac{10{,}000}{1{,}000} = \frac{10^4}{10^3} = 10^1 \text{ and } \frac{100}{1000} = \frac{10^2}{10^3} = \frac{1}{10} = 10^{-1}.$$

Most numbers, of course, contain digits other than 1 and zero. According to convention, any number may be represented in a form in which the significant figures appear as a number between 1 and 10 multiplied by the appropriate power of 10. For example: 200,000 may be written as 2×10^5; 2,120,000 as 2.12×10^6; and .00236 as 2.36×10^{-3}. When multiplying or dividing numbers in this form, the operation is first carried out with the significant figures and then with the exponents. For instance, in the calculation 400,000 x 200, the two significant figures are multiplied — $4 \times 2 = 8$ — and the exponents of their powers of ten are then added — $10^5 \times 10^2 = 10^7$. Thus $(4 \times 10^5)(2 \times 10^2) = (4 \times 2)(10^5 \times 10^2) = 8 \times 10^7$. A similar procedure is followed in division:

$$\frac{4 \times 10^5}{2 \times 10^2} = \frac{4}{2}(10^5 \times 10^{-2}) = 2 \times 10^3.$$

If the class works through a few calculations in full using power-of-ten notation, they will recognize that such a procedure can often simplify their calculations.

HOW MANY DICTIONARIES WOULD FIT INTO A ROOM THE SIZE OF AN ORDINARY CLASSROOM?



If there are 10^6 books and each room will hold 1.3×10^5 books, 7.7 rooms will be required for their storage. (Since the last figure used in reporting any measurement is uncertain to some degree, the estimated number of rooms would actually fall within a range of from 7.0 to 7.9 rooms.) Estimating the number of rooms beyond the nearest 0.1 room may seem absurd even though it is possible to measure the dimensions of both the room and the dictionary with more precision.

Some may insist that even a precision to 0.1 of a room is unwarranted. They may point out the existence of irregularities such as electrical outlets or lighting fixtures in the room, floor, or walls. Furthermore, it is unlikely that such a room could be filled completely to the ceiling. In these circumstances it might be necessary to reserve an additional room — not just an additional 0.1 of a room.

If an additional room should be reserved, was the precision involved in obtaining the estimate of 7.7 rooms warranted? Is it necessary to attain such a degree of precision in measuring the quantities used in making these calculations? What sort of estimates could be made in this situation if all the dimensions were known to only one significant figure? Estimates of this sort are frequently made to provide an approximate solution to a given problem. The previous measurements can be used to make such an estimate if all quantities in the calculation are rounded off to one significant figure:

$$N = \frac{42.7 \text{ ft} \times 28.0 \text{ ft} \times 8.0 \text{ ft}}{0.82 \text{ ft} \times 0.58 \text{ ft} \times 0.15 \text{ ft}}$$

$$N = \frac{(4 \times 10^1)\ (3 \times 10^1) \times 8}{(8 \times 10^{-1})\ (6 \times 10^{-1})\ (2 \times 10^{-1})}$$

$$N = \frac{12 \times 10^2}{12 \times 10^{-3}} \text{ or } 1 \times 10^5 \text{ books/room.}$$

The estimate that 1×10^5 books can be stored in one room is not as precise as the previous one which called for 1.3×10^5 books for each room. The estimate of 1×10^5 books requires that 10 rooms rather than 7.7 rooms be set aside to store the million dictionaries. The difference in these estimates is due to the use of but a single significant figure in each quantity appearing in the second calculation. Since each significant figure could also vary to either side of the one used in the calculation, the number of books that will fit into a room could actually range from 4.8×10^4 $\left(\frac{35 \times 25 \times 7.5}{.85 \times .65 \times .25}\right)$ to 2.2×10^5 $\left(\frac{45 \times 35 \times 8.5}{.75 \times .55 \times .15}\right)$. With such a range the number of rooms required could vary from about 5 rooms $\left(\frac{1 \times 10^6}{2.2 \times 10^5}\right)$ to 20 rooms $\left(\frac{1 \times 10^6}{5 \times 10^4}\right)$.

This estimate is not nearly so precise as the previous one, which indicated that 7.7 rooms (7.0-7.9 rooms) were required for storing the dictionaries. The use of one significant figure in the calculation produced an estimate which is quite clearly not precise enough for the purpose. On the other hand, improving the precision of measurement so that students can predict the number of rooms to better than the nearest 0.1 of a room seems unprofitable. In this instance quantities measured to two significant figures produced an estimate which was appropriate after all. The precision sought for any series of measurements is determined by the purpose of the investigator and by the difficulty of making the measurements.

An Order of Magnitude Estimate

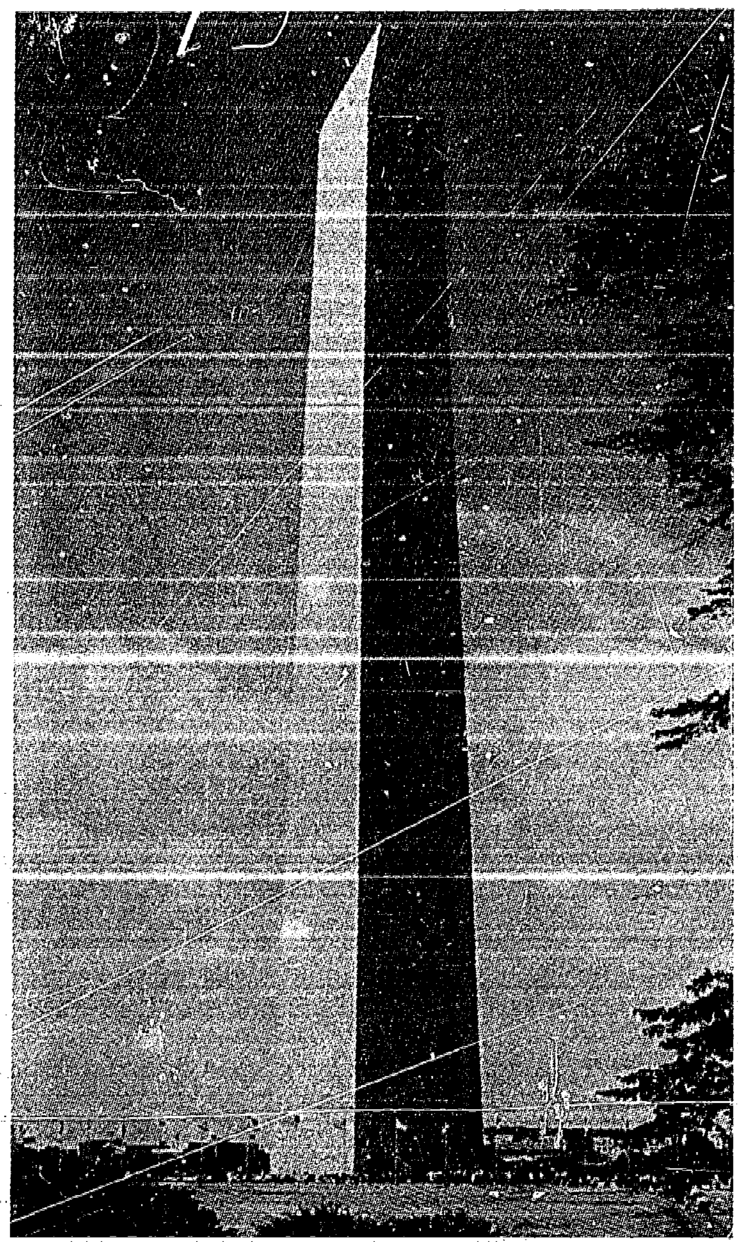
It is not always possible to measure a particular quantity very precisely. In some instances students will not be able to measure a quantity even to one significant figure. The attempt to measure the thickness of mica flakes with a millimeter ruler provided an example of this. In such a case students are not entitled to maintain even a single significant figure in the final estimate. It is possible to make only what is called an order-of-magnitude estimate.

In making calculations involving quantities whose value to even one significant figure is uncertain, a single figure should nonetheless be maintained throughout the calculation. The final result can then be rounded off to the nearest order of magnitude. The nearest order of magnitude or power of ten alone, represents a numerical first approximation.

> There is no hard and fast rule about the dividing line between one order-of-magnitude category and the next. As an operating procedure, if the digit is 5 or over, the order of magnitude is considered to be in the next highest category. (3.2 is sometimes used as the rounding-off point when multiplying or dividing by powers of ten, although 5 will be used throughout this Folio.) Thus, the category of 100's will include any number between 50 and 499; the number 680, which the class may at first think is in the category of 100's is really closer to 1000 than to 100 and is of the order-of-magnitude of 1000's.

Order-of-magnitude calculations are frequently used to make estimates since they are easily and quickly made and provide the investigator with a rough assessment of the numerical solution of a problem. This provides information which often helps in deciding whether or not a particular so-

THE VOLUME OF THE WASHINGTON MONUMENT CAN BE CALCULATED BY USING THE HEIGHT OF THE PEOPLE AT ITS BASE AS A UNIT OF MEASURE.



lution should be pursued any further and, if so, whether more precise measurements should be made.

The students may have some initial difficulty with order-of-magnitude calculations, and they should be encouraged to work through a few problems. Material for calculations can be found throughout the Investigation Books.

From the picture on the fold-out on page 5 of Investigation Book 4, for example, the volume of the Washington Monument can be calculated to an order of magnitude by using the height of the people at the base of the monument as a unit for comparison. (The taper at the top of the monument would not influence this calculation enough to change it by an order of magnitude.)

> The height of the people is approximately 5 feet and the monument is approximately 100 times as high. It is about 10 times as wide as a person is tall. Since the base is square, each side has the same dimension. Thus, multiplying the area of the monument's base by its height and holding one significant figure, the calculation for the volume is:
>
> $V = (1 \times 10^1 \times 5 \text{ ft})^2 \ (1 \times 10^2 \times 5 \text{ ft})$
>
> $V = 25 \times 5 \times 10^2 \times 10^2$
>
> $V = 125 \times 10^4 \text{ ft}^3$
>
> $V = 100 \times 10^4 \text{ ft}^3$
>
> $V = 1 \times 10^6 \text{ ft}^3$ or, expressed to an order of magnitude, 10^6 ft^3
>
> Students may be interested in comparing this approximation with that obtained by using the dimensions for the monument given in the Science Reading Series book, *How Big is It?* In that book, the height of the monument is given as 555 ft and the length of a side of the square base as 55 ft. Thus the volume can be calculated to be $1.7 \times 10^6 \text{ ft}^3$.

Another interesting calculation can be made from the earlier demonstration involving drops of india ink in containers of water. As before, 3 or 4 drops of india ink should be added to a tumbler of water. Then, 3 or 4 drops of this liquid should be added to a second tumbler of water. The problem is to estimate to an order of magnitude the dilution of ink in the second tumbler.

> Students found earlier, by measuring with their calibrated vials, that 20 drops of liquid have a volume of approximately one cubic centimeter. Four vials of water, or 200 cc, equal 3/4 of one tumbler. If one cc is equal to 20 drops (2×10^1), a tumbler 3/4 full will contain $(2 \times 10^1)\ (2 \times 10^2)$ or 4×10^3 drops of water. When 4 drops of ink are added to this quantity of water, the dilution is equal to $\frac{4}{4 \times 10^3}$. In other words, for each drop of india ink in this mixture there are 1000 or 10^3 drops of water.
>
> When 3 or 4 drops of this liquid are added to a second tumbler of clear water, no change can be observed in its color. This is not surprising — the dark liquid, which contains one drop of india ink for every 1000 (10^3) drops of water, has been diluted by a factor of 10^3 again. For every drop of ink in the second container there are 10^6 drops of water, to an order of magnitude.

When they learn that there are one million drops of water for every drop of ink, the members of the class may understand why the ink seems to disappear in the water in the second container and why, at this level of observation, they could not detect the presence of the ink in the water at all.

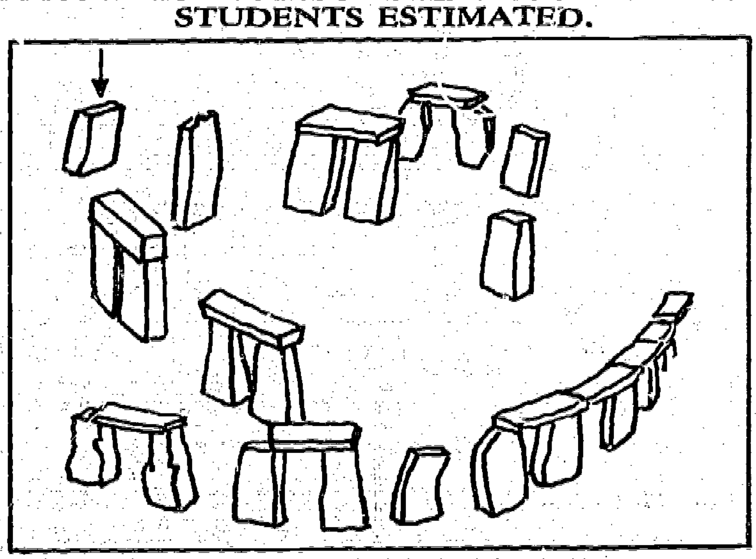
A number of other order-of-magnitude calculations may be made by the students until they have gained some familiarity with the use of the technique, which will be used from time to time during this course. In many instances the results of such a calculation are satisfactory. If such rough approximations are found to be inadequate for the purpose at hand, more precise measurements must be sought. Of course, it may turn out that the uncertainties involved in the measurements cannot be reduced and that only an order-of-magnitude estimate can be made.

The Mass of a Stonehenge Block

Students should consider one additional order-of-magnitude calculation which summarizes many of the problems of measurement that they have encountered in their work. This calculation concerns the large block at Stonehenge whose height was previously estimated. What is the *mass* of this block?

Obviously, such a massive object cannot be placed on a balance. But there is a way that students can make a rough calculation of its mass from the information they already have about it and from the techniques and procedures they have learned. They know that the density of any object is related directly to its volume and mass and that any one of these can be determined if the other two are known. Therefore, the mass of the block can be calculated if its volume and density are known. The volume of the block can be determined by multiplying its height by its length and width; the density of the block could be determined if a representative specimen of the material were available.

THIS IS A DIAGRAM OF THE PICTURE OF THE STONEHENGE BOULDERS ON THE BACK COVER OF INVESTIGATION BOCK 5. THE ARROW IDENTIFIES THE BLOCK WHOSE HEIGHT STUDENTS ESTIMATED.



The class can estimate the length and the width of the boulder from the photographs on the front and back covers of Investigation Book 5. The width and thickness of the rock compared with its height can be estimated from the picture on the back cover. Earlier, by estimating the height of the woman in the picture on the front cover and comparing it to the height of the boulder, the class found that the block was approximately 12 feet tall. Students will find that, on the average, the stones in the outer ring, including this specific one, are about half as wide as they are high and that their thickness is about ¼ of their height. Thus the volume of the rock can be expressed in the following manner: $(12 \times 12/2 \times 12/4) = 12 \times 6 \times 3 = 216 \text{ ft}^3$. This figure may be rounded off to $2.2 \times 10^2 \text{ ft}^3$.

What is the density of the rock material of which the block is composed? There appears to be no way in which a sample of the material can be obtained for density measurements. In view of these circumstances what estimate of its density can be made? Someone in the class may remember from their earlier work that most common rock materials have a density close to 3 gm/cm^3. It is reasonable to assume that the blocks at Stonehenge are similar in composition to the type of material generally found on the surface of the earth. However, this assumption together with the uncertainty in the measurement of volume provide the reason for making this calculation only to an order of magnitude. A better estimate would be possible if the density and volume could be determined with greater precision.

The next step in the calculation is to convert the units for both volume and density to the same system. The figure for density is expressed in grams per cubic centimeter; thus the figure for the volume of the block must be expressed in cubic centimeters. Using the simple conversion that 12 inches on the ruler are equivalent to approximately 30 centimeters, the volume of the block would be:

$$V = (2.2 \times 10^2 \text{ ft}^3)\ (30 \text{ cm/ft})^3$$

$$V = (2.2 \times 10^2 \text{ ft}^3)\ (3 \times 10^1 \text{ cm/ft})\ (3 \times 10^1 \text{ cm/ft})\ (3 \times 10^1 \text{ cm/ft})$$

$$V = (2.2 \times 10^2)\ (3^3 \times 10^3)$$

$$V = 59 \times 10^5 \text{ cm}^3 = 5.9 \times 10^6 \text{ cm}^3$$

The mass of the rock will then be equal to its volume multiplied by the value for average density:

$$M = (5.9 \times 10^6 \text{ cm}^3)\ (\ \text{gm/cm}^3)$$

$$M = 2 \times 10^7 \text{ gm}$$

To an order-of-magnitude, the mass of the block is 10^7 grams. Since 1 metric ton is about 10^6 grams, the mass of the block is equivalent to approximately 10 metric tons.

With the mass of this block estimated to be 10^7 grams, students should recognize that this implies the mass lies between 5×10^6 grams and 5×10^7 grams, or between 5,000,000 grams and 50,000,000 grams.

The class is now in a position to take part in the scholarly attempt to unravel the puzzle of Stonehenge. Scholars believe that the blocks were brought to the site of Stonehenge from quarries many miles away. What kind of vehicle was used to stand them upright? Students should be able to make some suggestions on the basis of their calculations of the size and mass of these blocks.

