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PRACTICAL HIGH SCHOOL BIOLOGY PROJECTS

BY

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A THESIS

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# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>List of Illustrations</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chapter</td>
<td></td>
</tr>
<tr>
<td>I. Introduction</td>
<td>1</td>
</tr>
<tr>
<td>II. Test-tube Aquaria</td>
<td>10</td>
</tr>
<tr>
<td>III. Observation of Ants</td>
<td>21</td>
</tr>
<tr>
<td>IV. Fish Dissection</td>
<td>32</td>
</tr>
<tr>
<td>V. Frog Dissection</td>
<td>41</td>
</tr>
<tr>
<td>VI. Identification and Photography of Leaves</td>
<td>51</td>
</tr>
<tr>
<td>VII. Terraria</td>
<td>65</td>
</tr>
<tr>
<td>VIII. Plant Experiments</td>
<td>79</td>
</tr>
<tr>
<td>IX. Chick Embryology</td>
<td>96</td>
</tr>
<tr>
<td>X. Conclusion</td>
<td>109</td>
</tr>
<tr>
<td>Appendix</td>
<td>114</td>
</tr>
</tbody>
</table>
# LIST OF ILLUSTRATIONS

<table>
<thead>
<tr>
<th>Plate</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Test-Tube Aquaria</td>
<td>17</td>
</tr>
<tr>
<td>II. The Ant Palace and Specimens</td>
<td>28</td>
</tr>
<tr>
<td>III. Dissection of the Fish</td>
<td>36</td>
</tr>
<tr>
<td>IV. Diagram of the Frog</td>
<td>48</td>
</tr>
<tr>
<td>V. Photograph of a Redbud Leaf</td>
<td>61</td>
</tr>
<tr>
<td>VI. Drawing of Seed Germination I</td>
<td>87</td>
</tr>
<tr>
<td>VII. Drawing of Seed Germination II</td>
<td>88</td>
</tr>
<tr>
<td>VIII. Hydroponics Experiment</td>
<td>89</td>
</tr>
<tr>
<td>IX. Chick Embryos</td>
<td>106</td>
</tr>
</tbody>
</table>
CHAPTER I

INTRODUCTION

The problem of this thesis is to present a number of biological projects which have been found suitable for development in a medial class in a secondary school with moderate equipment. It is intended that portions of this thesis will be used as a guide for instruction of future students, and as a basis for further development of the project method of approach to high school science. A beginning biology teacher will find this thesis a workable introduction to laboratory projects dealing with plants and animals.

Plato's theory, that education is a release of internals and learning a self-generated process, has been an inspiration in working out this series of high school projects. True education is a development of the hands, mind, and spirit, not a lamination of external facts.

In most high schools, biology is a required subject, and the teacher works with an unselected group. To be a successful subject it must have life and movement for it is the study of life. When the science
becomes an experience of textbook memorization interspersed with a laboratory study of inanimate objects, it is a dead subject to the student. The aim has been to promote mental growth, and to develop the satisfaction and adventure of personal discovery in a beginning science, for the arts, trades, and crafts of mankind are all expressions of physical energy directed by original thinking. In this search for knowledge teacher and pupil should form a partnership, each teaching and each learning. The requirements of the laboratory course should be adapted to the varying natural abilities and interests of the students.

The problems to be presented are those which, through actual experience and trial over a period of two years, were found to stimulate the mind and sustain the natural curiosity of this particular age group. Improvements were made and unsatisfactory materials deleted as experience indicated.

The world of science is a world of facts, and to be unable to discern and use these facts is to be in a state of ignorance. A desire to know precedes the learning process, but a problem must be accurately defined before observable facts seem of any importance to the student. In the average textbook a student is faced with innumerable facts that are of no personal concern to him
until he has a project or a problem to solve. In order to develop this personal concern, the teacher suggests a number of laboratory projects and allows the student to choose one that appeals to him. As an experience in original thinking the student is forced to make observations and test their worth, weeding out the non-essential from the essential, continually trying to find the answer to his questions. This trial and error method aids in forming a correct problem solving attitude and sustains active interest throughout the course.

The textbook, while forming the basis for the required course of study followed in the daily classwork, is enriched for the student by his contact with actual problems in biology.

Often a brilliant student finds that he lacks mechanical skill to carry out ideas which he has planned in his project. On the other hand, an otherwise slow student may prove an outstanding success in developing manual techniques. Each of these students has the opportunity to discover that his own talents are of equal value in this work. The teacher can team the thinker and the doer to their mutual advantage.

The need for special information, reinforced by interest, encourages wide reading and library research. In developing a project a student may acquire laboratory
techniques far beyond high school requirements. As he increases his knowledge of the physical world and of his relations to this world, an alert teacher can suggest and aid the transfer of this knowledge as a background for social studies and other school subjects.

Failure of expected results should not lessen the excitement of the student's research. He learns that negative answers are as important as positive ones. The question, "Why not?" can be as interesting as "Why?" It is important in a science, as in all experiences, to learn that failure can be a spur to continued effort.

In brief, the projects selected for presentation are those which have proved effective aids in (1) stimulating a spirit of inquiry; (2) developing correct problem solving attitudes and experiences; (3) providing opportunities for individual development of manual laboratory techniques and skills; (4) broadening and intensifying knowledge of the forces and materials of environment; (5) creating situations in which students may enjoy the excitement of successful exploration; (6) encouraging persistence when failure, attendant upon work with living things, is encountered.