Questions and Suggestions

. . . How could the height of the white shingled house on the left be determined? On what does the precision of your estimate depend?

. . . Look at the picture (sic) Stonehenge . . . How could you determine the height of the Stonehenge block to the extreme left?

. . . Estimate the diameter of the Stonehenge circle shown on the back cover. Is the degree of precision to which this can be determined adequate? Explain.

. . . Suppose you had a job of arranging for the storage of a million dictionaries in rooms the size of a typical classroom.

a) How would you determine how many such rooms would be needed?

b) To what degree of precision did you determine the number of rooms needed? Would greater precision be possible? Would greater precision be desirable? Explain.

c) Find the number of rooms needed, using only one significant figure in the calculations. Compare the usefulness of this answer with that obtained previously.

. . . How is increased precision indicated numerically, using power-of-ten notation?

. . . What is an order-of-magnitude estimate? What would represent a reasonable "dividing line" between the orders of magnitude?

. . . Under what circumstances might an order-of-magnitude estimate be useful to an investigator? Under what circumstances might it be the only estimate justified?

. . . Make an order-of-magnitude estimate of the volume of the Washington Monument.

. . . Quantitative approach to the india ink demonstration:

a) How many drops are there in a tumbler of water 3/4 full?

b) To an order-of-magnitude, what is the proportion of ink to water in the first tumbler?

c) To an order-of-magnitude, what is the proportion of ink to water in the second tumbler?

. . . Given a large specimen whose density is known, how could you find its mass without using a balance?

. . . How could you determine the volume of the huge Stonehenge block whose height was estimated earlier? To what degree of precision can its volume be determined?

. . . What is your estimate of the average density of Stonehenge rock material? What assumptions are involved in this estimate?

. . . What is the mass of the Stonehenge block, to an order-of-magnitude? Record the calculation in your Record Book.

FREEZING AND MELTING

Model Lesson — Junior High School (Physical Science)

INTRODUCTORY PHYSICAL SCIENCE

The freezing point of a substance is identified as the temperature at which a plateau occurs on the cooling curve when a substance changes from a liquid to a solid. To show that the freezing point does not depend on the amount of substances present and is, therefore, a characteristic property, have each group determine the freezing point of a different amount of material.

The usefulness of the freezing point as an identifying characteristic property is illustrated by giving the class two different substances and allowing them to discover that the substances are different because they have different freezing points.

Typical graphs are shown in graphs A and B. Both graphs show slight dip just before the substance starts freezing. Many substances exhibit this effect. The liquid cools off below its freezing point; then, as soon as crystals begin to form, the temperature rises a little and remains constant until all the liquid has solidified. The dip in the graph is not always observed in doing this experiment and therefore may not appear on the graphs your students plot. Do not make a great point of it. It is not important in this experiment.

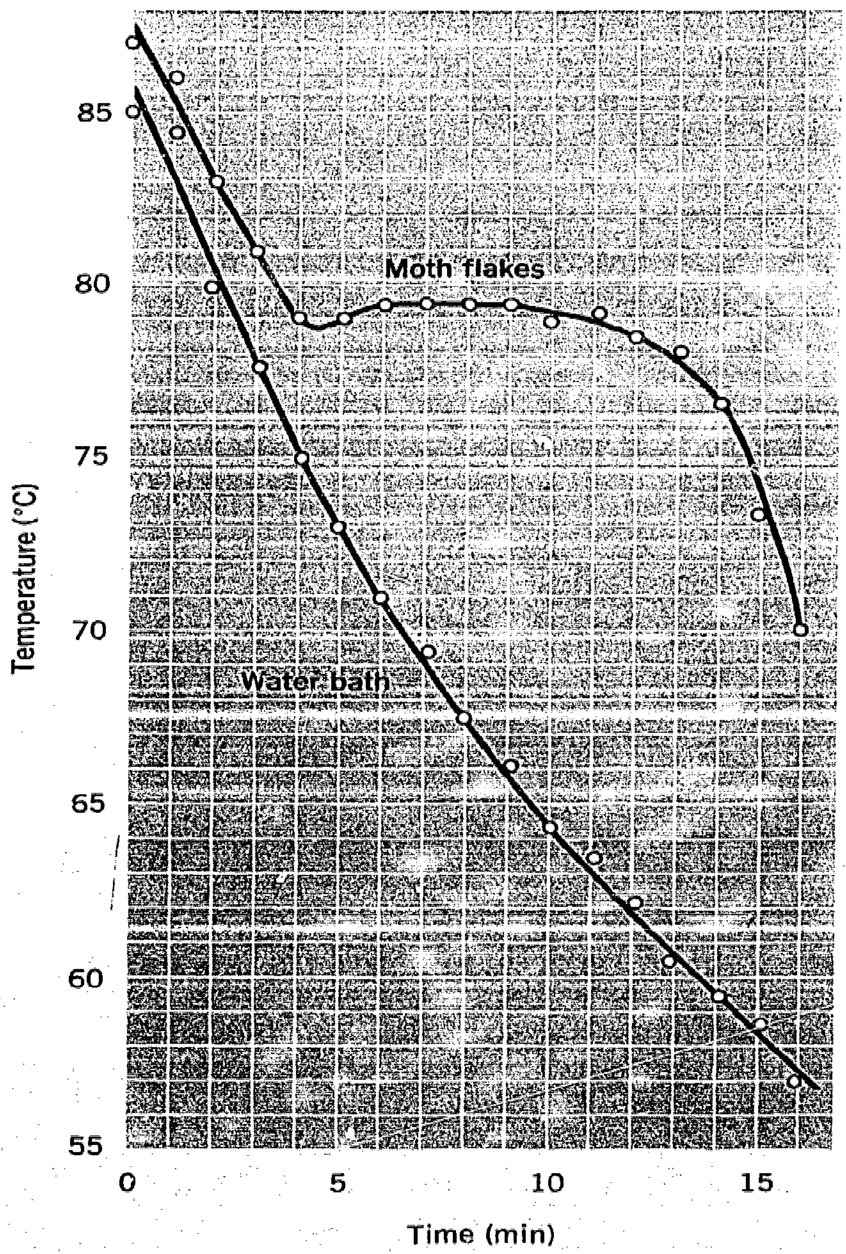
We are not concerned here with the question of why the temperature remains constant while the substance freezes. It is sufficient that students realize that the plateau does give the freezing (or melting) point, and that the substance does solidify during the period when the temperature remains at a constant level.

Nowhere in the text (except on the cover) is there a cooling and freezing curve showing a plateau. Do not tell students what the curve should look like. Let them find out for themselves.

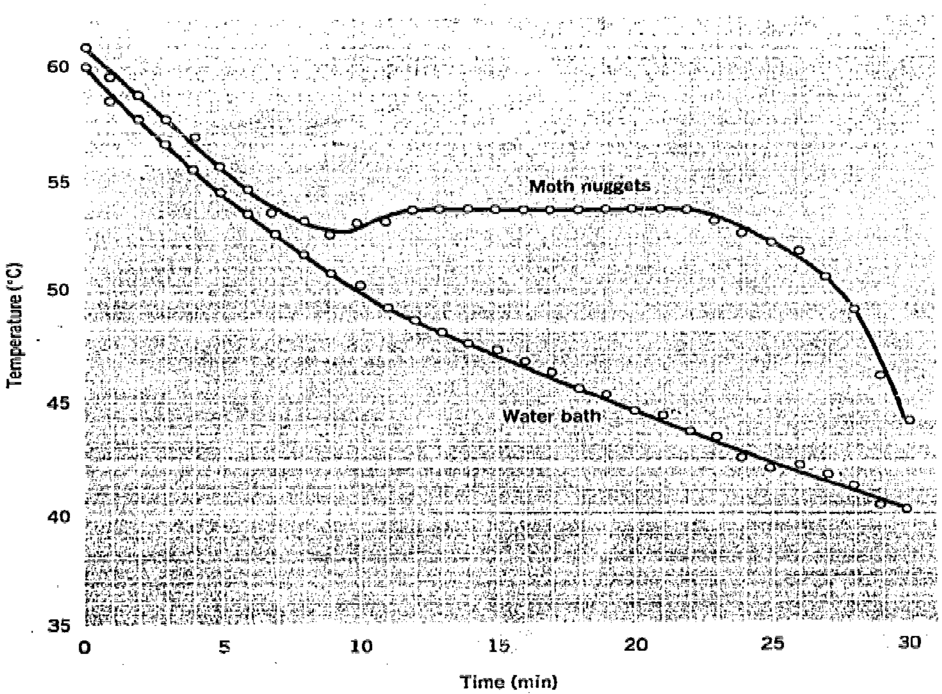
By plotting the cooling curve of both the water bath and the substance under investigation, students will see that the plateau is characteristic of the freezing substance and not of the water in the water bath as it cools to room temperature.

Do not bother about explaining why the two curves have the shapes they do. This experiment is concerned only with the identification of freezing point as a characteristic property, not with the rate at which substances cool.

GRAPH A


Moth flakes
Water bath
Temperature (°C)
85
80
75
70
65
60
55
0
5
10
15
Time (min)

GRAPH B



The Experiment

Slit cork stoppers supporting the thermometers make the whole temperature scale visible. They are made by boring a hole lengthwise through the stopper and then cutting out a wedge-shaped section. The thermometer should be fixed in the melted liquid so that the bulb is clear of the bottom and centered in the test tube.

To determine the extent of the variation in calibration of the thermometers, they can all be checked together in a single large beaker of boiling water.

Give half the class varying amounts of moth flakes (naphthalene) and the other half moth nuggets (paradichlorobenzene) without telling them that they are different substances. At this time point out to the students that they do not all have the same amount of material.

In order to get the experiment completed in a single class period, you may have to have the apparatus set up and hot water in the water bath before the class period begins. Use two burners to speed up the melting of the material. A tube containing more than 10 g of paradichlorobenzene or a beaker larger than 250 cm^3 for the water bath will extend the experiment beyond a class period. To speed up the cooling, see that the water in the beaker comes just above the level of the material in the test tube, and remind your students to stir the water during the cooling.

Be sure that all the material is molten when readings are started. The students should take readings until the temperature has again started to fall after remaining constant during the freezing. It is not worthwhile to make thermometer readings to better than 0.5° C.

Caution: When the experiment is finished, be sure that students melt the material in the test tube before extracting the thermometer, so that they will not break it. This can be done directly over the burner flame, but care must be taken not to heat the material beyond the range of the thermometer. After the thermometer has been withdrawn, the material in the test tube can be allowed to freeze and the test tube of solid can be stored for use another time. The material should not be disposed of in the sink. The thermometers and test tubes can be cleaned with alcohol, which dissolves both moth flakes and moth nuggets.

The student should use the same thermometer for Expts. 3.11 and 3.12 to avoid apparent differences in melting point due to small differences in thermometer calibration. It is a good practice to label each thermometer with a number on tape or tag.

Plotting the graph will take quite a long time; if your students are not proficient in drawing graphs, you can make this a home assignment.

The students may need help in choosing a range for the temperature scale. The scale need not have zero at the origin.

To summarize the results effectively, list on the chalkboard mass of material used and the plateau temperatures found by your students. Make a histogram of the plateau temperatures.

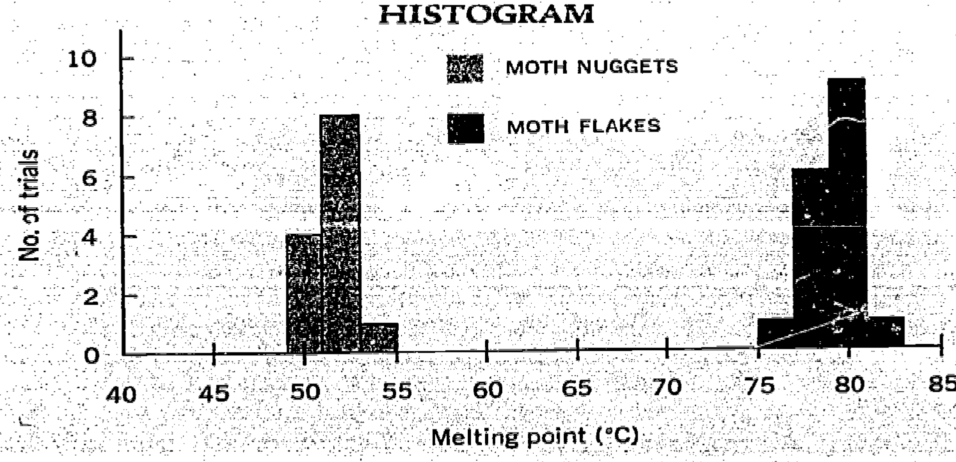
Answers to Questions

All graphs have flat sections.

All the flat sections of the graphs occur at two temperatures. These do not depend on the amount used.

The fact that all graphs show a temperature close to either 80° C or 53° C for the flat section indicates that two different substances were investigated although other properties such as color and smell were the same. Since the readings of two thermometers may differ slightly from each other, there will be some difference in the recorded melting points for each substance. The histogram will make it clear that thermometer differences are small compared with the differences in the melting points of the two substances.

HISTOGRAM



Apparatus and Materials

- Pegboard
- 2 Burners
- Burner stand
- Test tube (20 x 150 mm)
- 2 Clamps
- 2 Slit cork stoppers
- Beaker (250 cm^3)
- 2 Thermometers
- 10 g moth flakes (naphthalene) *or* 10 g moth nuggets (paradichlorobenzene) small enough to fit in test tube
- Matches
- Water
- Paper towel
- Stirring rod

Student Activity

Experiment: Freezing and Melting

If you live in a part of the country where it snows in the winter, you know that a big pile of snow takes longer to melt than a small one. Does this mean that the big pile melts at a higher temperature? To see whether the temperature at which a sample of a substance melts or freezes is really a characteristic property of the substance, we shall measure the freezing temperatures of some substances, using samples of different mass. For convenience we shall use substances that freeze above room temperature.

Fill a test tube one-third to one-half full of moth flakes or nuggets, and immerse it in a water bath. Heat the water until the solid in the test tube is completely melted. Insert a thermometer into the liquid. Make sure that no solid remains in the test tube before removing the burner. For comparison it may be interesting also to measure the temperature of the water with a second thermometer. While the liquid cools, measure and record both temperatures every half minute. Stirring the water will ensure that the temperature will be the same throughout the water when you read it.

Record the temperature of the molten substance when it begins to solidify, and continue to take data for about 5 min. after it has all solidified. On the same graph plot the temperatures as a function of time, and compare your graph with those of your classmates. Do all the graphs have a flat section? Does the temperature of the flat section depend upon the mass of cooling material? Do you think that all the samples used in the class were of the same material?

In this experiment you identified the freezing point of a substance by the plateau in the cooling curve. With some substances, the plateau is more easily recognizable than with others. Some cooling curves, however, may not have a flat section at all.

The fact that no part of the curve is flat means that candle wax has no freezing point; that is, there is no temperature at which it changes from liquid to hard solid without continuing to cool down during the process. Similarly, as you warm a piece of candle wax in your hand, it becomes softer and softer, but there into temperature at which it changes from hard solid to liquid without continuing to warm.

It is harder to measure the melting point of a substance than to measure the freezing point; since we cannot stir a solid, it is necessary to heat it very slowly and evenly. If, however, we do very careful experiments to measure the melting point of a solid by heating it until it melts, we find that we get a curve with the flat portion at exactly the freezing temperature. A solid melts at the same temperature as its liquid freezes.

The above material came from **Introductory Physical Science**, pp. 43-45 and Teacher's Guide pp. 65-69. Reprinted by permission of the Education Development Center, Physical Science Group.

INVESTIGATING CHANGE

Model Lesson — Junior and Senior High School (Earth Science)

EARTH SCIENCE CURRICULUM PROJECT

This investigation enables the student to recognize and to investigate the variety of changes a single substance can undergo and to relate some of the processes producing these changes to natural earth changes.

SEQUENCE OF ACTIVITIES

Pre-lab 5-10 minutes

Discuss homework assignment and hand out halite samples.

Lab

Student takes sample home and changes it in at least three ways.

Post-lab 15-20 minutes

Student reports on changes he produced in the sample and relates these changes to the natural environment.

PREPARATION

Time One-half period

Student grouping Individual

Materials per group

Piece of halite (rock salt), larger than 1 cm^3 if possible

Advance preparation: Prepare the halite so that it can be distributed to the students quickly and with a minimum of trouble.

Pitfalls and Cautions

1. Do not tell the student what the material is; let him discover for himself.
2. Do not pass out the halite samples until the end of the class period.
3. Caution the student to practice common safety procedures when he changes his earth material.

PROCEDURE

Pre-lab During the last five or ten minutes of class, initiate a discussion of change by asking the student if he has done anything that day to change his environment. This will lead into a discussion of changes occuring in the student's surroundings. An example of such change is breathing, which increases the carbon dioxide content and temperature of the air near the student's mouth. Another example is washing one's hands, which removes dirt that will eventually be deposited somewhere else on the earth.

Before distributing the halite, tell the student that he is to try to change this *earth material* in as many (at least three) ways as he can devise. Leave the methods of change completely up to him. The student will probably ask for suggestions on how to change the sample. *Do not give him any specific answer,* but encourage him to be imaginative in the ways he attempts to alter the material.

Ask the student to submit a report at the beginning of the next class period on his treatment of the material and on his results. You can ask that this report be either oral or written.

Hints on procedure Leave the procedure entirely up to the student.

Range of results Treatments will cover a relatively wide range and may include dissolving in water, freezing, heating, crushing, or treating with various liquids (at various temperatures), including lubricating oil, alcohol, and soft drinks. Some students may even taste their sample. They will change the surface texture slightly by holding it in their fingers or breathing on it. Some students may want to use a microscope or hand lens to examine the material before and after attempting to change it in order to detect changes not noticeable to the unaided eye.

ANALYSIS

Treatment of data Each student will submit a report for class discussion.

Post-lab At the beginning of the class, ask the student to report on his efforts. Use the board to record methods and results. Keep a tally to find the most common changes made. Attempt to relate changes made in the halite to actual changes that occur above, on, and within the earth. For example, if a student placed the sample under running water, the edges became rounded. Ask if there are situations in nature that produce similar changes in earth materials. Making the student aware that many of the changes he produced also occur naturally on the earth is an important objective of this investigation.

Recognition of change is a vital aspect of earth science. Have the student develop criteria for recognizing that change occurs. In trying to change the halite he should have observed what occurred and tried to determine what changes were produced. Recognizing evidence of change requires observing differences in the material before and after the change. The student should be able to describe what aspect of the material is different after the treatment. This part of the investigation can be related to Investigation P-1, which tested the student's powers of observation.

Evaluation suggestions A criterion for evaluation is the degree of ingenuity, thought, and effort that went into changing the halite. Some students may perform a large variety of rather routine treatments. Those whose efforts were fewer but more unusual should be given equal or greater credit.

Other skills to look for are the ability to sight evidence of change and to relate the changes in this investigation to natural earth processes.

SUBSEQUENT ACTIVITIES

Some students may want to try changing other substances. Give them samples of other earth materials, such as a piece of granite, some soil, a vial of water, or a piece of quartz or barite. Once again, let the student devise his own methods of inducing change, but warn him to use caution and safety measures. This extension of the investigation can provide a basis for discussing the relative resistance to different kinds of change in certain earth materials.

VARIATION IN LIVING THINGS

Model Lesson — High School (Biology)

BIOLOGICAL SCIENCE CURRICULUM STUDY

The main purpose of this exercise is to have students become familiar with and understand the normal range of variation in organisms. Students should also appreciate the fact that some variations have obvious survival value while others have no apparent survival value. Last, students should gain further experience in collecting data in an organized manner, in making graphs, and in interpreting data.

If the specimens suggested for the exercise are not readily available, other specimens may be substituted. Beans may be used instead of peas, for example.

After completion of Investigations 1 and 3 graphing should present little difficulty. It may be helpful, however, to prepare a new graph — a histogram — from the height data of Investigation 1 and to compare the configuration of this graph with the shape of the normal curve of variation. Discussion:

1. The largest.
2. Weight or volume.
3. The larger the seed, the greater the food reserve for the embryo in case of a diverse conditions.
4. If graphed, both variations would probably conform to the bell-shaped curve of "normal" variation.
5. The average for girls and boys may be almost identical or quite different, depending on age. Population statistics show 13-14-year olds of both sexes to be about the same height. On the other hand 17 or 18-year-old males are 5-10% taller than females of the same age. (Your classes are likely to be in the period of rapid change, so it is impossible to predict how large the differences will be.)
6. The computation of separate averages for girls and for boys will be especially helpful in the interpretation of bimodal or flat-topped curves. The averages should indicate whether the shape of the curve is due to the mixture of two populations.
7. (This can be a very interesting discussion question. If the species are similar there will undoubtedly be some overlapping of measurements. If the species are truly different, there must be some quantitative way of telling them apart. If no such quantitative separation can be found, it might be an indication that the two groups are not really separate species.)
8. A large sample. More work is involved in obtaining such a sample, particularly in insuring that the sample is truly random.

Student Activity

Variation in Living Things

Background:

No two humans are exactly alike. Even identical twins can usually be told apart by parents and close relatives. Yet, if a Martian were to suddenly appear in your classroom, he would undoubtedly wonder how your teacher can distinguish one pupil from another. And you might be faced with the same difficulty as the Martian if you were asked to distinguish between individuals in a large group of robins, cocker spaniels, or p. apods.

The differences by which similar organisms are distinguished are known as variations. It is possible to describe these differences in pictures, words, or measurements; probably the most significant description is made in terms of measurements. An appreciation of the range of variation in organisms will add to your understanding of evolution.

Materials:

Peas in pods	Graph paper	Millimeter rule
Grasshoppers	Petri dish halves	

Procedure:

Open each pod carefully; observe the size and position of the peas in the pod. Remove the peas and place them in a petri dish. Your teacher will show you how to divide the pea in half. Place the flat surface of a half pea on the ruler and measure the longest dimension to the nearest millimeter. Place the used peas in a second petri dish. Keep your area clean. Summarize your data by recording on a chart or table the number of peas of each length. Combine your results with those of your classmates.

Prepare a bar graph plotting length in millimeters on the horizontal axis and number of peas of each length on the vertical axis. Starting with the bar on the left, draw a line connecting the top of each bar with the top of the next bar.

Calculate the average length (to the nearest 0.1 mm) of the peas. (Remember that an average is obtained by dividing the sum of all the measurements by the total number of measurements.) Find the position of the average value along the horizontal axis of your graph. Then draw a vertical line to indicate the position of the average length.

Re-examine the graph you prepared in Investigation I to show the heights of the class members. Calculate the average height and indicate its position on the graph. If yours is a mixed class, calculate the average height of girls and the average height of boys and draw lines to indicate these averages. You will be provided with several grasshoppers of the same species and of similar size. There may be variations in color, or some individuals may have parts missing. There also will be differences in the total length, the weight, or the length of parts like legs or wings. Try to devise a quantitative method of telling each grasshopper from all the rest. Make sketches to show the kind of measurements you used.

Discussion:

1. The two large halves of a pea seed, except for the seed cover, are modified leaves containing a large amount of stored food which will be used by the young plant as it grows. Which of the peas that you measured would contain the most stored food?

2. What kind of measurement other than length would give you a better answer to Question 1?
3. In what way is large seed size advantageous in the survival of peas?
4. How does the variation in the lengths of peas compare with the variation in the heights of people?
5. Are the separate height averages for girls and boys the same as the average for the class as a whole?
6. Does the computation of these averages help you to understand your graph of heights? Explain.
7. Do you think it would be possible to devise a system based on measurement to separate closely related species of animals? Explain.
8. Your own measurement of a few peas represent a small sample of all the possible measurements; the combined results of the whole class make up a larger sample. Which is preferable, a small sample or a large sample, for describing natural variation? What difficulties would be involved in a sample of this size?

The above material came from **Biological Science — Molecules to Man**, pp. L17-L18 and Teacher's Guide pp. 197-198. Reprinted by permission of Houghton Mifflin Co., 1963.

MASS RELATIONSHIPS ACCOMPANYING CHEMICAL CHANGE

Model Lesson — High School (Chemistry)

CHEMICAL EDUCATION MATERIAL STUDY

EXPERIMENT 8—MASS RELATIONSHIPS ACCOMPANYING CHEMICAL CHANGES

PURPOSE. To allow the student to "discover" the law of conservation of mass; to further the establishment of molar relations in order that this may later serve as a basis for balancing equations; and to develop some common laboratory techniques.

PRELAB DISCUSSION. Students will move directly into this from Expt. 7, which requires little discussion. As yet, they do not know the terms "reaction" and "equation," but these occur early in Chapter 3. Emphasize the need to learn the laboratory techniques presented, and avoid discussion of what is "expected" as experimental results. Discuss the dark color of silver from Expt. 7, and tell students that this will not affect their results.

TIMING. Start this experiment as soon as Expt. 7 is finished. Immediately add 6 M HNO_3 to the silver obtained in Expt. 7 in order that the slow reaction can occur overnight. Heating to speed the reaction is not recommended. Both the hot HNO_3 and the fumes from it are dangerous. While the experiment is in progress, the first assignment in Chapter 3 may be made, but as much as possible of the experiment should precede the reading. Do not assign Sec. 3-1.3 before this experiment.

EQUIPMENT NEEDED (PER STUDENT OR PAIR)

250 ml beaker (from Expt. 7)
100 ml beaker (or another 250 ml

burner, ring stand, ring, wire gauze

beaker may be used)
stirring rod
wash bottle
filter paper
funnel and support
graduate (10 to 25 ml)
arrangement for drying (see lab hint 1)
10 ml 6M nitric acid (384 ml conc. reagent HNO_3/liter)
2-2.5 g sodium chloride (solid) (see lab hint 6)

TIME REQUIRED. This should take 1½ periods.
First day (at end of Expt. 7): 10:15 minutes, Part I. (Add 6 M HNO_3, and set aside to react and evaporate.)
Second day: full period; Part II (a-1).
Third day: final weighing; 15-20 minutes.

PRECAUTIONS. See the precaution about silver nitrate, indicated in Expt. 7. Use care with 6 m acid; flood spills or spatters with water. Avoid inhaling fumes in I(b). Use special precautions if sand baths are used.

LABORATORY HINTS

1. The product in Part I *must not* be dried in an oven, since the fumes will cause severe corrosion. Two or three infrared lamps in the fume hood make the most satisfactory arrangement. In some climates, overnight evaporation near an open window is sufficient. If necessary, sand baths may be used, but the room must have forced ventilation. The product in Part II may be dried in an oven. A sand bath is not recommended for this drying step, because AgCl will spatter violently if dried too rapidly. If no other means is available, tell the students to minimize spattering by putting a watch glass over the beaker and by removing the beaker frequently to break up the AgCl clumps with a stirring rod. Sometimes excessive heating gives a dark product which does not interfere with the quantitative results.
2. In I(b) there may be a slight blue color, indicating that some copper remained mixed with the silver from Expt. 7. It will not precipitate in II(f), thus it will introduce a slight error in the final calculations, but the error will probably be less than other errors, and not enough to be noticeable.
3. In II(g) heating the mixture is very important in coagulation of the precipitate. On the other hand, students must be cautioned to heat the mixture gently to avoid bumping.

   Make a remark about the darkening of the AgCl on exposure to light. Point out that although the change is quite visible, no weight change will be measurable with the balances used.
4. If the AgCl melts (m.p. 455°C)—it will do so only if the sand bath is used—the resulting "cake" will tend to stick to the beakers. It may be remelted and poured into a "collection" beaker provided. (See next lab hint.) That which remains may be dissolved by leaving a concentrated solution of photographer's hypo (sodium thiosulfate) in the beaker for two or three days.
5. Collection of AgCl: The AgCl resulting from this preparation is often pure enough to dissolve in sodium thiosulfate for use in Expt. 25. It may also be saved for Expt. 2 (melting) for next year. If there

is doubt about its purity, washing with warm water will remove traces of $Na+$ and NO_3-. It is questionable whether many teachers will want to bother with reclaiming silver nitrate, but for the sake of those who do, the following procedure is included. It is a modification of a system used by the University of California stockroom, and is presented as a "recipe" with no attempt at explanation. If silver wastes from other sources are included, the AgCl should be allowed to stand overnight in 6 M NaOH or KOH and then be filtered and washed.

Suspend (or resuspend) the AgCl in 6 M NaOH (for 100 grams of Ag, use about 500 ml of NaOH), and boil it for ½ hour, during which time add sucrose (about 250 grams or 1 cup for 100 grams of Ag) in small amounts at frequent intervals. Stirring is not necessary, only occasional swirling. At first there is considerable frothing, and then the solution becomes dark brown. Finally a heavy, gray precipitate forms.

Filter and wash this precipitate, and dissolve it in as little nitric acid as possible. For about 100 grams of Ag, use 60-70 ml of concentrated (15-16 M) HNO_3. Filter and pour the filtrate into 2 M MaOH to precipitate brown Ag_2O. (For 100 grams of Ag, use about 500 ml of 2 M NaOH).

Filter, wash, dry, and store the Ag_2O. It can be dissolved in HNO_3 when $AgNO_3$ solution is needed.

6. It is hoped that by this time the student will have gained sufficient facility to weight a specified amount of solid easily. Some discussion of this may be necessary, especially on why one pours out an approximate quantity from the stock bottle. It is wise to have a container with the correct approximation fastened to or near the stock bottle. Smooth paper should be available and the reason given for using a smooth surface paper rather than a piece of paper towel or filter paper.

POSTLAB DISCUSSION. Collect data from all students in order that the sum of the weights of the $AgNO_3$ and NaCl may be compared to the sum of the weights of the AgCl and $NaNO_3$ with excess NaCl (called "residue" in beaker #2). This comparison (answer to question 2) is the basis for Sec. 3-1.3, which should be assigned after the experiment. Prepare a class graph to show the comparison in order that all may see the central tendency. Since some students' results will not be good, this will insure that everyone understands the experiment.

For review, discuss the molar relationship of the silver compounds measure in Expts. 7 and 8. Make sure the student knows why the moles of $AgNO_3$, Ag, $AgNO_3$ (made in Expt. 8), and AgCl are the same. Later in the chapter, have the student work Exercises 9 and 10 to bring out the equation for this reaction and to calculate the moles of NaCl actually used.

SAMPLE DATA

Weight of:	silver from Expt. 7	2.56 ± 0.02 g
	$AgNO_3$ used in Expt. 7	4.05 ± 0.02 g
	beaker #1	72.60 ± 0.01 g
	beaker #1 and solid $AgNO_3$	76.67 ± 0.01 g

beaker #1, filter paper, and solid AgCl	76.55 ± 0.01 g
beaker #2	51.48 ± 0.01 g
beaker #2 and NaCl	53.74 ± 0.01 g
piece of filter paper	0.56 ± 0.01 g
beaker #2 and solid residue	54.38 ± 0.01 g

CALCULATIONS

	Weight (g)	Number of moles
Ag (from Expt. 7)	2.56 ± 0.02	2.37×10^{-2}
$AgNO_3$ (used in Expt. 7)	4.05 ± 0.02	—
$AgNO_3$ (produced in Expt. 8)	4.07 ± 0.02	2.39×10^{-2}
NaCl (added)	2.26 ± 0.02	3.86×10^{-2}
AgCl (in beaker #1)	3.39 ± 0.02	2.35×10^{-2}
Residue (in beaker #2)	2.90 ± 0.02	—

ANSWERS TO QUESTIONS

1. How does the weight of $AgNO_3$ produced in this experiment compare to the weight used in Expt. 7? How do you account for any similarity or difference?

   Answer: These should agree quite well unless Ag was lost in Expt. 7, and in such a case, the ratio of Ag to Cu would give a clue. Since this is early in the course, errors in weighing technique are often discovered at this time.

2. Compare the sum of the weights of the $AgNO_3$ and NaCl used with the sum of the weights of the AgCl and the residue in beaker #2. Your conclusions will be more meaningful if they are based on class data compiled by your teacher. What is the significance of these results?

   Answer: See the postlab discussion. This is the most important part of this experiment. Make sure all students understand that these weights are equal for this and all other reactions.

3. Compare your results for the number of moles of silver used, of silver nitrate produced in Part I, and of silver chloride produced in Part II by computing the ratio between the moles of silver and each of the other substances, $AgNO_3$ and AgCl. Use the nearest whole number to express your result. What can you conclude about the number of moles involved in this series of chemical changes?

   Answer: Expressed to the nearest whole number, the ratios will certainly be 1/1. This should bring up a discussion as to why the Ag/NaCl mole ratio is not also 1/1, but discussion of this should be delayed until after Sec. 3-2.3 has been assigned in order that the student may calculate the weight of NaCl that would actually react.

4. Pure silver nitrate is a white solid. How do you account for any color which may be present in your sample or in the samples prepared by other students?

   Answer: Some students will observe a blue color. Recalling that the color of the "discarded" solution in Expt. 7, was blue they will probably suggest the presence of some copper compound as an impurity.

ADDITIONAL INVESTIGATION—*to be undertaken as an extracurricular experiment. Consult your teacher before proceeding.*

Devise an experiment to determine the composition of the residue in beaker #2. Study Exercises 3-9 and 3-10 as a preliminary step to this investigation.

The student may see two kinds of crystals and guess that two substances are present. He may think to add $AgNO_3$ solution to see if there is more chloride. The most valuable extension is to collect qualitative data to show that the NaCl which reacts (in the main experiment) is related to the $AgNO_3$ in the simple 1/1 mole ratio.

STUDENT ACTIVITY

In this experiment you will use the silver you produced in Experiment 7 to form a water solution of silver nitrate, $AgNO_3$, by allowing the silver to react with nitric acid, HNO_3. You will next prepare a water solution of sodium chloride, NaCl, add it to the silver nitrate solution and weigh the products formed.

You will review and learn many techniques: careful weighing, decanting, filtering, washing, and drying. Carry them out well, for it will be assumed in future work that you are able to use these techniques.

Record your data carefully and neatly. Take special care to show the units used in your measurements. Include the uncertainty in each measurement. Before you come to the lab to do an experiment, you should have planned what you are to do. This preparation will free your mind from mechanical details and allow you to concentrate on making the required observations in the allotted time.