Eight selected biological projects are presented by the dialectical method. The plan for each project
includes:

A. Suggestions for procedure
B. Difficulties encountered
C. A student's summary
D. List of materials and equipment
E. Bibliography (material usually available in a high school library)

(A) Since, in our crowded high schools, the majority of pupils are unfamiliar with a highly individualized method of study, confusion will result unless the teacher adequately prepares the class for the freedom of a laboratory workshop. A period devoted to the display and discussion of the achievements of the preceding classes is helpful. Because several groups of students will work simultaneously on different projects, the fundamental privileges of the project laboratory must be made clear. They include: freedom of movement about the laboratory; independent and varied individual activity; discussion of work between members of the group; observation of other projects; conference with the teacher when desired. As independence, if it is to be of value, implies responsibility, a distinction between license and freedom must be made.

Pupils may work alone, in partnership, or in small groups. Each student is required to keep a notebook from
the start to the conclusion of the project. Drawings, posters, photographs, and graphs are desirable, and accuracy of records with careful notation of individual endeavor is expected.

The semester's laboratory time should be divided by the teacher between the conventional laboratory curriculum and the projects. This division depends upon two factors: (1) the formal laboratory requirements, (2) the amount of detail that the students are expected to achieve in their projects. The problems outlined are exceedingly flexible, and may be limited to such variable periods as four, six, or nine weeks without losing their essential stimulating quality. From experience it was found that the best results were obtained from the nine weeks' period. Whatever limit is set, all projects should be completed at the same time. The final grade of the project is based on three achievements: a class demonstration, an oral report, and the submission of a satisfactory notebook.

(B) The meaning of the word laboratory is place of labor, and the basic courtesy of the laboratory must be a respect for the work of others including their table, their equipment, and their time. If a student does not follow this simple golden rule, he is removed immediately from group work. He is provided with mimeographed
study sheets, based on the textbook, and required to prepare daily written assignments. Since no one is indispensable, the group goes on, rarely giving much heed to the missing member. In every case, the necessity for such a removal was found to be temporary as segregation was painful to the student and so the lesson of cooperation was soon learned.

The laboratory class may consist of as many as twenty-five pupils. When a student encounters a difficulty which he believes requires consultation, he has to learn to be patient and to await his turn. He must be taught that laboratory time is limited and valuable. Other phases of the project can be developed while he is waiting for assistance. Recourse to the reading references together with notebook preparation is advised.

There is ordinarily no decline in interest if the teacher is continually alert to the needs of each group. Achievements should be reviewed and suggestions concerning failures made as often as progress ceases. To the teacher and student the urgent proverb, "Try, try again," becomes a prime requisite for success.

(C) All knowledge of matter comes to us through the windows of our senses, and learning is an intrinsic and personal experience. Whenever this learning process is desired, strong motivation of the student is necessary
before he will make the effort required in learning. There are as many ways and means of motivation as there are teachers and students. The project method is one way that answers simply and consistently the need for creative activity by the student, rather than an over-emphasis of that extrinsic agent, the teacher. This plan of instruction reaches students on all levels of intelligence, circumstance, and personality, and once started is self-generative.

(D) The materials and equipment given are those that were actually used and numerous variations are possible. Supplies not at hand in the laboratory were provided by the class. Whenever a project was repeated, it was found that students took pride in refining the techniques and improving the apparatus previously used, striving to produce more accurate and conclusive results.

(E) Each bibliography is divided into two sections. The first division contains the references intended to arouse curiosity and furnish inspiration; to provide a broad background of knowledge for the specific problem chosen; and to supply reading matter for those inactive periods that always occur in this type of work. The second portion is devoted to those references essential to the general outline of the project. In no one book, pamphlet, or magazine listed is there a complete
presentation of single project. This is neither to be expected nor desired since originality and thought on the part of the student is sought.

The appendix includes a representative program of projects presented by secondary school students for a summer session institute at Creighton University. Such a program may be an educational service for any interested group, and it is a valuable experience for the students.

Growth is natural to man, and the growing man has a growing mind which demands experiences that will increase his skill in thinking and in doing. Project work provides these experiences, and teaches that "the way things are is always tremendously more exciting than the way we thought they were!" To learn the lessons of patience and the necessity for obedience to natural laws, from nature, is a splendid opportunity.

To understand life and nature more fully is to recognize and accept the divine principle and power in all things. This is an objective of all science teaching.

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TEST-TUBE AQUARIA

Five students worked together on this project, each having his own equipment and keeping a notebook. The exchange of information gained through observations and the discussion of problems were encouraged. This cooperative sharing of information helped maintain interest and increased knowledge. The references listed in the bibliography were available for group use.

Procedure, Difficulties, and a Student's Summary

Student: What are test-tube aquaria?

Teacher: These three words can best be defined by considering them singly. Test, the first word, means to examine. Tube means a cylinder, in this instance, closed at one end and made of glass. The tube is closed at one end so that it will hold liquids, and is of glass for the purpose of permitting observation of the material inside. Now, we come to "aquaria." This word means vessels constructed to hold water in which are growing plant and animal life of aquatic nature. We can group the three words with the following result: a cylindrical tube of glass of the type used in testing materials, closed at one end and containing aquatic plant and animal life. The word, aquatic, may be strange to you; can you help define it?

Student: In Latin we had the word aqua, and in history we studied the Roman aqueducts. The words have a similar sound.
Teacher: That is right. *Aqua* is the Latin word for water; aquatic plants and animals are those which live in water. An aqueduct is a duct for water. The root or principal idea of the words aquatic and aqueduct is the same. If you notice how scientific words are built, learning to recognize common roots, you will be able to increase your vocabulary rapidly. Your Latin will help you to do this.

Student: How do we know this project will be interesting?