PROCEDURE

PART I. PREPARATION OF SOLID SILVER NITRATE FROM METALLIC SILVER

a. Refer back to Experiment 7 and record the weight of the beaker used (label this #1), the weight of the silver nitrate used, and the weight of the silver produced.

b. To the beaker containing the silver, add 10 ml. of nitric acid, labeled 6 M* HNO_3. Avoid inhaling any of the poisonous reddish-brown fumes of nitrogen dioxide, NO_2, which form as the silver dissolves. Identify your beaker with your name or locker number and leave it in the fume hood or near an open window overnight to be evaporated to dryness.

c. When it is dry, weigh the beaker which now contains $AgNO_3$. Remember the caution given in Experiment 7 concerning the handling of silver nitrate.

PART II. THE EFFECT OF ADDING A SOLUTION OF SODIUM CHLORIDE TO A SOLUTION OF SILVER NITRATE.

a. Add about 15 ml. of distilled water to the $AgNO_3$ in beaker #1. Stir until no more change takes place.

* The term 6 M refers to the concentration of the solution, which is defined in Chapter 5 of the Textbook. This solution is moderately concentrated to be sure to w[illegible] it off your skin or clothes if it is spilled and off the graduate before you put it away.

b. Remove from the stock bottle about 2-2½ grams (approximately ½ teaspoonful) of sodium chloride, NaCl.
Gently rotate the bottle back and forth to pour out the approximate amount needed on a piece of clean paper.

c. Label a clean, dry 100 ml beaker as #2 and weigh it to the nearest 0.01 g.

d. Adjust your balance so it reads somewhere between 2 and 2.5 grams greater than the weight of beaker #2, and add carefully enough table salt, NaCl, from the paper to make the balance pan drop. Discard any salt remaining on the paper, then determine the weight of the NaCl and beaker to the nearest 0.01 g.

e. Add about 15 ml of distilled water to the solid NaCl. Stir until no more change takes place.

f. While briskly stirring the $AgNO_3$ solution in beaker #1, slowly add the NaCl solution. Note the result. The white solid produced is the compound silver chloride, AgCl. Rinse the empty beaker, #2, with about 5 ml of distilled water from the wash bottle by directing the water around the inside of the beaker. Add the rinse water to the mixture in beaker #1. Rinse beaker #2 again with distilled water and this time discard the rinse water. The clean beaker will be used again in step 1.

g. Heat the resulting precipitate (the solid which settles out) and the solution to boiling for about 2 minutes or until the solution becomes reasonably clear as the precipitate settles. Place a stirring rod in the beaker to help prevent unsteady boiling. (bumping).

h. Fit filter paper into a funnel and moisten the paper with some distilled water from a wash bottle. Set up the funnel for filtering.

i. Place beaker #2 under the funnel. The tip of the funnel should touch the beaker so a steady stream can run down the side. Decant the clear *liquid* from beaker #1 into the funnel, pouring it into the funnel along a glass rod. A small amount of the precipitate may transfer to the filter paper, but try to keep most of it in the beaker where it can be washed more readily.

j. Wash the precipitate in the beaker with about 15 ml of distilled water, stirring with a glass rod to aid the washing. Decant the wash water into the funnel. Repeat the washing procedure with another 15 ml of water. Decant the wash water again into the funnel.

k. After the filtration is complete, place the filter paper and any solid it contains in beaker #1 containing the precipitate.

l. Place both samples, the filtrate (the solution passing through the filter) in beaker #2 and the wet precipitate in beaker #1, in the place designated by your teacher for evaporation and drying overnight. Be sure each beaker is numbered and has your name or locker number on it.

m. Weigh both dry samples and record the weights. Save the silver chloride
Your data table should include the following:
as directed by your teacher.

Weight of silver from Experiment 7
Weight of silver nitrate used in Experment 7
Weight of beaker #1

Weight of beaker #1 and solid $AgNO_3$
Weight of beaker #1, filter paper, and solid AgCl
Weight of beaker #2
Weight of beaker #2 and solid NaCl
Weight of a piece of filter paper
Weight of beaker #2 and solid residue

CALCULATIONS AND RESULTS

	Weight in grams	Number of moles
Ag (from Experiment 7)	2.56	2.37×10^{-3}
$AgNO_3$ (used in Experiment 7)	4.05	No entry
$AgNO_3$ (produced in Experiment 8)	—	—
NaCl (added)	—	—
AgCl (in beaker #1) (Remember to subtract weight of filter paper)	—	—
Residue (in beaker #2)	—	no entry

QUESTIONS AND EXERCISES

1. How does the weight of $AgNO_3$ produced in this experiment compare with the weight used in Experiment 7? How do you account for any similarity or difference?
2. Compare the sum of the weights of the $AgNO_3$ and NaCl used with the sum of the weights of the AgCl and the residue in beaker #2. Your conclusions will be more meaningful if they are based on class data compiled by your teacher. What is the significance of these results?
3. Compare your results for the number of moles of silver used, of silver nitrate produced in Part I, and of silver chloride produced in Part II by computing the ratio between the moles of silver and each of the other substances, $AgNO_3$ and AgCl. Use the nearest whole number to express your result. What can you conclude about the number of moles involved in this series of chemical changes?
4. Pure silver nitrate is a white solid. How do you account for any color which may be present in your sample or in the samples prepared by other students?

Additional Investigations—to be undertaken as an extracurricular experiment. Consult your teacher before proceeding.

Devise an experiment to determine the composition of the residue in beaker #2. Study Exercises 3-9 and 3-10 in Chapter 3 of the Textbook.

The above mentioned material came from: CHEMISTRY, AN EXPERIMENTAL SCIENCE, Laboratory Manual", produced by CHEM Study, published in 1963, G. C. Pimental, Editor. Pages 22-25 "Mass Relationships Accompanying Chemical Change". Reprinted by permission of The Regents of the University of California.

"CHEMISTRY, AN EXPERIMENTAL SCIENCE, Teacher's Guide," a teachers' guide to accompany I and II, published in 1963 (hereinafter, called "III"), pages 105-106. Reprinted by permission of The Regents of the University of California.

ACCELERATED MOTION
Model Lesson — High School (Physics)
HARVARD PROJECT PHYSICS

The Harvard Project Physics uses the history of science as a basis to introduce the student to physics ideas and concepts through the processes of science. The experiments in this guide are an example of Galileo's ideas concerning accelerated motion, and Experiment 6 places this in a contemporary setting.

The teacher should provide for student investigation and discussion. The teacher will note that at the end of the experiment questions are provided for discussion. These questions are "open-ended" and may also provide a source for the identification of new problems to be investigated. This experiment is related to chapter two in the *Project Physics* Text.

In chapter 2 you have been reading about Galileo's interest in accelerated motion. Scientists are still interested in accelerated motion today. In the following experiments you will try to find, as Galileo did, whether d/t^2 is a constant for motion down an inclined plane.

The remaining experiments are measurements of the value of the acceleration of gravity, a_g — the value that $2d/t^2$ would approach as an inclined plane is made more and more nearly vertical. Perhaps you would like to try one of them.

EXPERIMENT 5 *A Seventeenth-Century Experiment*

This experiment is similar to the one discussed in the Two New Sciences by Galileo. It will give you first-hand experience in working with tools similar to those of a seventeenth-century scientist. You will make quantitative measurements of the motion of a ball rolling down an incline, as described by Galileo. From these measurements you should arrive at a suitable definition of acceleration — the major purpose of the exercise. It is also possible to calculate the value of a_g (acceleration due to gravity), which you should try to do.

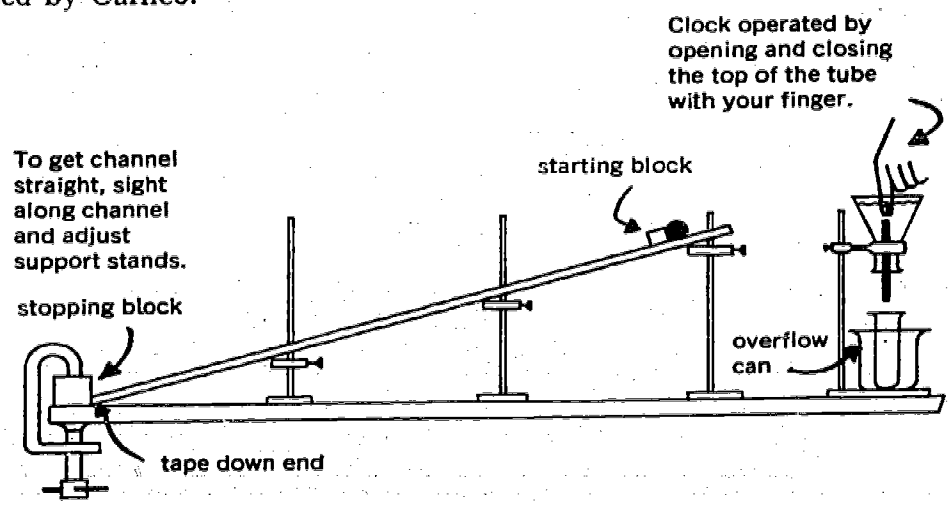
The Reasoning behind the Experiment

You have read in Sec. 2.6 how Galileo discussed his belief that the speed of free-falling objects increases in proportion to the time of fall — that is, that they have uniform acceleration. But since free fall was much too rapid to measure, he assumed that the speed of a ball rolling down an incline increases in the same way as an object in free fall does, only more slowly. Its average speed could now be measured.

But to see if the accelerations of the ball were the same from point to point required a knowlede not of *average* speed but of instantaneous speed at each point, and even a ball rolling down a low incline still moved too fast to measure the speed *at a point* at all accurately. So he worked out the relationship $\frac{a}{2} = \frac{d}{t^2}$, an expression for acceleration in which speed has been replaced by the total time and total distance rolled by the ball. Both these quantities can be measured. Be sure to study Sec. 2.7 in which this derivation is described. If Galileo's original assumptions were true, this relationship would hold for both freely falling objects and rolling balls. Since total distance and total time are not difficult to measure, seventeenth-century scientists now had a secondary hypothesis they could test by experiment. And so have you. Section 2.8 of the text discusses much of this.

Apparatus

The apparatus which you will use is shown. It is similar to that discussed by Galileo.



You will let a ball roll various distances down a channel about six feet long and time the motion with a water clock.

Some early water clocks are illustrated on page 56 of your text book. The way yours works is very simple.

Since the volume of water flowing into the cylinder is proportional to the time of flow you can measure time in millimeters of water. Start and stop the flow with your finger over the upper end of the tube inside the funnel. Be sure to refill the "clock" to about the same point for each trial, for its rate of flow changes slightly with the level of the water. Whenever you refill it let a little water run through the tube to clear out the bubbles.

It is impossible to release the ball with your fingers without giving it a slight push or a pull. Dam it up, therefore, with a ruler, and release it by quickly moving the ruler away from it down the plane. The end of the run is best marked by the sound of the ball hitting the stopping block.

A brief comment on recording data

We should emphasize the need for neat, orderly work. Orderly work looks better and is more pleasing to you and everyone else. It may also save you from extra work and confusion. If you have an organized table of data, you can easily record and find your data. This will leave you free to think about your experiment or calculations rather than worry about which of two numbers on a scrap of paper is the one you want, or whether you made a certain measurement or not. A few minutes' preparation before you start work will often save you an hour or two of chasing around checking in books and with friends to see if you did things right.

Some operating suggestions

You should measure times of descent for several different distances, keeping the inclination of the plane constant and using the same ball. Repeat each descent four times, and average your results. Best results are found for very small angles of inclination (the high end of the channel raised less than about 30 cm). At greater inclinations the ball tends to slide as well as to roll. With these data you can check the constancy of d/t^2.

Then if you have time, go on to see if Galileo or Aristotle was right about the acceleration of objects of various sizes. Measure d/t^2 for several different sizes of balls, all rolling the same distance down a plane of the same inclination.

If you try to find the acceleration of an object in free fall, a_g, you should measure the time a ball takes to descend the full length of the plane at various carefully measured angles. Use angles up to the steepest for which you can measure the times of descent. From these data you can extrapolate to free fall (90°). You might want to use a stopwatch here instead of a water clock.

From data to calculations

Galileo's definition of uniform acceleration (text, page 49) was "equal increases in speed in equal times." Galileo expected that if an object actually moved in this way the total distance of travel should be directly proportional to the square of the total times of fall.

Q1 Why does this follow from his definition? (See Sec. 2.7 in the text if you cannot answer this.)

When you have collected enough data, plot a graph of the distances rolled (vertical axis) against the squared times for each inclination.

Q2 What must your graph look like if it is to support Galileo's hypothesis?

Q3 Does your graph support the hypothesis?

You have been using a water clock to time this experiment because that was the best timing device available in Galileo's time. How accurate is it? Check it against a stopwatch or, better yet, repeat several trials of your experiment using a stopwatch for timing.

Q4 How many seconds is one milliliter of time?

EXTENSION

Review Sec. 2.7 There you learned that $a = 2d/t^2$.

Use this relation to calculate the actual acceleration of the ball in one of your runs.

If you have time you might also try to calculate a_g from your results. This is a real challenge. Your teacher may need to give you some help on this.

ADDITIONAL QUESTIONS

Q5 Does the acceleration depend upon the size of the ball? In what way does your answer refute or support Aristotle's ideas on falling bodies?

Q6 Galileo claimed his results were accurate to 1/10 of a pulse beat. Do you believe his results were that good? Did you do that well?

Q7 Galileo argues that in free fall, an object tends to accelerate for as long as it falls. Does this mean that the speed of an object in free fall would keep increasing to infinity?

EXPERIMENT 6 *A Twentieth-Century Version of Galileo's Experiment*

In Sec. 2.9 of the text you read about some of the limitations of Galileo's experiment.

In the modern version with improved clocks and planes you can get more precise results, but remember that the idea behind the improved experiment is still Galileo's idea. More precise measurements do not always lead to more significant conclusions.

The apparatus and its use

For an inclined plane use the air track. For timing the air track glider use a stopwatch instead of the water clock.

Otherwise the procedure is the same as that used in the first version above. As you go to higher inclinations you should stop the glider by hand before it hits the stopping block and is damaged.

Instead of a stopwatch your teacher may have you use the Polaroid camera to make a strobe photo of the glider as it descends. A piece of white tape on the glider will show up well in the photograph. Or you can attach a small light source to the glider. You can use a magnifier with a scale attached to measure the glider's motion recorded on the . hotograph. Here the values of d will be millimeter on the photograph and t will be measured in an arbitrary unit, the "blink" of the stroboscope.

Plot your data as before on a graph of t^2 vs. d.

Compare your plotted lines with graphs of the preceding cruder seventeenth-century experiment, if they are available. Explain the differences between them.

Q1 Is d/t^2 constant for an air-track glider?

Q2 What is the significance of your answer to the above question?

As a further challenge you should, if time permits, predict the value of a*q*, which the glider approaches as the air track becomes vertical. To do this, of course, you must express d and t in familiar units such as meters or feet, and seconds. The accepted value of ag is 9.8 m/sec² or 32 ft/sec².

Q3 What is the percentage error in your measurement? That is, what percent is your error of the accepted value?

Percentage error =

$$\frac{\text{accepted value - measured value}}{\text{accepted value}} \times 100$$

so that if your value of ag is 30 ft/sec²

percentage error =

$$\frac{32\ \text{ft/sec}^2 - 30\ \text{ft/sec}^2}{32\ \text{ft/sec}^2} \times 100$$

$$= \frac{2}{32} \times 100 = 6\%.$$

Notice that you *cannot* carry this out to 6.25% because you only know the 2 in the fraction 2/32 to one digit. You cannot know the second digit in the answer (6%) until you know the digit following the 2. This would require a third digit in the measurements of 30 and 32.

Q4 What are some of the sources of your error?

The above material came from **An Introduction to Physics, Concepts in Motion**, Howard Project Physics, Holt, Rinehart and Winston, Inc., 1968-69, New York, pp. 21-25.

THE CASE HISTORY OF A LAKE
Model Lesson — Junior High School
EDUCATIONAL RESEARCH COUNCIL OF AMERICA

In Problem 33, the student is presented with a very brief history of Lake Erie. The problem considers some of the cultural and industrial developments that have occurred around the shores of Lake Erie, as well as some of the effects of this development. The student is asked to look over this information and make an evaluation of the severity of the problem that exists. Obviously, any in-depth or definitive answer is not possible, but the design of Problem 33 is to have the individual student face the immensity of the problem of trying to save just one lake in our total environment. It is not anticipated that even the cumulative efforts of the class will really arrive at a solution.

The teacher's role in developing student insight in the problem is a very sensitive one. On the one hand, it is essential that attention be focused upon the imminent disaster brought about by man's polluting his environment. On the other hand, it is equally essential that students are led to understand that man will, as long as he survives, continue to produce waste products which will eventually be deposited on the environment. The outcome, therefore, that seems most desirable is a conviction on the part of the students that man must control the quality of his wastes and be aware of the effects of each of his wastes on the environment. Another equally important dimension of the total problem is a realization that pollution problems are directly related to population density. No possible solution could have long-lasting effects with the prospects of an unlimited number of people on the earth.

GUIDELINES TO THE PROBLEM

Materials

No particular materials are needed to implement this problem. It is recommended, however, that you have students research newspapers, magazines, as well as consulting with their parents for materials on the subject of water pollution. Student-designed displays, either in the classroom or throughout the school, are most appropriate and certain to stimulate interest in the whole of Topic IV. On the other hand, if the teacher prepares a bulletin board, she generates, largely, teacher interest. Since pollution is of interest in almost all communities, student-initiated discussions and experiments could well be the basis for the organization of a community-centered discussion on pollution. At that time, local authorities on pollution could be invited to participate. Certainly, if the students could see that their concern and their interests were reflected in community action, this might be the stimulus that would set their attitudes permanently.

The background materials that follow, plus recommended reading, plus films, and the student materials on the problem are designed to provide a framework for teacher-class interaction. The background materials are not designed to be exhaustive or definitive, but rather to provide the teacher with a minimum background for leading the classroom activity.

All of us, adults as well as students, have been exposed to a mountain of evidence on pollution. Very little of this exposure has resulted in a genuine commitment to change what we see. It would seem that just knowing what is happening is not enough to promote an active concern. It is predictable that if the problems in Topic IV are covered as just another recital of the demise of our countryside, significant changes in student behavior will not occur.

In order to understand the ways in which man changes his fresh water environments, students must first understand something of the unchanged environment and what happens in it. Some of the biological generalities that were emphasized in Topic III are applicable in Topic IV. The idea of food chain, for example, is applicable to biological relationships in aquatic environments. In addition, some understanding of the physical and chemical characteristics of an aquatic environment is essential.

Because of the signifcant difference in their physical and biological characteristics, fresh water environments are considered to have two major categories:

1. Running-water environments.
2. Standing-water environments.

The former would include all forms of inland waters in which the entire body of water moves continuously in a definite direction, such as a brook, creek or a river. The latter category is described as one where the water motion is not that of a continuous flow in a definite direction. In lakes, swamps or ponds, water is considered to be standing, although a certain amount of water movement may occur, such as wave action, internal currents or movements near inlets or outlets.

Topic IV limits its consideration of fresh water to standing water. In fact, the consideration is even more narrow since it considers only one of the standing water series, the lake. However, it is hoped that if the students' interests in a particular area come to focus on a local environment that can be readily studied, the teacher would capitalize on this opportunity. The literature cited at the end of the *Instructional Guide* suggests a variety of references, some of which apply to research on running-water environments.

How does one tell a lake from a pond? Since in many cases, ponds evolve from lakes, it is apparent that many intergrades appear between the two kinds of communities. Thus, any definition must be an arbitrary one. For the purposes of this problem, we will define a lake as a reasonably large body of water where one may find rooted aquatic plants in the shallower waters around the shore, but where the water in the central lake basin is too deep to allow the growth of rooted aquatic plants.

Lake basins originate in many different ways, the principal ones being as follows:

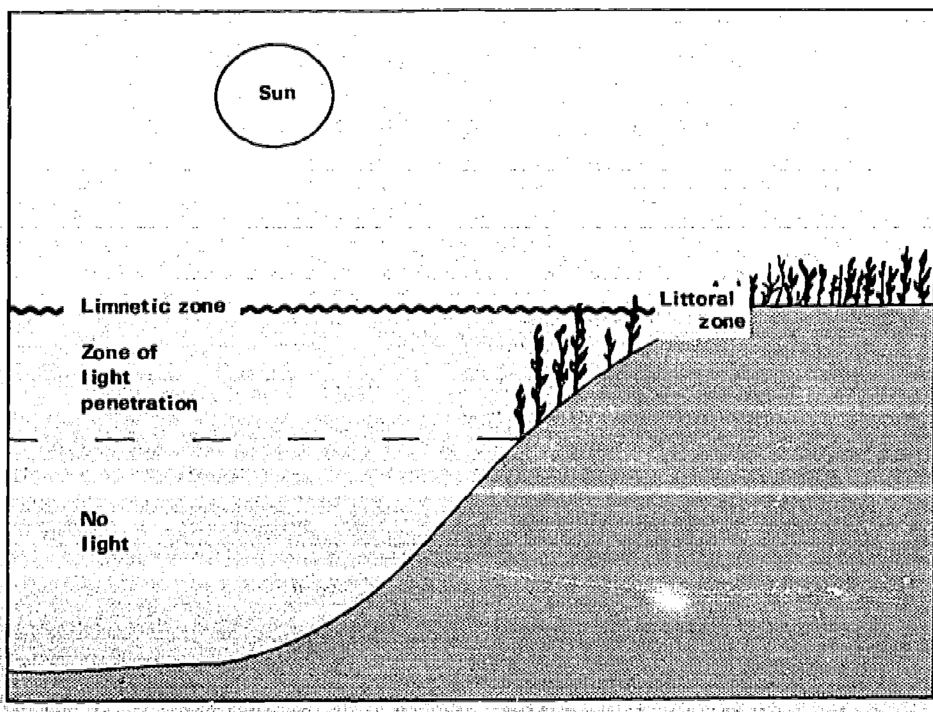
1. Glacial action. Glaciers can form basins
   a. by digging out basins
   b. by the deposits of moraines and other debris which form a closed basin
   c. by actual ice obstruction of the lower end of a mountain valley: and
   d. by the melting of the huge masses of ice imbedded in the glacial debris.
2. As a result of landslides which block valleys which then fill with water.

3. Craters of extinct volcanoes.
4. Various activities of rivers, such as change of channel which produces an oxbow lake, obstructions at the mouths of tributaries forming lakes above them and drift jams which obstruct streams.

Lake Erie, which is the focal point for Problem 33, along with the rest of the Great Lakes, is of glacial origin. As the last continental icecap retreated, ponds of melted water formed along its southern edge, damned by the ice front. These ponds grew larger with the disappearance of the ice, eventually spreading over a combined area larger than that of the present Great Lakes. As the glacial lakes grew and land levels changed, outlets formed in several directions. These outlets provided water routes for migrations of new organisms into the drainage system of the new lakes.

The chart Life Zones in a Lake, shows a convenient way of looking at the life zones in a lake. As you can see, that region of the lake which

LIFE ZONES IN A LAKE



extends from the shoreline outwardly to the limit of occupancy of rooted plants is described as a littoral zone. The development of a littoral area in a lake is limited by factors such as depth of water, the extent of vertical transmission of light for photosynthesis, wave action, the supply of nutrients and the texture of the bottom of the lake. It is in the littoral zone that one can find the largest numbers of kinds of organisms in the lake, because there is usually an abundance of protection, food and dissolved organic material.

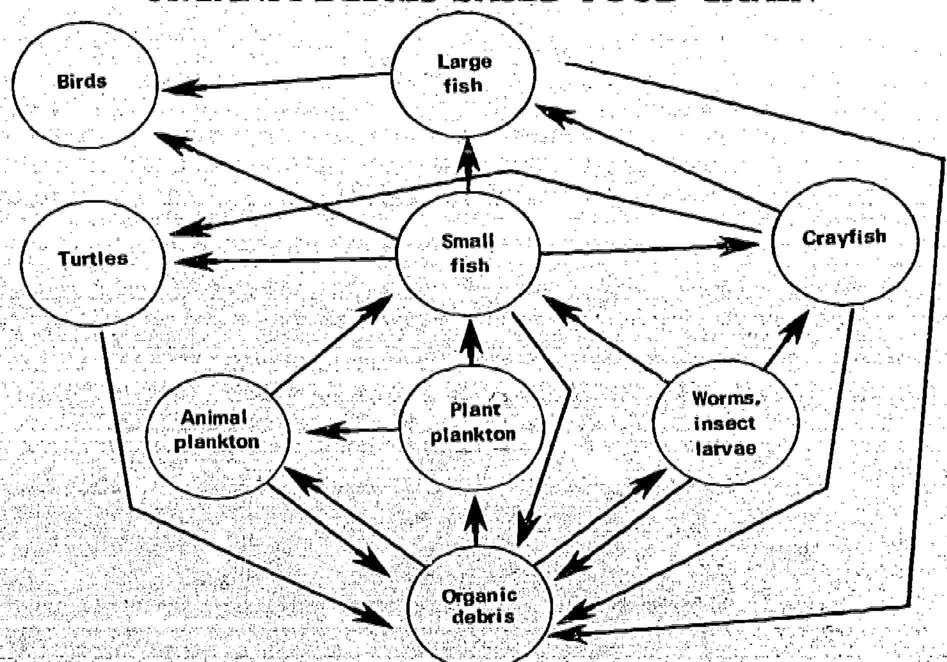
In addition to the variety of kinds of rooted plants, the water in the littoral zone is rich in numbers and kinds of floating microscopic organisms, *plankton*. This would include some of the sheltered waters in the littoral zone. Some of the more conspicuous inhabitants of the littoral zone are many kinds of fish, beetles, watersnakes, turtles, salamanders and frogs.

The region of open water in a lake between the zones of emergent plants is called the limnetic zone. The limnetic zone extends vertically from the surface to the bottom of the lake. It can, on the basis of its populations and some physical characteristics, be considered to be two different areas. The upper zone normally corresponds to the lighted portion of the lake and serves as an environment for a community of microscopic photosynthetic plants and an anmal community that lives on these plants. The lower zone, which may not exist in all lakes, is characterized by the presence of many bacteria and generally limited numbers of other kinds of organisms.

When lakes are first formed, especially those of glacial origin, they are most likely to be at their lowest level of productivity. The reason for this is immediately apparent if one looks at the chart, Organic-debris Based Food Chain. As you can see, the living things within a lake basin are dependent on the amount of dissolved organic material which will supply the raw materials for the producers. A lake in the early stages of its evolution is likely to be very low in these kinds of materials. During the course of time, there will always be a surplus of organic sediments accruing in the lake as its tributaries empty into it and as organisms within its basin decay. This gradual aging, more specifically described as eutrophication, although it signifies an increase in productivity, also signifies a decrease in the amount of time that the lake has yet to survive. At an accelerated rate, debris gradually fills the basin, reducing the volume of the lake. At the same time, most lakes are also filling in along their edges,

The numbers, kinds, and distribution of living things in the lake often is a meaningful index as to the state of euthrophication.

ORGANIC-DEBRIS BASED FOOD CHAIN



There are both horizontal and vertical components to the distribution of organisms in a lake. This distribution is influenced by many factors, such as solar energy, temperature and prevailing winds. Since distinct areas of the lake often have unique assemblages of organisms, it is profitable to examine them independently, even though it is an artificial classification.

There is an interesting community associated with the surface film of the lake. The undersurface of the water film serves as a substrate for some snails and flatworms and during particular times of the year as a habitat for the larva and pupa of insects, such as mosquitoes. On the surface, one can find plants, such as duckweed, adults of the whirligig beetles, many of the true bugs, and a number of adult insects which light on the plants which are associated with the surface film.

The kinds of animals that inhabit the lower portion of the limnetic zone are typically those adapted to low-oxygen conditions. The primary food supply for most of the species in the lower limnetic zone are largely of two general types: the large free-swimming animals, such as fish, and the essentially microscopic to sub-microscopic plants and animals, *plankton*.

The plant members of the *plankton* community in any zone are represented by diatoms, blue-green algae, green algae and *photosynthetic flagellates*. The numbers and kinds of plant *plankton* communities vary widely from one body of water to another so that a truly typical community does not exist. The animal plankton community can claim membership mostly from rotifers and microcrustaceans, although *Protists* and insects are often found in this assemblage.

The *plankton* of a lake are not uniformly distributed within the lake. The *photosynthetic plant plankton* is restricted by its light requirements to the area where adequate light is available. Since the animal *plankton* are directly or indirectly dependent on the plants, the animals are also found in greatest abundance where the plant *plankton* are found. Other factors, such as temperature, water movement and nutrient supply, would also affect the distribution of *plankton* in a lake.

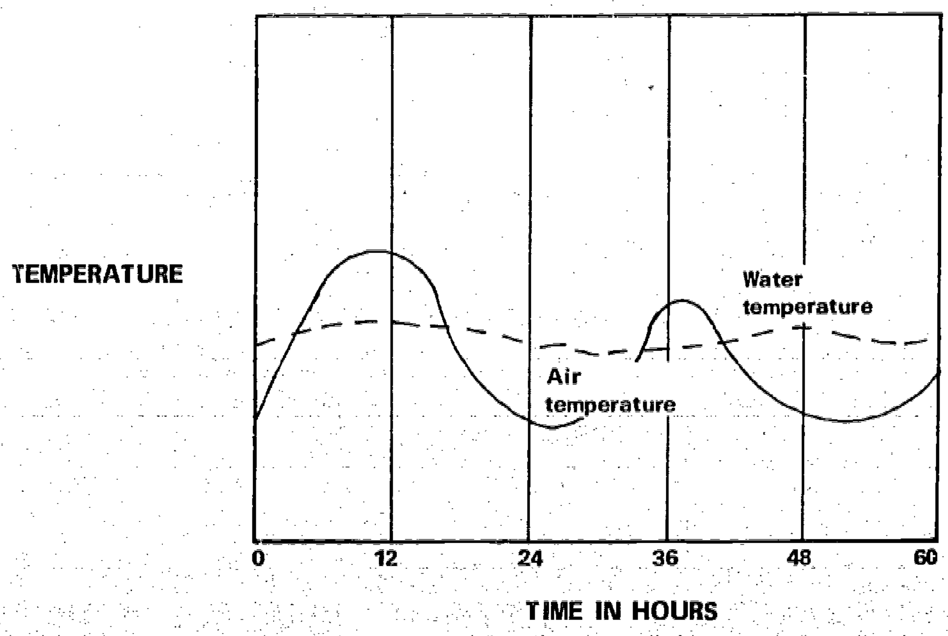
The communities of plants and animals which occupy the bottom of the lake, the *benthic* communities, exhibit a wide variety of kinds and numbers. Because environmental conditions change so rapidly from shore to the depths of the lake and often consist of a number of different kinds of substrates, the bottom contains a variety of environments for occupancy.

Among the factors that affect the kinds and distributions of bottom organisms in a lake are such things as temperature, water transparency, the amount of dissolved oxygen, availability of food and competition. The materials of the bottom itself also influence occupancy. For example, a typical sandy bottom in shallow water may be inhabited by sponges, snails and insects, however, if the bottom were covered with mud, silt or organic debris, one would more likely find crayfish, clams, the nymphs or mayflies, dragonflies and damselflies.

Living conditions on the bottom in deep open water would, of course, be quite different. If the lake were quite deep, or the water turbid, light could not penetrate and plants would be absent.

In addition to the foregoing description of a lake, it may be necessary for you to be acquainted with the following generalities about the exchanges that take place between a lake and its environment. It is quite reasonable to assume that your students have not given serious consideration to the effect that living in water has on an organism. For example, the Daily Temperature Changes in Water and in Air chart shows the diurnal temperature range in air as compared to that of a deep lake. The wide daily range of air temperatures in temperate climates does not occur in the water in the same areas. Consequently, plants and animals in most lakes are not usually subjected to sudden changes in temperature.

DAILY TEMPERATURE CHANGES IN WATER AND IN AIR



Another attribute of water which is very important in considering the effects of pollutants is that essential nutrients for plants and animals such as phosphates and chlorides and other mineral salts are dissolved in water and are widely available to aquatic organisms.

On the other hand, gases such as oxygen and carbon dioxide, which are available in the atmosphere in relatively large quantities are available to a much more limited degree in water. Most of the available dissolved oxygen in lakes is absorbed through the surface of the lake. The absorption rate is increased when wind or waves disturb the water surface. The amount of dissolved oxygen that water can contain decreases as temperatures in the water rise. The chart, Solubility Curve for Oxygen, shows the oxygen carrying capacity of water related to temperature. Carbon dioxide, which is more soluble in water than oxygen, comes from the decay of organic material, the respiration of plants and animals and also through the surface of the water. In addition to being essential for photosynthesis, carbon dioxide is also important in determining the pH of the water. It combines with water to form carbonic acid, which in turn reacts with dissolved limestone or dissolved lime, if present, to form carbonates and bicarbonates. These compounds are indirect sources of carbon dioxide and also serve as buffers that regulate pH.