Teacher: To begin with you do not know, as you have done no reading on the subject, nor have you actually done any work of this nature. After you have read some of the references listed in section I of the bibliography, you will know more about it. This project is on the list because other students found it intensely interesting and exciting. If the reading matter does not appeal to you, try some of the references on other projects.

The students spend two or three days reading on the project and discussing it with each other comparing ideas before making their decision.

Student: We believe we would like to do the test-tube aquaria project. How do we start?

Teacher: Here is a list of the materials you will need; all of the supplies except the pond water can be obtained in the laboratory. Since you will want to identify as many aquatic forms as possible, you should take samples of water from as many sources as you can find, fish pools, stagnant water from roadside and wood pools, creeks, and lakes. Water standing in old tin cans will provide you with mosquito eggs. Whenever you take a sample, be sure to label it, telling the source and the date. If the source is deep, get samples from different levels, top, middle, and bottom, labelling each carefully. The opening of each test-tube can be corked until it is placed in the rack in the laboratory when a cotton plug is inserted which allows air to enter but prevents contamination.
After pupils collect samples, preparing them according to directions, they observe them with a ten-power lens.

Student: The samples of water that we collected are very different; some look different from the way they did when we first set them up. Here are three samples from the same pond. The one in the sun has a green scum with bubbles in it floating on the top. There is one with a greenish-brown color and the third test-tube has something moving around in it; it looks like a bug but is transparent. We would like to know what we are seeing and what is happening.

Teacher: I see you have found that your project is an active one. Now, you want to become a naturalist. When a naturalist makes observations, he has to recognize and learn the characteristics of the plants and animals he finds. Just as you can tell a dog from a cat by certain differences in bodily formation, you can identify the various forms in your aquaria. Observe all of the events and the inhabitants in these test tubes. Start your notebook by writing down your general procedure, and then put in it daily observations of all that you see in the aquaria. Describe any activity and all of the living things. Note any changes and anything new that appears. In addition to your eyes use your nose as it will help you to be prepared for the decay cycle that will eventually take place. By numbering each test tube, you can keep your notes in order. After the laboratory periods, try to explain or find an explanation for some of the things you notice. For example, why are there bubbles in the pond scum which has been in the sun?

Student: It is a puzzle to us where all these things, especially the insects, come from when our test-tubes are plugged with cotton. We didn't see anything a few days ago. Some of the forms we have been watching have disappeared. Perhaps they died, but we never find any dead ones.
Teacher: The answer to your puzzle was still uncertain until the time of the French scientist, Pasteur. However, we can tell you now, with certainty, that living things, no matter how small, never just appear; something never comes from nothing. All living things come from other preceding living forms. The answer to the last part of your puzzle is that all living things must either make their own food or eat other living things. Now, I'll ask you a question. What living thing can make its own food using a gas, water, and the energy from sunlight?

Student: We found that plants are the only living things on the earth that can make their own food; all the rest of us either eat the plants or other animals. In the references there are pictures of microscopic organisms, and we would like to see some of them.

Teacher: Fine. When you have studied the pamphlet, Care and Use of the Microscope, come to me and I will check with you and teach you to use this instrument properly.

Students, after studying the pamphlet, receive instruction from the teacher and practice with a few prepared slides.

Student: We believe that we know how to operate the microscopes, but how do we put the things we want to examine under the objective?

Teacher: Read the Turtox leaflet, How to Prepare Microscope Slides of Simple Objects, then, come to me, and I will see if you can apply what you have read.

After questioning the students, a few sample slides are checked, and they proceed. The first sight of a culture of Protozoa is a high point in this project, and it is well to let the students share it with others.
Student: All of these things moving in just one drop of water! They move so fast we can't make any observations.

Teacher: It will be necessary for you to find a clump of food material. When the animals are feeding, they are relatively still. Also, you can learn to move your slide, following them from place to place.

Student: Now, we want to know what we are watching.

Teacher: You are seeing many different living plants and animals. In your pond water there are Protozoa, fresh water algae, hydra, snail eggs, insect larvae, crustaceans, and others. In order to find out exactly which of these you are observing, get the book *Fresh-Water Biology* or one of the other major references. You will be surprised to find that with little effort you will be able to recognize and name some of the forms. You have looked at your specimens so much that it will seem as if you were finding pictures of old friends.

Student: We have identified and described quite a few of the animals and plants. Is that all we put in our notebooks?

Teacher: Not quite all.

Student: What else is there to do?

Teacher: Draw. Draw what you see, and label your drawings. Show the different stages of development in the snail eggs you are observing. Draw the insect larvae you find. Try to make a drawing of a Protozoan observed under the high power objective.

Student: We were afraid of this. We can't draw pictures.

Teacher: I don't want you to draw "pictures." I simply want you to draw what you see. It is not what you think you ought to see, or what you think things should look like that you are to draw.

Student: They won't be pretty or artistic.
Teacher: A simple line drawing with every line indicating something you see makes a good biology drawing. Neatness and accuracy are what count. The drawings will be your permanent records. If you observe well, they will be accurate. If you are careless in your examinations, they will show you how little you saw.

Student: Should we copy the details we cannot see from the reference books?

Teacher: No, because most of those drawings are composite drawings, that is, made by scientists after years of studying many specimens. Often there are details in the drawings not visible to an amateur using our equipment.

Student: Will you count off if we do not spell the long terms correctly in the labelling?

Teacher: Yes, you are learning how a scientist works, and accuracy is his watchword. The names are long and difficult, but if you find out the method and reasons for scientific nomenclature, they will not be so tedious to learn.