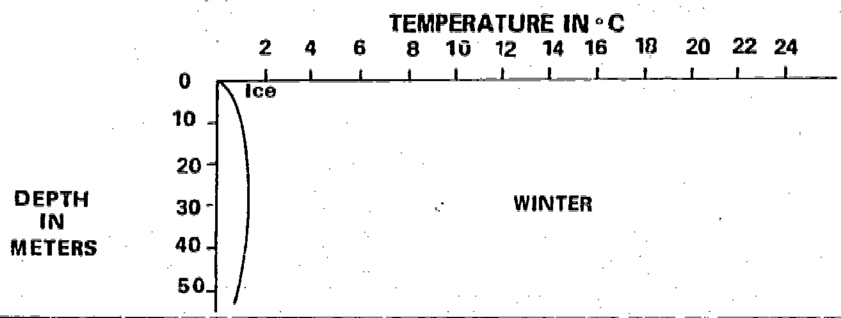
SOLUBILITY CURVE FOR OXYGEN

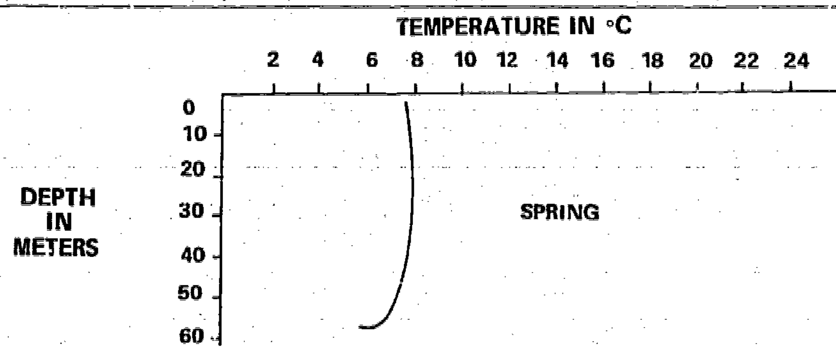
Temperature, °C	O_2 , p.p.m.
0	14.62
5	12.80
10	11.33
15	10.15
20	9.17
25	8.38
30	7.63

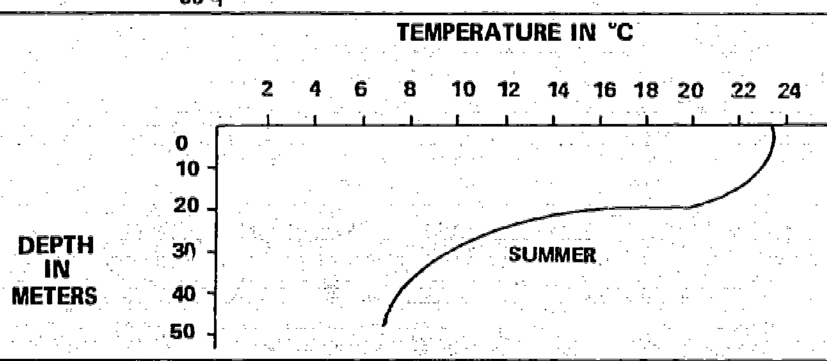
The chart, Seasonal Temperature Variations in a Lake, illustrates one of the most outstanding and biologically significant phenomena of lakes, that is, its seasonal variations in temperature. As you can see, during the winter the temperatures of the water in moderately deep to deep lakes is relatively uniform from surface to bottom. If there is an ice cover, the colder layer lies on top of the underlying water. In spring, under the influence of winds, circulation and mixing of waters result in a uniform temperature from surface to bottom. As summer approaches, the weather warms and the brisk spring winds subside. Under these conditions the surface waters warm very rapidly, expand and become much lighter than the lower waters. Although the wind may continue to blow, its contribution to mixing is significantly diminished since the lower, heavier waters resist mixing with lighter, upper waters. As the amount of solar energy increases in the summer season, the upper waters continue to warm and the resistance to mixing between the two layers increases until the resistance to mixing is greater than the force of the winds. This can cause a condition of thermal stratification which may last until fall.

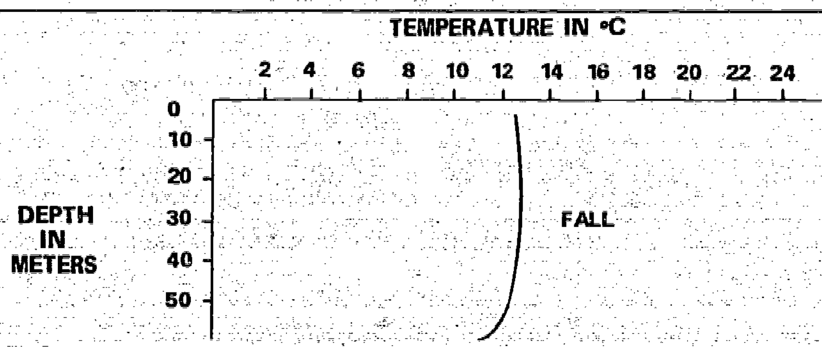
As you can see from the chart, thermal stratification results in the formation of three separate layers: the upper warmed layer, a middle layer in which the temperature drop is very rapid, and the lower non-circulating layer. The middle layer is an effective barrier to the distribution of heat, nutrients and gases between the upper and lower layers of the lake. This means that substances available in the surface layer are not available throughout the body of the lake. For example, the Dissolved Oxygen chart shows a typical oxygen profile of a moderately productive lake when it is thermally stratified. Often the effect of separating the lower portion of the lake from the rest means that the amount of oxygen in the bottom of the lake becomes progressively reduced and the carbon dioxide content increases. All of these factors have a severe effect on the kinds of organisms that inhabit the region.

SEASONAL TEMPERATURE VARIATIONS IN A LAKE

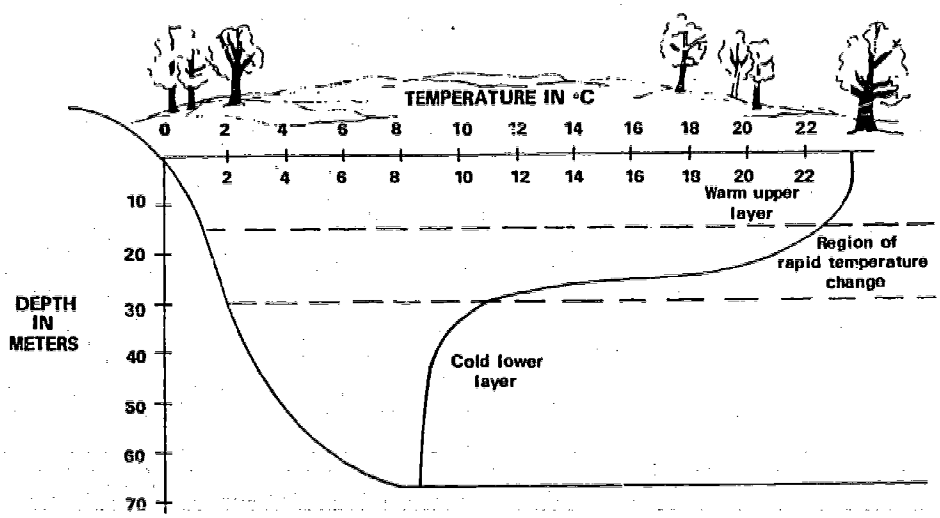




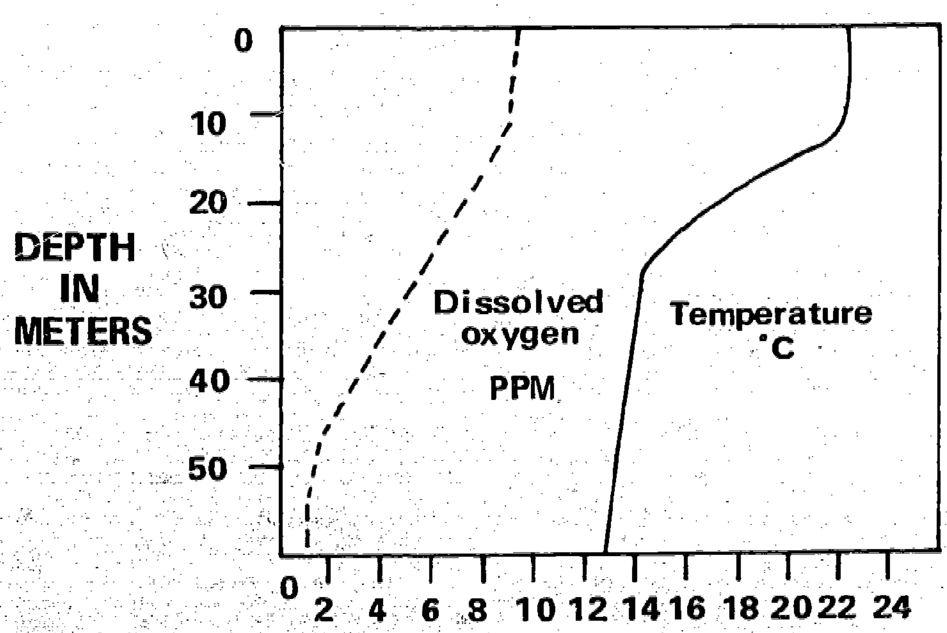




THERMAL STRATIFICATION



DISSOLVED OXYGEN CONCENTRATION IN A STRATIFIED LAKE



Now that we have the dimensions of a lake more clearly defined, how can one tell that it is polluted? *Webster's Collegiate Dictionary* describes "to pollute" as follows: "To make unclean, impure, corrupt; to desecrate; to defile; to contaminate; to dirty."

Certainly most of the lakes we know qualify, but what makes the problem of pollution so easy to see and difficult to deal with is that everybody pollutes.

The facts of Problem 33 are simple. Lake Erie is undergoing very rapid eutrophication. Man is not going to move away from the Great Lakes. In fact, all of the evidence indicates that just the opposite trend is the most likely one.

What can be done to try to "Save Lake Erie"? Certain paths seem to be open and possible. Available evidence indicates that pollution of all kinds is affecting the lake, generally for the worse. It is the most polluted of the Great Lakes. There is increasing evidence of oxygen depletion in the bottom waters, the disappearance of the mayfly larvae from the western end of the lake and the spectacular growth of floating algae are all signs of advanced eutrophication.

These are the major sources of pollution in Lake Erie:

1. The grossly polluted Detroit River is a major source. Cities and industries along the Detroit River add 1.6 billion gallons of waste to the river daily.
2. Of all Great Lakes, pollution is particularly serious in Lake Erie because of its relatively small volume.
3. Over the past 50 years, concentrations of the major contaminants have increased sharply.
4. Many industrial wastes, such as phenols and ammonia, act as poisons to fish and other living things in the lake.
5. Sewage wastes and farm fertilizers and large amounts of nitrogen and phosphorus are added to the lake and are largely responsible for the huge algae blooms.
6. The algae, which thrive in polluted water, contribute to the depletion of oxygen when they die and decay.
7. The excessive numbers of bacteria from human wastes constitute a serious health hazard to the people around the lake. This, in addition, seriously restricts the recreational utility of the lake.

At this present point in time, we still know far too little about the complex processes we have set in motion. Certainly, we do not have adequate information to insure the preservation of Lake Erie as well as the rest of of the Great Lakes.

Another interesting area not specifically covered in this problem is the effect on the introduction of new organisms into the St. Lawrence River. All natural drainage of glacial times from the Great Lakes into the Mississippi and the Atlantic Ocean has ceased to exist. Man, however, has restored these connections with the construction of numerous canals. The effect of these canals has been to introduce into the original post-glacial fauna new organisms which have profoundly disturbed the ecological balance.

Student Activities

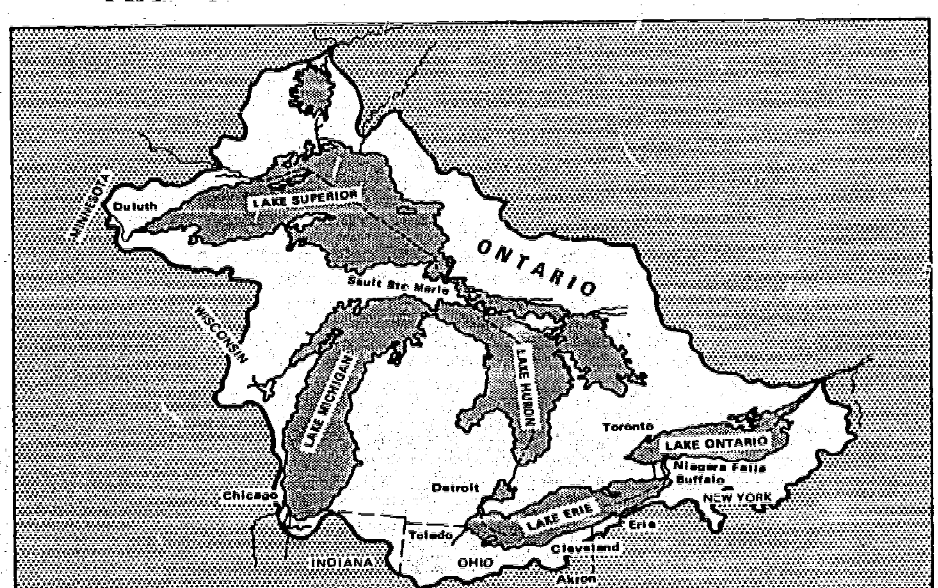
PROBLEM THIRTY-THREE — THE CASE HISTORY OF A LAKE

How do modern living standards and large numbers of people affect man's supply of fresh water? Let's take a close look at the largest supply of fresh water on the surface of the earth, the Great Lakes of North America.

Compared to other physical features of our country, such as the Rocky Mountains, the Great Lakes are quite young. The present shape of the Great Lakes was caused by the the last continental glacier. Before the glaciers, the lakes were only river valleys. As the glaciers moved southward they deepened and enlarged these valleys. When the glaciers began to melt, these scooped-out basins filled with water from melted ice and snow. Ten thousand years ago the last melting of the ice sheet left the Great Lakes in approximately their present form.

The map of the Great Lakes Drainage Basin shows some things that are important in understanding the Great Lakes. First, the heavy line that surrounds the Great Lake Basin shows you the amount of land that supplies water to the Great Lakes. As you can see, the area of the Great Lakes is about one-half as large as the land area that drains into it. A second important feature to notice is that the water finally flows out to the ocean through the St. Lawrence River. Find Buffalo on your map! You will find it at the eastern end of Lake Erie. Now, look for Niagara Falls! Did you know that Niagara Falls prevents animals from swimming up the St. Lawrence River and Lake Ontario into the rest of the Great Lakes? Can you explain why?

MAP OF GREAT LAKES DRAINAGE BASIN



Lake Erie Requiem or Reprieve, Lake Erie Basin Committee, League of Women Voters, 1966.

Before large numbers of people came to the area, the Great Lakes attracted many wild fowl and fur-bearing animals. Throughout much of the year these animals lived on the shores. The early European explorers of North America, such as Champlain and LaSalle, looked on these huge bodies of water with the large populations of animals with great admiration. The Great Lakes were also used by Europeans to explore deep into the continent before there were natural roads. The earliest settlements of Western man along the Great Lakes were usually situated at points of military importance.

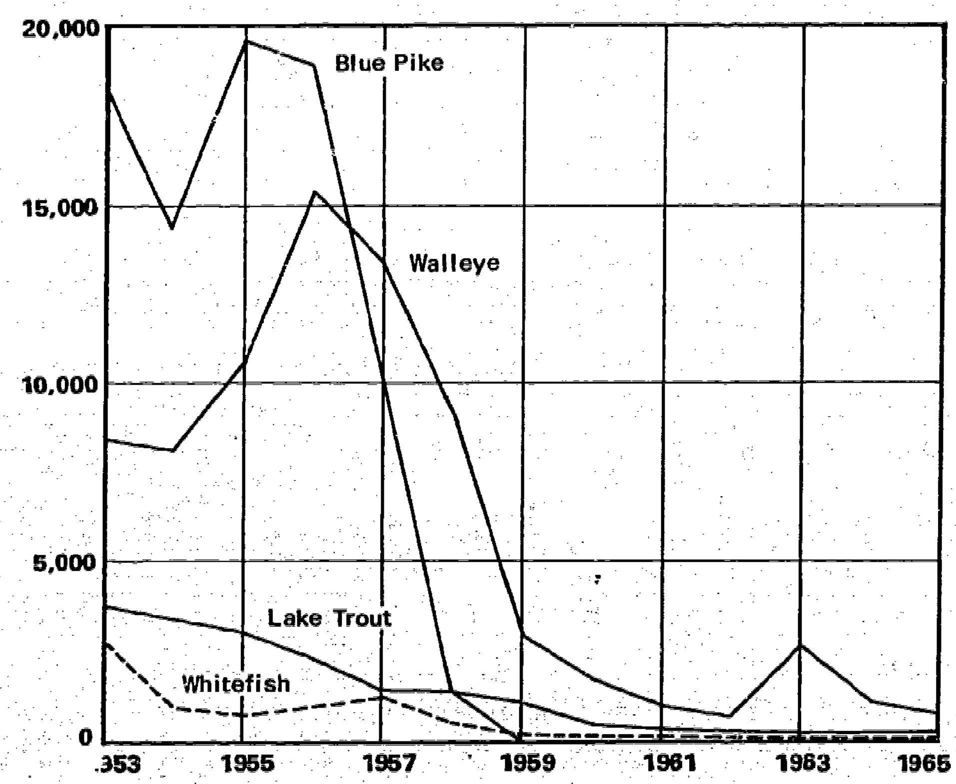
In 1848 a purely scientific expedition was launched on Lake Superior by Professor Louis Agassiz and 15 fellow scientists. Their only equipment was one large Mackinaw boat and two canoes. The observations of this group have been very important in determining the changes that have occurred within the Great Lakes. Professor Agassiz kept good records of the fishes and insects that were observed by his party.

The Great Lakes have become a center of industry for many areas. Among the most important are the location of certain natural resources nearby.

Large supplies of iron ore were discovered at the western end of Lake Superior near Duluth. Just southeast of Lake Erie there was a large supply of coal. Lake Erie was connected to the coal mines by canals between 1825 and 1850. Then, another canal that made boat travel possible between Lake Superior and Lake Huron was created. Now it was possible to easily ship both coal and iron to places on the Great Lakes. Follow the route iron would take from Duluth to Cleveland. A third canal, the Erie Canal, opened up a route for immigration up the Hudson River from Albany, New York to Buffalo on the Great Lakes. Now, with ore, coal and lake it was possible for large industrial centers to be located on the Great Lakes. Buffalo soon became the center of the flour and milling industry. The Cleveland skyline was illuminated by the tall chimneys of the iron and steel mills. Cleveland soon led in the production of iron and petroleum products. In Detroit there grew a thriving carriage industry which was to turn to the production of automobiles in the next century.

At the same time that the population engaged in industry was growing along the edges of Lake Erie, large numbers of people were making their

COMMERCIAL FISH CATCH IN LAKE ERIE SINCE 1963



living as fisherman. Apparently unlimited supplies of blue pike, walleyed pike, white fish, chubs, and cisco were available for anyone who wished to fish for them. As late as 1955 the commercial catch of blue pike in Lake Erie was almost 20,000 tons per year and the rate of walleyed pike was 5,000 tons per year. The chart, Commercial Fish Catch, shows data on the number of fish taken from Lake Erie in the last 18 years.

At the present time about 13.5% of the United States population and about 33.9% of the Canadian population now live in the drainage area of the Great Lakes. Stretching from the Canadian city of Quebec on the east, all the way to Milwaukee on the west, is an almost continuous chain of cities. The welfare of this large population of people is largely dependent on the Great Lakes for a continued supply of clean usable water.

What is the effect of such a large number of people on the water in the Great Lakes? Since a thorough look at all of the Great Lakes would be a tremendous task, let's just focus on one: Lake Erie.

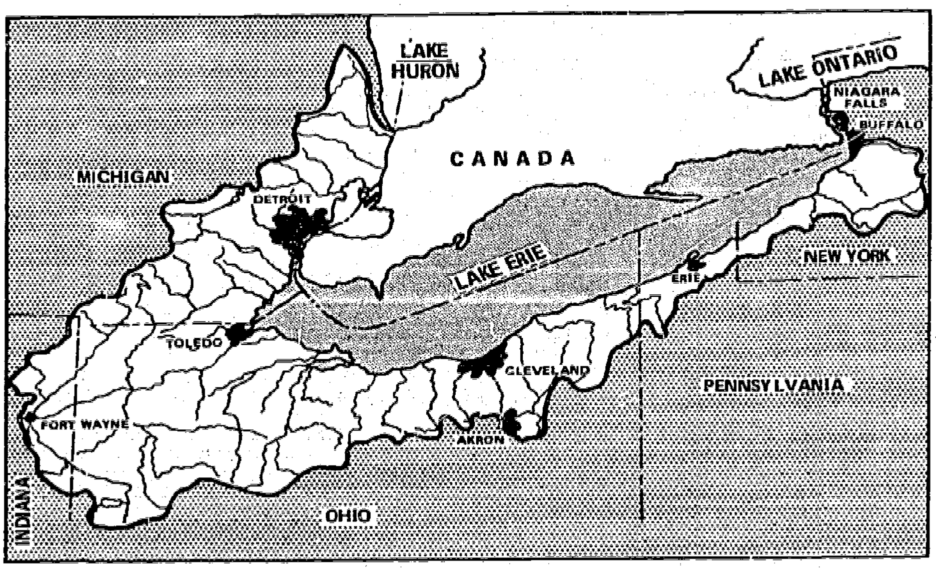
As you can see from the chart, Some Dimensions of the Great Lakes, Lake Erie is the shallowest of all the Great Lakes. It has an average depth of about 58 feet. You can also see in the chart, Lake Erie Drainage Basin, that two peninsulas extend from the northern shore of Lake Erie, one at the western end and one toward the eastern end. These peninsulas serve to divide the lake into regions. The shallow western basin, which receives water from the Detroit River, has an average depth of only 54 feet. The larger central basin has an average depth of between 60 and 78 feet, and the eastern basin has a maximum depth of 210 feet.

SOME DIMENSIONS OF THE GREAT LAKES

Lake	Length (mi)	Breadth (mi)	Maximum depth (ft)	Mean depth (ft)	Water surface (mi 2)	Drainage basin (mi2)
SUPERIOR	350	160	1,333	487	31,820	80,000
MICHIGAN	307	118	923	276	22,400	67,860
HURON	206	183	750	195	23,010	72,620
ERIE	241	57	210	58	9,930	32,490
ONTARIO	193	53	802	283	7,520	34,800

Where does the water in Lake Erie come from? Look at the following chart. This shows most of the rivers flowing into Lake Erie from the United States.

LAKE ERIE DRAINAGE BASIN



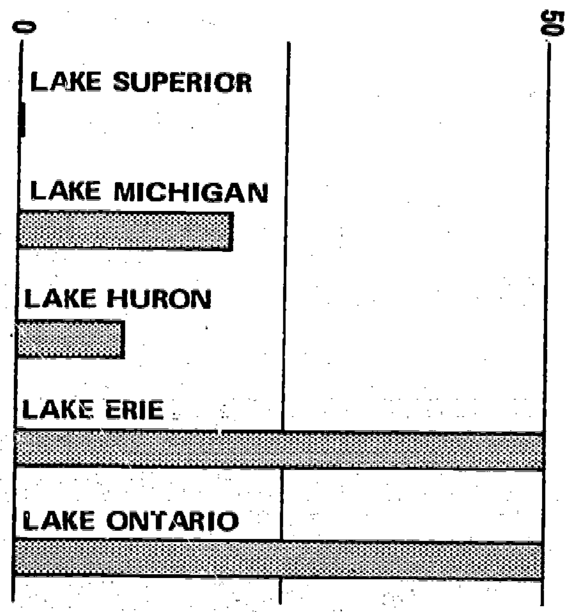
Lake Erie Requiem or Reprieve, Lake Erie Basin Committee, League of Women Voters, 1966.

The Maumee River which empties into the western end of Lake Erie at Toledo is the largest tributary. However, about 80% of the water that comes into Lake Erie comes from the other Great Lakes by way of the Detroit River.

Presently there are 8,528,000 people living on the American side of the Lake Erie basin. When you are 40 years old, if our population continues to grow at the same rate, there will be about 17 million people living in the same area. If we continue to use automatic washers, dishwashers, lawn sprinklers, air conditioners, and swimming pools, our demands for water from the Great Lakes will be hard to meet. City governments estimate that today they must process about 140 gallons of water for every person in the community to meet present day needs. If we require more automobiles, or more bicycles, or other conveniences which require metal, our industrial needs will increase more rapidly than our personal needs. It requires approximately 50,000 gallons of water to make 1 ton of steel; 600,000 gallons are needed for production of 1 ton of synthetic rubber; 320,000 gallons for 1 ton of aluminum. Perhaps what is even more impressive is that the electricity needed to light homes and to operate factories and businesses requires more water than any of the industries previously mentioned.

The increase in populaion and increase in industrial production has another effect in addition to requiring more water. More waste materials are added to the water. The chart, Increase in Dissolved Solids in the Great Lakes, shows the per cent of increase in dissolved materials in the Great Lakes in the last 50 years.

INCREASE IN DISSOLVED SOLIDS IN THE GREAT LAKES



Which lake do you think would have the clearest water?

Which lake would you least want to swim in?

Around which lakes would you expect to find the fewest people?

The waste materials include disease-causing bacteria and viruses. This means that, if large numbers of disease-causing microorganisms are present in a lake, the waters of the lake are no longer available for recreation. Some cities and towns treat their human wastes adequately, so that when they are discharges from treatment plants there is no health hazard. Other cities, smaller towns, and rural areas do not provide adequate treatment and dangerous health conditions in Lake Erie are a result. For example, in the water of the Detroit River the numbers of bacteria put into the water with human waste are three times more plentiful than they were in 1913.

Since many bacteria live very well in lake water, would you prefer to swim in Lake Superior or Lake Erie? Why?

The wastes from the growing industrial plants along the shores of Lake Erie are not a health hazard from bacteria but are a serious problem in other ways. Many industrial wastes, such as phenol and ammonia, act as poisons to fish and other animal life. Solid materials settle to the bottom and smother living things living there. In addition, some of these solid materials on the bottom rot, using oxygen, which is then not available to fishes and other living things. The chart, Changes in Bottom Organism in Western Lake Erie, shows the data.

CHANGES IN BOTTOM ORGANISM IN WESTERN LAKE ERIE

KIND OF ORGANISM	REQUIRES HIGH OXYGEN CONTENT IN WATER	ANIMALS PER SQ. METER OF BOTTOM		
		1929	1930	1958
Leeches (Hirudinia)	NO	6	4	37
Small Worms (Oligochaetes)	NO	6	3	559
Mayfly Larvae (Hexagina)	YES	312	515	49
Midge Flylarvae (Tendipidae)	NO	81	22	257
Snails (Gastropode)	YES	12	24	7
Fingernail Clams (Mollusca)	NO	16	8	55
Caddis Fly Larvae (Tricoptera)	YES	20	1	3

Microcscopic green plants such as algae, on the other hand, thrive in polluted water because sewage contains considerable amounts of elements that are necessary for their growth. Large amounts of algae give the lake water disagreeable tastes, smells, and make it very difficult to purify the water for drinking. The following chart shows data on the changes in the numbers of floating microscopic plants in western Lake Erie in the last thirty-five years.

COMPARISON OF ALGAE CONCENTRATIONS IN WESTERN LAKE ERIE

KINDS OF ALGAE	NUMBER PER LITER	
	1938-42*	1964**
Stephanodiscus-Cyclotella	260,000	828,000
Aphanizomenon-Oscillatoria	366,000	725,000
Anabaena	1,500	215,000
Carteria-Chlamydomonas	None reported	210,000
Glenodinium	None reported	210,000
Chlorophyceae	31,800	415,000
Myxophyceae	400,000	2,750,000
Total	871,000	3,500,000

A phytoplankton bloom in western Lake Erie. Victor L. Casper, U.S. Public Health Service.

Scientists who have looked at the problem of increased numbers of algae in the lake have concluded that probably the chief cause is the increase in the amount of phosphorus in the lake. The chart below shows some recent data on from where the phosphorus comes. These same scientists suggest that the best way to control the algae is to control the phosphorus input.

SOURCES OF PHOSPHORUS IN LAKE ERIE

Source	Phosphorus (PO_4 –P) Lbs/day
Lake Huron	20,000
Rural land runoff	20,000
Municipal	
Detergents	70,000
Human excreta	30,000
Urban land runoff	6,000
Industrial (direct discharge)	6,000
TOTAL	152,000

Lake Erie Enforcement Conference, Technical Committee, March 1967.

According to the chart, Comparison of Algae Concentrations in Western Lake Erie, are there more or fewer algae in Lake Erie than there were in 1940?

Using the data in the chart, Sources of Phosphorus in Lake Erie, what seems to be the major reason for the increase in numbers of algae?

Extensive farming along the shores also contributes to the pollution of Lake Erie. The water running into rivers from farmlands carries with it large amounts of soil which not only muddies the water but eventually is deposited in the lake and contributes to filling the lake more rapidly than it would if the land were not disturbed by agriculture. In addition, the fertilizers that were intended to aid the growth of plants on land are carried into streams and lakes. There they nourish the growth of algae and other undesirable water plants. The poisonous chemicals used to control insects or plant diseases are also carried into the water with sometimes disastrous effects on the living things in the streams and lakes.

Another increasing health hazard is the pollution contributed by the hundreds of thousands of pleasure boats, many of which are used in Lake Erie. The exact amount of human waste that is emptied into the lake from this source is difficult to estimate but certainly must be large.

Ohio is presently considerng a law that would forbid pleasure boats from emptying human wastes into lakes.

Do you think this would be a good law? Why?

Commercial shipping, the large ore boats, the grain boats, the boats from overseas which do not put into port as often as pleasure boats, frequently dispose of garbage and debris creating serious nuisance conditions. With the large number of vessels coming in through the St. Lawrence Seaway, there is the strong possibility of introducing plants, or animals, or human diseases which would not normally be found in the Great Lakes.

Just how serious is the problem? Is there really a problem, or are we concerned with no real reason?

The above material came from **Man's Effect on Environment**, Second Experimental Edition, 1967-68, Educational Research Council of America, Cleveland, Ohio, pp. 19-34.

CHAPTER VII

INQUIRY PROGRAM — BIBLIOGRAPHY

In this section a representative number of the nationally recognized secondary science experimental programs are summarized in regard to the purposes and objectives of the programs and a description of the materials and guides available. This information will be helpful in selecting or developing an inquiry program in science.

The information contained here was obtained from the "Annual Reports of the International Clearinghouse on Science and Mathematics Curricular Developments." The International Clearing House was established at the University of Maryland's Science Teaching Center in the fall of 1962. Financial support comes mainly from the National Science Foundation and the University of Maryland.

EDUCATIONAL RESEARCH COUNCIL OF AMERICA (ERC)

Purposes and Objectives:

Develop an interdisciplinary, sequential science curriculum for all educable students from kindergarten through grade twelve.

Address of the Project:

Dr. Ted R. Andrews
Director of Science
#312 Rockefeller Building
614 West Superior Avenue
Cleveland, Ohio 44113

Specific Subject, Grade, and Age Level:

Science, Grades K-12

Description of Materials Available:

1. ERC Life Science, Second Experimental Edition (for grade seven.) The program is man-centered, stressing inquiry approach in laboratory investigations of problems concerning man and his environment. Student Investigations, in four volumes.
2. ERC Science Problems First Experimental Edition (for grades 11-12.) Planned to meet the needs of students who do not take physics and chemistry; the materials are organized in three phases: Phase I, Heartbeat Problems are teacher-directed; Phase II, Pendulum Problems, are transitional; Phase III, Problem Areas, are designed for self-pacing, individual investigation by the students.
3. ERC Science News, a newsletter published bi-monthly from October through June.
4. Testing instruments for evaluating student attitudes and knowledge of science processes.
5. The ERC Science Program, a brochure describing the goals and philosophy of the program.

Free Materials:

ERC Life Science Prospectus; ERC Science Problems Prospectus; ERC *Science News* is free to persons associated with the Council participating school systems; The *ERC Science Program* brochure, and sample copies of the newsletter, working papers, and other information is available upon request. Direct all requests for information and materials to the director of Science, Educational Research Council of America, Rockefeller Building, Cleveland, Ohio 44113.

Materials for Purchase:

Item 1, ERC Life Science: Student Investigations, four volumes, $16.00; Instructional Guide, four volumes, $5.00. These materials are available only in complete sets of four volumes. The Student Investigations materials are interleaved throughout the Instructional Guide, in addition to being bound separately for the student. Fly Facts, per copy, $0.60. Item 2, ERC Science Problems materials are available on a limited basis: Sample Set, $25.00; Classroom Set (for 30 students) $385.00. Item 3, ERC Science News, subscription for one year (five issues) $2.25. Direct all requests for information and materials to the Director of Science, Educational Research Council of America, Rockefeller Building, Cleveland, Ohio 44113.

MICHIGAN SCIENCE CURRICULUM COMMITTEE JUNIOR HIGH SCHOOL PROJECT (MSCC-JHSP)

Purpose and Objectives:

To develop and test open-ended laboratory experiences which are directed toward interdisciplinary ideas; to develop a means of evaluating the extent of students' understanding of these ideas as a result of open-ended laboratory experiences. The project is centered on inquiry. The process of inquiry is taken to mean the approach to an idea by students and teacher in terms of open-ended laboratory experiences through questions asked at various levels of difficulty. As a basis for evaluation, the investigators believe that the questions students ask furnish a better indication of the extent and the quality of their thinking in relation to an idea than any answers they may give to questions asked of them.

Address of the Project:

Dr. W. C. Van Deventer, Project Director, MSCC-JHSP, State of Michigan Department of Education, Lansing, Michigan 48902.

Specific Subjects and Grade Levels:

Seventh Grade General Science. Some of the materials have been used successfully, however, at the sixth and eighth grades.

Description of Materials Available:

1. Rationale of the project: *A New Approach to Interdisciplinary seventh Grade Science.*
2. *Criteria for Writing or Evaluating Laboratory Experiences.*
3. Thirteen units consisting of a total of 55 laboratory experiences. Each unit is directed toward a specific idea. The ideas are groups under two of the basic assumptions of scientists in dealing with the natural world.
   a. *Scientists in looking at the natural world assume the universality of change;*
      (1) Idea of dynamic equilibrium.
      (2) Idea of change and variation.
      (3) Idea of normal curves and warping factors.
      (4) Idea of gradients.

(5) Idea of extrapolation and interpolation.
(6) Idea of cycles and cyclic change.
(7) Idea of directional change in response to the challenge of the environment.

b. *Scientists think of the natural world in terms of relationships rather than absolutes.*

(1) Idea of measurement as an expression of relationship.
(2) Idea of templates or transference of pattern.
(3) Idea of interdependence and interrelationship.
(4) Idea of the necessary interaction of heredity and environment.
(5) Idea of differential rates of processes in development.
(6) Idea of tools, machines, and outside sources of energy as extensions of man's body and its capabilities.

4. *Suggested Procedure of Teachers Wishing to Use MSCC-JHSP Materials.*
5. *Sample Tests,* based on student questions.

Free Materials:

All the materials 1 through 5 listed above are available free from Dr. W. C. Van Deventer, Director of MSCC-JHSP at Project Headquarters.

SECONDARY SCHOOL SCIENCE PROJECT (SSSP)

Purpose and Objectives:

Curriculum development: The Project is currently involved in completing work on the interdisciplinary, physical science course *Time, Space and Matter* (TSM). The course is divided into nine sequential investigations, each of which is accompanied by a student book providing a source of observations and data not obtainable in the laboratory. Course content, objectives and procedures are contained in the Teacher Folios which also accompany the Investigations. There is no text — students keep a record of their progress in the course in a notebook — but specially selected readings are provided. Laboratory work is an integral part of *Time, Space and Matter* and equipment and supplies for that work also come in the course "package."

Teacher training: The Project is actively involved in the training of teachers and resource people. Various media, especially video tapes, are being explored for this purpose.