Teacher: Since you have studied the gross and microscopic forms present in your aquaria, I suggest that you make a hay infusion. Look up this method of culturing Protozoa in the references. If you wish, you may also try some of the Infusoria powder. These cultures will add many new forms to your collection, and you will have them available for your class demonstration.

The students complete their notebooks and prepare class demonstrations. The aquaria, slides of fresh material, and drawings are displayed. The oral report is a summary of the high points of the work including the achievements, conclusions, and failures. At the end of the report a free discussion and evaluation of the project occurs.
This project isn't easy, as I thought it would be, but it is interesting. I thought I would have time to sit around, but the laboratory periods were actually too short to do all of the things I planned. I learned to observe rather than just to look. I know how to use a microscope although I haven't been able to see everything that the skilled scientists can see. Maybe this is due to lack of experience. I learned to draw just what I saw, but the drawings were still difficult. I am proud of mine. I don't suppose that I shall remember the scientific terms very long, but I shall think twice before using water that hasn't been boiled or chemically treated. The two most important things I learned were that plants make food for the rest of us, and that there are many invisible worlds—even in a single drop of water.
PLATE I

TEST-TUBE AQUARIA
**Materials and Equipment**

- Cotton
- Cover glasses
- Hay
- Infusoria powder
- Low-power hand lens (x10)
- Microscope
- Pan
- Pipettes
- Pond water
- Slides
- Slide box
- Test tubes
- Test-tube brush
- Test-tube holder
- Test-tube rack
Bibliography


CHAPTER III

OBSERVATION OF ANTS

The best results from this project are obtained when two or three students work together, for ants are such busy little creatures that there is always activity to be observed in the ant house.

Procedure, Difficulties, and a Student's Summary

Student: I have looked over the list of suggested projects, and, since I have to do something, I have decided to do the observation of ants.

Teacher: The study of ants is always a popular one, but, before deciding definitely, read some of the references listed so that you will know more about the project.

Student: Is it all right for me to read some other books about ants instead of the ones you have listed?

Teacher: Of course, but read them in addition to those on your list. Other books may be as good, and, in some respects, better than those suggested. However, the references recommended were chosen because they give specific information you need, and they are all available in the high school library or laboratory. In reviewing the books, many were selected because they were written especially for high school students.

As the ant is familiar to the student, he will not require more than a day or two to make his decision.

Student: I have read parts of two references, and I believe that I want to do this project. My folks
said that they thought it would be a good idea as I might learn how to get rid of the ants in our kitchen. Probably, I won't learn anything as practical as that.

Teacher: Why not? As soon as you learn some of the characteristics of ants and the active ingredients of insect poisons, you will be able to recommend a method of extermination. The project method of instruction is designed to teach the practical application of scientific knowledge.

Student: Will I spend the entire time just looking at ants?

Teacher: No. You will prepare the ant house, secure a colony, and then, observe the insects. In all intelligent observation a definite effort by both eye and mind is required. Observing is seeing with learning. There is no doubt that you have seen many ants, but if you use your eyesight intelligently, some insight into their habits will be gained. To develop insight is one of your goals. Do not worry about having enough to do. You will find it more of a problem to get everything done. Many naturalists have devoted their lives to the study of ants, and, although they have recorded much information, our knowledge is not complete. I do not expect you to discover something new to science, although that is not impossible, but I do expect you to learn much of what is known about these animals through your own initiative.

Student: I did not realize that there was so much to it. When do I start?

Teacher: Fortunately, ants are obtainable in every vicinity, and can be collected at any season of the year. Before beginning your work, read carefully the Turtox leaflet, *Studying Ants in Observation Nests*, and the pamphlet, *How to Care for Ants*. Write down in your notebook a general plan of what you intend to do and any questions you may have. Check this material with me.
After the student has his procedure checked, he is ready to start the work of the project. The ant house is cleaned and filled with fine dirt. A small piece of clean sponge is placed in the house to serve as a humidifier.

Student: I have decided to stock the ant house with the large black carpenter ants. According to Turtox, different species cannot be mixed; I am going to start another colony of the red Formica in a glass-covered pan.

Teacher: Why start two colonies?

Student: The red ants are sometimes slave-maker ants, according to an article I read, while the carpenter ants are large and will be easy to see. One of the other students on this project didn't know what to do; I suggested that he be responsible for the red Formica.

Teacher: That is a good idea. I don't believe that we have had a comparative study of the characteristics of the two species. There are a few suggestions I would like to make before you get your colonies. It is important to get as many of the eggs, larva, and pupa as possible. Try to find the queen; she is wingless and larger than the others. If you find any other living insects in the nest, be sure to include them as they may be either parasites or animals living in a symbiotic relationship with the ants. Later, you can study the behavior of the ants toward these insects.

Student: What is a symbiotic relationship?

Teacher: I'll write the word down for you and you can look it up.

Student: What are the purposes of the sawdust and the red glass listed in the materials?

Teacher: When you capture the carpenter ants, take some of the sawdust from their excavations to place in the ant house with them. It is believed
that this sawdust forms part of their diet. This fact is questionable. Perhaps you can arrive at some conclusion regarding it. When you find out the reason for the red glass, you will be ready to use it.

The ants should be collected by the student over the weekend so that laboratory time may not be wasted with a hastily gathered, non-representative colony.

Student: I dampened the soil according to the directions, and I am ready to add the ants.

Teacher: To prevent injury to your specimens during the transfer, use the atomizer bulb attached to the tubing. The ants can be sucked up into the tube and then blown into the ant house without damaging them.

Student: I have discovered something very unusual. There are six winged ants in the colony. Are they a different species?