Address of Project:

Dr. George J. Pallrand
10 Seminary Place
Rutgers, The State University
New Brunswick, New Jersey 08903

Specific Subject, Grade and Age Level:

The Physical Sciences (geology, astronomy, physics, chemistry, mathematics) Grades 8-9.

Use of Materials:

Some specific schools where course is being taught. Write to:
Webster Division

McGraw-Hill Book Company
Manchester Road
Manchester, Missouri 63011

Description of Materials Available:

1. Progress Reports — course materials.
2. Student Investigation Books.
3. Teacher Folios: Provisional Edition 1-9 and published edition 1-4.
4. Laboratory equipment and supplies.
5. Science Reading Series 3.

Free Materials:

Progress Reports; Publisher's course description pamphlet available from:
Webster Division
McGraw-Hill Book Company

CHEMICAL BOND APPROACH (CBA COMMERCIAL EDITION)

Present Commercial Affiliation:

McGraw-Hill Book Company
Webster Division
Manchester Road
Manchester, Missouri 63011

Purpose and Objective:

Design of introductory course in Chemistry, Course includes classroom text and laboratory experiments. Presentation of chemistry as a process of investigation with imaginative ideas used to interpret laboratory findings.

Address of the Project:

Contact McGraw-Hill Book Company for prices and information on CBA.

Specific Subjects and Grade Level:

Chemistry, 11th and 12th grades and first year of college.

Description of Materials Available:

1. Text, Chemical Systems
2. Student's Laboratory Guide, Investigating Chemical Systems
3. Teacher's Guide to Chemical Systems
4. Teacher's Guide to Investigating Chemical Systems
5. Set of Examinations (Contact McGraw-Hill for price)

Free Materials:

None available other than descriptive brochures from McGraw-Hill Book Company.

Materials for Purchase:

See text materials from McGraw-Hill Book Company.

QUANTITATIVE PHYSICAL SCIENCE (QPS)

Purpose and Objective:

To provide guidance to administrator and teacher so that the latter can successfully teach primarily through guided experiences rather than through a textbook. The objective is for the student to develop knowledge, skills, and vocabulary through an organized series of experiences. The staff seeks to promote this method of instruction feeling that it will simultaneously result in: greater student and teacher interest, a general-education course, and specific preparation for the student to obtain greater benefit from the more modern courses in senior high biology, chemistry and physics.

Address of the Project:

Dr. Sherwood Githens, Jr.
Department of Education
Duke University
College Station
Durham, North Carolina 27708

Specific Subject, Grade, and Age Level:

Physical Science, primarily for 9th grade (age 14), but usable in grades 7-12.

Description of Materials Available:

1. Descriptive brochure (13 pages mimeographed).
2. Newsletters to cooperating teachers and administrators.
3. Teacher's Manuals (6 volumes, mimeographed).
4. Worksheet package (96 manipulative learning operations, MLO worksheets).
5. Interim textbook (211 pages, lethoprinted.)
6. Lists of equipment and suppliers.

Free Materials:

Item I from project headquarters.

Materials for Purchase:

At this time the staff has no materials for general sale as samples. To schools that have decided to acquire the related equipment and try teaching the course as the staff has planned it, the staff supplies materials at a slight increase over cost of production.

Use of Materials:

The following is a partial list: Anderson W. Clark Jr. High School, Glendale, California; Lakewood Senior High School, Denver, Colorado; Maine Township High School West, Des Plaines, Illinois; The Harley School, Rochester, New York.

PORTLAND PROJECT — AN INTEGRATION OF BIOLOGY, CHEMISTRY, AND PHYSICS

Purpose and Objective:

1. To develop a three year integrated biology, chemistry, physics sequence for secondary schools mostly from existing materials, such as: IPS, BSCS, CHEM, PSSC.
2. To equip students with some of the skills and modes of behavior that characterize the working scientist.
3. To capture students' interest and enthusiasm for later encounters with science.

Address of the Project:

Dr. Michael Fiasa, co-director
Portland Project

Portland State College
P. O. Box 751
Portland, Oregon 97207

Specific Subject, Grade, and Age Level:
Biology, Chemistry, and Physics, a 3-year sequence for secondary schools.

Description of Materials Available:
Biology, Chemistry, Physics — Teacher's Guide, Part I & II.
Biology, Chemistry, Physics — Teacher's Guide, Part III & IV.
Biology, Chemistry, Physics — Student's Guide, Part I & II.
Biology, Chemistry, Physics — Student's Guide, Part III & IV.
Excerpts from Teacher's Guide.

Free Materials:
Excerpts from the Teacher's Guide.

Materials for Purchase:
Write to project headquarters for information.

Use of Materials:
Name of location of specific schools where course is being taught: Portland, Oregon High Schools; Benson High School, Cleveland High School, Franklin High School, Jefferson High School, Roosevelt High School, Wilson High School; Beaverton High School, Beverton, Oregon; Rex Putnam High School, Milwaukie, Oregon.

BIOLOGICAL SCIENCES CURRICULUM STUDY (BSCS)

Description of Materials Already Produced:

1. Blue Version — *Biological Science: Molecules to Man;* Houghton Mifflin Company, 110 Tremont St., Boston, Mass. 02107.
2. Green Version — *High School Biology, BSCS Green Version;* Rand McNally & Co., P. O. Box 7600, Chicago, Illinois 60680.
3. Yellow Version — *Biological Science: An Inquiry Into Life;* Harcourt, Brace & World, Inc., 757 Third Avenue, New York 10017.
4. Version Tests — Quarterly Achievement Tests in two alternate forms and Processes of Science Test (POST): for all versions: The Psychological Corp., 304 East 45th Street, N.Y., N.Y. 10017.
5. Second Course — Biological Science: *Interaction of Experiments and Ideas;* Prentice Hall, Inc., Englewood Cliffs, N.J. 07632.
6. Second Course Tests — *Quarterly Tests and Final Examination;* Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632.
7. Special Materials — *Biological Science: Patterns and Processes;* Holt, Rinehart and Winston, Inc., 383 Madison Ave., New York, N.Y. 10017.
8. Special Materials Tests — *Unit Tests* and *Final Examination;* The Psychological Corporation, 304 E. 45th St., New York, N.Y. 10017.
9. Laboratory Blocks — *Plant Growth and Development; Animal Growth and Development; Microbes: Their Growth, Nutrition and Interaction; The Complementarity of Structure and Function; Field Ecology; Regulation in Plants by Hormones — A Study Experimental Design; Animal Behavior; Life in the Soil; Genetic Continuity;* C. C. Heath & Co., 285 Columbus Ave., Boston, Mass. 02115.

Innovations in Equipment and Techniques for the Biology Teaching Laboratory; C. C. Heath & Co., 285 Columbus Ave., Boston, Mass. 02116.

10. *Teacher's Handbook — Biology Teacher's Handbook;* John Wiley & Sons, Inc., 605 Third Ave., New York, N.Y. 10016.
11. Biological Investigations for Secondary School Students — *Research Problems in Biology: Investigations for Students, Series One, Two, Three, and Four;* Doubleday & Co., 277 Park Avenue, New York, N.Y. 10017.
12. Pamphlet Series (24 titles); D. C. Heath & Co., 285 Columbus Avenue, Boston, Mass. 02116.
13. Techniques Films (16 mm sound or 8 mm loop, silent); Thorne Films, 1229 University Ave., Boulder, Colorado 80302.
14. *BSCS Newsletter.*
15. BSCS Special Publication No. 3, *BSCS Materials for Preparation of In-Service Teachers of Biology.*
16. BSCS Special Publication No. 4, *The Teacher and BSCS Special Materials.*
17. BSCS Special Publication No. 5, *Laboratory Blocks in Teaching Biology.*
18. BSCS Bulletin No. 1: *Biological Education in American Secondary Schools 1890-1960,* by Paul DeH. Hurd, 1961.
19. BSCS Bulletin No. 2: Teaching High School Biology: *A Guide to Working With Potential Biologists,* by Paul Brandwein, Jerome Metzner, Evelyn Morholt, Anne Roe, and Walter Rosen, 1963.
20. BSCS Bulletin No. 3: *BSCS Biology — Implementation in the Schools,* by Arnold Grobman, Paul DeH. Hurd, Paul Klinge, Margaret McKibben Lawler, and Elra Palmer, 1964.
21. Laboratory Blocks, experimental editions.
22. *The Molecular Basis of Metabolism.*
23. *Physiological Adaption.*
24. Information Film, *The Story of BSCS.*

PUBLICATIONS IN SECONDARY SCIENCE

The following brief description is of a project being carried on as a regular function of the New York State Education Department.

Project Address

Contact Gordon E. Van Hooft, New York State Education Department, Albany, New York 12224.

Materials Available:

This is a partial list of the materials produced.

1. Mathematics 7-8
2. Science 7-8-9, Block G, Living in the Space Age 1967
3. Science 7-8-9, Block H, Weather and Climate 1967
4. Science 7-8-9, Block I, Forces at Work 1966
5. Science 7-8-9, Block K, Energy At Work 1967
6. Experimental Biology Syllabus, 1967
7. Physics Syllabus, 1966
8. Tips and Techniques for Elementary Science, 1966
9. Air Pollution, 1967

CHEMICAL EDUCATION MATERIAL STUDY (CHEM STUDY)

Present Commercial Affiliation:

W. H. Freeman and Company, 660 Market Street, San Francisco, California 94104, publisher of the written materials; Modern Learning Aids, distributor of the film materials.

Purpose and Objective:

To diminish the separation between scientists and teachers in the understanding of science; to stimulate and prepare those high school students whose purpose it is to continue the study of chemistry in college as a profession; to further in those students who will not continue the study of chemistry after high school an understanding of the importance of science in current and future human activities; to encourage teachers to undertake further study of chemistry courses that are geared to keep pace with advancing scientific frontiers, and thereby improve their teaching methods; to guarantee the existence in the near future of a variety of excellent high school chemistry texts significantly influenced by the CHEM Study but produced under a normal author-publisher relationship; to reduce the likelihood that textbooks of the future will, by their failure to keep pace with the accelerating movement of science, make repeated curriculum studies necessary.

Specific Subjects, Grade and Age Levels:

Senior High School Chemistry.

Description of Materials Already Produced:

1. *Chemistry — An Experimental Science* (textbook, 466 pages, clothbound.)
2. *Chemistry — An Experimental Science* (laboratory manual, 138 pages, paperbound.)
3. *Chemistry — An Experimental Science* (teacher's guide, 785 pages, paperbound.)
4. Programmed Instruction Pamphlets· *Slide Rule* (64 pages and *Exponential Notation* (31 pages.)
5. Achievement tests (set of 7 open-book, multiple choice tests.)
6. Films.

Materials for Purchase:

All items above are available from W. H. Freeman Co., 660 Market Street, San Francisco, California 94104.

PHYSICAL SCIENCE STUDY COMMITTEE PHYSICS COURSE (PSSC)

Project Director:

Contact Miss G. Kline, PSSC, Education Development Center, 55 Chapel Street, Newton, Massachusetts 02160, for information about the program. The program is now available in textbook form and is no longer experimental.

General Information:

The specific purposes and objectives of this course are to present physics as a unified but continuing process by which men seek to understand the nature of the physical world. Employs laboratory experimentation to encourage the student's spirit of inquiry. This is a high school physics course dealing with matter, time, space, light, motion, and the nature of electrical forces and energy. Materials already produced are a textbook, Physics, (the PSSC physics course textbook is published by D. C. Heath and Co. There is a *Laboratory Guide for Physics* produced by the same publisher and *PSSC Physics Teacher's Resource Book and Guide*. The required laboratory apparatus is manufactured by MacAlaster Scientific Corporation, Science Electronics and Welch Scientific Company. There are also PSSA Films, Science Study Series and tests available. Teachers are trained by NSF-supported summer, inservice, and academic year teacher training institutes.

EARTH SCIENCE CURRICULUM PROJECT (ESCP)

Present Commercial Affiliations:

Houghton Mifflin Company; Encyclopaedia Britannica Educational Corporation; Prentice-Hall, Inc.; The National History Press; Hubbard Scientific Company; Damon Educational, Inc.; Raytheon Education Company.

Purpose and Objectives:

This program provides an interdisciplinary approach to earth science which weaves the various disciplines together to provide a comprehensive view of the planet earth and its environment. A series of investigations provide the student with experience to better understand the content. The main difference between this and earlier efforts is the interdisciplinary treatment and the investigative nature of the approach.

Address of the Project:

Joseph L. Weitz, Earth Science Curriculum Project, P. O. Box 1559, Boulder, Colorado 80302.

Specific Subject, Grade and Age Levels:

All of the earth sciences — astronomy, geology, geography, meteorology, and oceanography — are served. The materials are developed for ninth grade students in the 13 to 15 age bracket. However, about 1/4 of the children now in the course are in the eighth grade level. The methods of instruction include independent study, laboratory investigations, lectures, and discussion groups.

Description of Materials Available:

1. *Investigating the Earth* (test book) laboratory manual, and two-volume teacher's guide)
2. Teacher training film, *Toward Inquiry*.
3. Equipment packages (see commercial affiliation section)
4. Newsletter, available upon request from the project headquarters.

Materials Purchasable:

1. *Investigating the Earth,* Houghton Mifflin Co., 110 Tremont Street, Boston, Massachusetts 02107. Textbook, two volume teacher's guide.
2. Equipment: Complete Package for 30 students
   a. Hubbard Scientific Co.
   b. Damon Educational, Inc.
   c. Raytheon Education Co.

INTERMEDIATE SCIENCE CURRICULUM STUDY (ISCS)

Purpose and Objective:

The student materials are written as a programmed study which allows them to progress at their own rate. The "package" will contain materials designed for all student levels. "Excursions" (supplemental materials) are written for both the better than average and below average students. The sequence features gradual building of process skills and sequential development of basic notions. Transition is from a tight structure in grade 7 to open ended activities in grade 9. The program stresses independent study through laboratory investigations which can lead to content mastery, process acquisition and scientific literacy.

Address of the Project:

Ernest Burkman, Professor of Science Education Intermediate Science Curriculum Study, Kellum Hall Basement, Florida State University, Tallahassee, Florida 32306.

Specific Subject, Grade, and Age Level:

Science for grades 7, 8, and 9.

Description of Materials Available:

1. 7th Grade core sequence, Vol. 1-2
2. 7th Grade excursion sequence, Vol. 1-2
3. 8th Grade core sequence, Vol. 3-4-5
4. Supplementary problems booklet, Vol. 1-2-3-4
5. Equipment Kit for Volumes 1-5
6. Teacher's manuals for Volumes 1-5
7. Achievement tests for Volumes 1-5
8. Computer-assisted instruction program for Volumes 1-2

Materials Purchasable:

Contact: Silver Burdett Publishing Company.

INTRODUCTORY PHYSICAL SCIENCE (IPS)

Present Commercial Affiliations:

Prentice-Hall, Inc., Englewood Cliffs, New Jersey 07632; MacAlaster Scientific Corp., 186 Third Avenue, Waltham, Massachusetts 02154; Modern Learning Aids; 1212 Avenue of the Americas, New York, New York 10036.

Purposes and Objectives:

To develop a one-year course in physical science for use in the junior high schools. The student laboratory work is of primary importance. To emphasize this the laboratory instructions are incorporated in the body of the text; the results are not described. The equipment has been designed in such a way that the students can perform the experiments in ordinary classrooms.

Address of the Project:

For information about the project contact: Introductory Physical Science (IPS), Education Development Center, 55 Chapel Street, Newton, Massachusetts 02160. However, to purchase materials contact the affiliated publisher. (See Materials Purchasable section.)

Specific Subjects, Grade and Age Levels:

The major emphasis in the course is the study of matter. The course has been extensively used in grades 8 and 9 with students who have a wide range of abilities. In addition, many schools have used the course in grades 11 and 12 for students who do not plan to take further physics or chemistry.

Materials Purchasable:

1. *Introductory Physical Science* (text) hard cover, paper back, from Prentice-Hall, Inc., Englewood Cliffs, N.J. 07632. *Teacher's Guide Introductory Physical Science, Achievement Tests,* also available from Prentice-Hall.
2. Laboratory equipment and supplies. Write for a catalog describing the equipment and supplies from either Prentice-Hall, Inc., or MacAlaster Scientific Corp., 186 Third Ave., Waltham, Mass. 02154.
3. IPS films are available from Modern Learning Aids, 1212 Avenue of the Americas, New York, New York 10036.

HARVARD PROJECT PHYSICS (HPP)

Present Commercial Affiliation:

Holt, Rinehart and Winston, Inc., 383 Madison Avenue, New York, New York 10017.

Purpose and Objective:

The presentation of physics in a broad, humanistic context and to show the connection between physics and man's other intellectual artistic, and social activities. Designed in the course is the maximum flexibility with regard to context, emphasis, and teaching strategies.

Address of the Project:

Dr. F. James Rutherford
Harvard Project Physics
Pierce Hall-G2
Cambridge, Massachusetts 02138

Specific Subject, Grade and Age Level:

Introductory physics course for High School and Junior College students.

Description of Materials Available:

1. 6 basic text units
2. 6 teacher guides
3. 6 physics readers
4. 6 student handbooks
5. Laboratory and demonstration apparatus
6. Overhead transparencies
7. Film loops and strips
8. Test booklets
9. Supplementary units
10. Programmed instruction booklets
11. Newsletters (Write the Headquarters for Free Copies)