Teacher: Your project is progressing rapidly, but questions like this indicate that you need to do more reading. Write down your daily observations in your notebook. If there are questions, find the answers during your library periods or in slack moments here. Tell me tomorrow the answer to your question about winged ants.

Student: The ants have been very active this week, and I have many entries in my notebook. According to the references, ants have an antennae comb. I have seen them clean their antennae, but I can't see the comb.

Teacher: Remove one of the ants from the house, and, using a ten-power hand lens, examine it. Get a reference book and learn to identify the parts of the body. Make a detailed drawing of the living specimen, labeling all structures. When you have finished drawing the whole ant, make several drawings of the different parts of the body, the antennae, the mouthparts, and the posterior leg. Complete metamorphosis of
an insect is exemplified by the eggs, larva, pupa, and adults present in the ant house. Draw them in a life cycle. These drawings will be an important part of your notebook.

The average student will require about a week to complete the drawings in a satisfactory manner. During this time, the tunnels and rooms of the ant house have been started and the colony well established. If the student wishes, a valve may be arranged so that the tunnelling will occur only when he is present.

Student: My required drawings are completed, and I also made a drawing showing the tunnelling in the ant house.

Teacher: These drawings are fair. I am especially pleased to see that you figured out new work, and that you had the initiative to go ahead with it as evidenced by this plan of the nest. I am going to suggest several experiments for you to try. In addition, you may work out and try others.

Student: I have already used the whistle in the handle of the feeder plug. The ants come for food now when I blow it. Whether it is the sound of the whistle or my breath that affects them, I don't know.

Teacher: Find out. Also, can you think of a way to make them change that habit, now that they have acquired it?

Teacher: Here are the experiments I mentioned.

1. Place a small obstacle in a well-traveled runway. Increase the size of the obstacle. Note results.

2. Weigh a worker ant in a balance. I'll show you how to use it. Then, weigh a piece of dirt that you have seen her lift. Compare the ratio of the ant's weight with what she can lift to the ratio of your weight with what you can lift.
3. Measure the distance of a main runway, and time the speed of an ant under different conditions.

4. Place a red ant in with the carpenter ants. Place a housefly, beetle, or other insect in the house. Note the activity.

5. Do ants grow larger after they are removed from their pupal cases? Try a feeding experiment and see.

6. Crush a red ant. Remove a carpenter ant and smear it with the remains of the red ant. Place the black ant back into its ant house. What happens? On what stimuli does ant recognition depend?

The last experiment is a good reminder of the difference between sight and insight.

The project is completed, and the pupil makes his demonstration and oral report to the class. His conclusions should be general.

Student: Observing animals for six weeks is tiresome and requires patience, and trying to reach accurate conclusions about their activities requires effort. Ants are called social insects because they live in colonies and all work for the common good; however, they are not socially minded toward ants of the same species that are not a part of their own colony. There are only a few exceptions to this fact, and I didn't see any of them. The nest is more important than the individual ant as shown by the way ants tackle intruders and fight to the death. The eggs, larva, and pupa are the most important possessions of the society. They get constant care and attention from their nurses who try to save them when the nest is disturbed. The young ants do not look like the adults; the stages of growth are so different that they have special names. Some ants have ant slaves that they capture in the young stages. Many of the colonies have aphids, and other domesticated insects.
Teacher: You didn’t mention any discovery of a method of exterminating the ants.

Student: I told my folks, but forgot to mention it in my report.

Teacher: Finish your report by telling us how ants that are household pests can be killed.

Student: Ants chew and lap. I discovered this fact when I drew the mouthparts. They chew from side to side as scissors cut. This indicates that a poison may be placed on the surface of their food. However, such poison would only kill the foraging ants. A type of poison that has a corrosive action on the tracheae, as sodium fluoride, is effective. One of the latest methods is the use of paper strips impregnated with DDT. The paper strips last for several months and are handy for use in a kitchen.

The ant house may be cleaned and the ants destroyed at the conclusion of the project; or, the project may be continued with the same colony. One colony containing a fertile queen was maintained for an entire year.
PLATE II

THE ANT PALACE AND SPECIMENS
Materials and Equipment

Ant homes (purchased): The Austin Ant House
The Turtox Observation Ant House

Ant homes (built): Field nest, best adapted for scientific study. See Bibliography II, A Source Book of Biological Nature-Study by Elliot Downing for materials and directions for building.

Lubbock nest, well adapted for schoolroom observation. See Bibliography II, Handbook of Nature-Study by Anna Comstock for materials and directions for building.

Atomizer bulb and tubing
Food for ants
Forceps
Garden trowel
Hand lens (xl0)
Pipette
Sawdust
Small piece of sponge
Specimen jars
Ten inch square piece of red glass
Bibliography


CHAPTER IV

FISH DISSECTION

The dissection projects, the fish and the frog, may be assigned to several congenial pupils to their mutual interest and advantage. A spirit of emulation in a group is a stimulus to greater achievement. However, each individual must have his own specimen and dissection set.

Procedure, Difficulties, and a Student's Summary

Teacher: Are there any pupils in this class who plan to study nursing?

Student: I want to be a nurse. That is the reason I signed up for this course.

Teacher: Fine, then you will need dissection experience. The dissection of the frog has been chosen by a student who wants to be a doctor. The dissection of the fish has similar problems. The two projects can be coordinated, and their solution can be more readily achieved with mutual assistance. A comparison of the analogous and the homologous structures in both animals can be made.

Student: My mother is a nurse, and I could borrow some of her old dissecting instruments.

Teacher: Tell your mother about the project, and ask her opinion of its value to you.

Student: My mother says that of late years many students entering nursing from small high schools have
had no experience in actual laboratory work; they have studied and copied drawings from their textbooks. These students have not learned to use their hands, and find it difficult to apply what they learn. If I study and do my dissection conscientiously, I will have an advantage over students who have not had a course incorporating this work.

Teacher: Now that you have decided to study the fish, read The Life Story of the Fish by Brian Curtis. In my opinion, this book combines technical accuracy with humor in an unusual fashion. William Beebe, who wrote the introduction to it, says: "As you read it, you learn and laugh, and learn again." Here is a list of questions that you should be able to answer when you have read the book.

The list of questions is appended to this chapter.

Student: I am following the laboratory manual for the dissection, and here is a drawing of the lateral view of the perch.

Teacher: This is an artistic representation of a perch, but it is not a useful laboratory drawing. Read the leaflet on laboratory drawings and try again. Ask questions if you do not understand any phase of the dissection. Before you complete your study of the external structures, mount a scale on a slide and observe it with a hand lens. Fish scales have growth rings like tree trunks, and the age of the fish can be determined from them. You will not be able to do this, but you will see the growth rings. If possible, get scales from other species and compare them with those of your specimen.

Student: I have opened the body wall.

Teacher: From this point on I want you to collaborate with the pupil working on the frog. Compare

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the visceral organs and their arrangement
within the body wall. Make comparisons of each
organ, and then, each system, as you proceed.
Note the similarities and the differences, ex­
ternal and internal, between these animals. In
your notebook try to explain or suggest possible
reasons for what you find.

At the conclusion of the project, be­
sides a report on the dissection, the
student is asked to make a brief sum­
mary of some of the results of the
comparative study of the two animals.

Student: A fish is a vertebrate with usually scaly skins,
permanent gills, and paired fins. According to
Brian Curtis, it is practically impossible to
make a universal statement about fish. The
words "always" and "never" are misleading when
discussing them since fish differ so much. The
perch is considered a perfect example of a fish
by biology teachers. It is highly specialized,
but not an oddity. While the fish is well
adapted to its environment, the adult frog
leads a double life, and cannot be perfectly
adapted to both water and land. Externally,
the frog differs from the fish in possessing a
smooth skin, legs, eyelids, a neck, and no gills.
Internally, the scientist feels that the frog is
a step ahead of the fish. The frog's skeleton
is stronger, in most cases, since it must sup­
port the animal in the air. A three-chambered
heart is found in the frog as compared to the
two-chambered heart of the fish. The frog has
a movable tongue which is used for catching
food. One reference said that such a develop­
ment was necessary for the articulation of
sound. This does not mean that fish do not make
sounds. Some do, with the air-bladder. The
fish breathes with gills during its entire life.
In the life history of the frog is found the
change from a gill-breathing tadpole to a lung­
breathing adult. I appreciated the opportunity
of comparing my project with a related one. I
learned something about the frog, and the neces­
sity of explaining my work to another student
taught me more about the fish. As I acquired
manual laboratory skill and gained self-con­
fidence, I began to enjoy dissection. I
learned to follow instructions accurately, and that is one of the most important requirements of a good nurse.
PLATE III

PERCA FLAVESCENS

DISSECTION OF THE FISH
Can You Answer These Questions?²

Why are fish slimy?
Can fish tell color?
Do fish ever stop growing?
Can a fish smell and taste?
To what extent do fish feel pain?
How can you tell the age of a fish?
Can catfish taste with their tails?
How does the weakfish make a noise?
Can the fish get along without fins?
What fish lives inside another fish?
How does the fish recognize heat and cold?
Why have very young tarpon never been found?
What is the greatest fighter among all fish?
Does the trout see the fly before it hits the water?
Do fish drink water? Do saltwater fish drink salt water?
How does the flounder get two eyes on one side of his head?
Why is the fish's face one of its notoriously weak features?
Do salmon return to the same stream in which they were born?
Are there any cases of internal development of young in fish?

Is it true that a fish can see a man before a man can see a fish?

Why are tarpon and trout considered low and primitive forms of fish?

Why do trout like swift streams while the carp can live in a mud puddle?

In what species does a mother fish become the father of her own granddaughter?

Why should a fish be handled with wet hands only if you wish to return it to the water?

In what one locality do eels of all countries bordering the North Atlantic gather to spawn?

What is a fish?
Materials and Equipment

- Dissecting pins
- Dissecting sets
- Dissecting trays
- Formalin
- Fresh or preserved specimens, preferably perch
- Sheet cork
- Stoneware storage jars

Turtox Key Card for Perch Dissection, Subject No. 13.11
Turtox Key Card for Perch Skeleton, Subject No. 13.14

If living specimens are to be studied preceding dissection, an aquarium is required.
Bibliography


CHAPTER V

FROG DISSECTION

The dissection of the frog is of special value to students who intend to major in biological science. The adaptation of structure to environment is particularly evident in the life history of the frog, and the complexity of the animal is a challenge to the student's ability. Four or five students usually volunteer for this project.

Procedure, Difficulties, and a Student's Summary

Student: When I finish high school, I plan to become a doctor. Some of my friends who are doctors tell me that the knowledge gained from dissection will help me in a pre-medic course. I believe that the frog is somewhat like a human being in structure so I would like to dissect it.

Teacher: This project will give you a little preview of the future. Even if you do not go into medicine, you will find it of value because you will know more about your own body after you have concluded the work.

Student: Shall I catch a frog, bring it to school tomorrow, and start to cut it up?

Teacher: You could bring a frog; however, we have specimens that are preserved and especially prepared for dissection.

Student: I thought it would be fun to catch and bring my own frog.
Teacher: Very well, bring your frog. You can keep it in woodland terrarium. The pupils who are working on the terraria project will be glad to add your frog to their collection. Then, you can make a drawing of the external structure from your living specimen, and observe its characteristics, habits, and protective coloration in the natural surroundings of the terrarium.

Student: I have decided that I am not going to make any drawings of my project.

Teacher: I see. Suppose that when you are a doctor, a patient comes to you and says, "I am too fat and I want to get thin." What would you do?

Student: I'd examine him and if he should diet, I'd give him one.

Teacher: What would you say if he said that he wanted you to make him thin, but he would not diet?

Student: He couldn't take off weight if he wouldn't diet.

Teacher: You signed up for this project. Drawings are a part of it.

Student: I want to dissect the frog, but I don't see why I have to draw it.

Teacher: All of the science books have diagrams to supplement the reading material because the authors know that a written description is not enough. Your observations are not enough to learn about the frog.

Student: I still don't want to make the drawings.

Teacher: If you are unable to fulfill the requirements, I shall be unable to give you a grade. Wishes do not always coincide with obligations.

Student: I suppose I'll have to do them?

Teacher: Yes.
Student: After I have drawn and studied my frog, shall I dissect it?

Teacher: Would you want to kill it?

Student: I don't know.

Teacher: You won't have to make that decision. You will not dissect your frog. Preparing specimens for dissection demands technical skill which you do not possess. A distorted animal with organs imperfectly preserved is unfit for accurate dissection and careful study.

There are valid reasons for not permitting students to kill their specimens. Young students may not be accustomed to death, especially when they are the direct cause of it. Often, they will indicate repugnance, vocal or silent, to the idea of the teacher performing the operation. Sometimes, the psychological shock of killing and then working on a body so recently observed in its natural activities will cause the pupil to want to drop the project. Then, there is the rare student who is intrigued with the act of killing. This abnormal tendency should not be encouraged.

Student: I have completed the drawing, and have started my notes of all the things I see the frog doing. Yesterday, I placed several flies in front of it, but they are still in the terrarium. How often do frogs eat?

Teacher: This drawing can be improved by making the sketchy lines definite. Show it to me again. Were the flies alive or dead?

Student: They were dead. Why?

Teacher: Your frog will starve if you don't learn more about it.

Student: Tell me what to do.
Teacher: That frog belongs to you and is your responsibility. Part of your job is to learn all about it and how to take care of it. Why not consult The Book of Wild Pets by Clifford Moore?

Student: My frog was really hungry for living insects. I thought it was just sluggish, but I guess I was the sluggish one. Now, can I have the preserved specimen? I can cut it up and watch the frog in the terrarium too.

Teacher: After two or three laboratory periods, you may start the dissection, and it will be a full time job. You will not cut up a frog because that is not the true meaning of the word "dissect." You would spoil your specimen if I gave it to you when you did not know how to use it properly. Read the leaflet, Laboratory Dissections. Acquaint yourself with the different instruments in your dissection set. Learn what tools to use and how to use them. Study the directions for dissecting. A definite plan of procedure is clearly outlined in the Laboratory Manual of General Biology by Arnold and Duggan. After you have read the directions, review each step mentally. Have in mind a complete outline of just what you are going to do. Work constructively, not in a hit or miss fashion. When you are ready to begin, let me know, and I will check with you.

After the teacher is satisfied that the student knows how to proceed, the specimen and other materials are assigned to him. At the same time directions for their care are given.

Student: This frog smells terrible.

Teacher: The odor is formaldehyde. That is one of the chemicals used to preserve the frog so that it will not decay. No germ can live in this solution. The frog is cleaner, in this sense, than your hands. Wash it in cold water before you begin. Gradually the odor of formaldehyde will not be so noticeable.

Student: You said to keep the frog in a jar of fresh
water when I am not using it. Won't it start to spoil?

Teacher: No. You will finish the dissection before there is any danger of decay. When you have exposed the viscera, as explained in the instructions, locate the different organs, being careful not to disarrange them any more than is absolutely necessary. Then, draw the ventral view of the frog with viscera exposed; show each organ in its natural position and label carefully.

Student: If I draw what I see, my drawing won't look like the diagrams in the books because this frog looks different inside.

Teacher: A diagram is a generalized plan giving only the essentials. The diagrams in the books are made for purposes of instruction. Some of the organs may be deleted or shown in a different position in order to display the structures underneath. You are drawing a particular specimen, and your drawing should look as much like it as possible. Be accurate. Don't sketch. Scratchy lines do not conceal, they indicate faulty observation and lack of knowledge. Remember, the labelling represents about fifty per cent of the work. Never forget that the purpose of a laboratory drawing is to gain knowledge, to perfect your ability to observe, and to provide you with a permanent record of what you have observed. When you can identify the visceral organs, you must study their functions. Correlate your reading with your laboratory activities.

Student: How am I going to demonstrate to the class what I have done? If I follow the directions in the manual, only the skeleton will be left when I finish the project. I can tell them quite a few things from my notebook, but I cannot illustrate the report of the dissection.

Teacher: What about using the living frog?

Student: I could show it in the terrarium, and tell about its habits and environment.
Teacher: Get all of the pupils working on frogs together. Let them select two or three of their best drawings. One of the group can enlarge these on show card paper.

Student: They would look nice colored.

Teacher: By custom, each system is designated by a special color for easy and universal recognition. Find out what these specific colors are and use them. During the oral reports these drawings can be used by each member of the group to teach the class about the frog. Be sure to give credit in your report to the person who prepares the demonstration drawings. We will file these drawings for future use.

Student: I have located and drawn the external muscles as directed in the manual. Shall I go on and do the sense organs and the nervous system?

Teacher: Yes. The dissection and removal of the brain and spinal cord will be a difficult job.

Student: With this sharp scalpel it shouldn't be hard to do. I'll just cut down through the bone. Ouch! I've cut myself. Look at the blood!

Teacher: Let me see your finger. This isn't a bad cut. I'll get my first-aid kit and take care of it for you.

The teacher gives immediate first-aid, and if there is a nurse in the building, sends the student to her for further treatment. An accident report must be made out for the principal to protect the school board.

Student: That scalpel slipped.

Teacher: Sharp tools must be handled with care to avoid accidents. You were impatient and in too big a hurry. The skull of the frog is thin but fairly resistant. The nerve tissue under it is very soft. Let me show you how to begin.

Student: I see how to do it.
Teacher: Try to remove the brain so that the olfactory nerves and other cranial nerve attachments are left intact. Make dorsal and ventral view drawings.

When the dissection is finished and the drawings completed, sets of the Turtox Key Cards should be distributed to the students. Have them compare their drawings, check their labelling, and evaluate their work.

Student: Can't I study the Turtox cards and then give the class an oral test from them when I finish my report?

Teacher: That is a splendid idea. You test the class, and we will see how much they were able to learn from your report. What are you going to tell them? What have you learned in this project that will help you in your everyday living?

Student: I am going to tell them that an animal is a very wonderful organism; much more difficult to understand than a man-made machine. In another project I was amazed to see the microscopic, one-celled animals, and when I found that a frog has millions and billions of cells all working together to make it function, it seemed like a miracle. I found that a body is so sturdily constructed that it is very adaptable, and yet is made of such delicate material that it must have intelligent care. I know what dissection means and, doing it, I discovered that it required manual skill. My uncle who is a doctor once said; "Medicine is an applied science. To apply it you must be able to use your head, your hands, and your heart. The knowledge you have of medicine will do your patients little good unless you can use it to their advantage. Your hands, which you must train, are the instruments of your mind."
INTERNAL ORGANS
FEMALE RANA PIPiens

DIAGRAM OF THE FROG
Materials and Equipment

Dissecting pins
Dissecting sets
Dissecting trays
Formalin
Fresh or preserved specimens, preferably *Rana pipiens* or *Rana catesbeiana*
Sheet Cork
Stoneware storage jars
Turtox Key Card for *Frog*, Subject No. 14.5
Turtox Key Card for *Frog Brain*, Subject No. 14.13
Turtox Key Card for *Frog Dissection*, Subject No. 14.6
Turtox Key Card for *Frog Urinogenital Systems*, Subject No. 14.12

If living specimens are to be studied preceding dissection, a terrarium is required.
Bibliography


CHAPTER VI
IDENTIFICATION AND PHOTOGRAPHY OF LEAVES

Because of the photographic procedure, two students must work together on this project. Generally, the equipment is limited, and this problem is restricted to two sets of partners. Each partnership works independently. A practical and beautiful collection of leaf photographs can be made for reference use.

Procedure, Difficulties, and a Student's Summary

Student: Can we choose our own partner?

Teacher: Yes. There is much to be done in this project, and you will find it easier to do if you choose a partner who can help you pull the load. Since I am not acquainted with you, I do not know which of you work well together. However, as the semester progresses, if I see that you are not fulfilling the requirements, and that one of the partners is shirking, I shall replace that person.

Student: Can we have any fun doing this project?

Teacher: We are not here for fun. Work is the prime reason for our meeting. There is much enjoyment to be gained, but pleasure is not the major consideration.

Student: I guess I will look for another project.

Teacher: For the moment that is your privilege. However, in fairness, I must warn you that the projects are being assigned rapidly. By the
time you are ready to decide, you may find that you will have to take what is left.

Student: My friend and I have been fellow scouts, and we are accustomed to working together. We learned how to identify some of the trees, and believe that we would like this project.

Teacher: Good. You will find reference books in the bookcase and in the library. Plan a collecting trip for the leaves will be dropping soon. Take a heavy manila folder containing damp blotting sheets with you. Select several perfect leaves from each tree for leaves break easily, and you will need one perfectly pressed specimen from each tree. Flatten the leaves carefully and place them between the blotting sheets in the folder. Bring your specimens to the laboratory in the morning before school.

Usually the students will bring leaves the following day. By giving instructions before school, they are ready to start work during the laboratory period, and the teacher will have more time to devote to other pupils.

Student: We collected fourteen leaves from six different kinds of trees.

Teacher: That is a fine beginning. While you are pressing the leaves, remember to change the blotting sheets every two or three days as the moisture from the leaves encourages the growth of mold. What kind of a leaf is this?

Student: We do not know, but we thought we could find the name of it in one of the references.

Teacher: You would find it difficult to identify this one because it is not an entire leaf but a leaflet.

Student: What is the difference between a leaf and a leaflet?
Teacher: I will give you a clue. The leaf from this tree is composed of from thirteen to forty-one leaflets.

Student: How can you tell where a leaf ends?

Teacher: That is a good question, and you can locate the answer to it in any of the main references.

Student: The vocabulary that those books use in describing the leaves and trees is too hard to understand.

Teacher: Use the Turtox Key Cards for Leaves to learn the names of the leaf types, venation, and margins. There is a diagram with each term so that you will find them easy to understand. I want you to learn to use a key also.

Student: A key?

Teacher: A key, in this case, is a series of clues to lead you to the name of the leaf you wish to find. There is a simple key with directions in Trees of the Eastern United States and Canada by William M. Harlow.

Student: After we have identified the different leaves we can find around here, what can we do?

Teacher: In your notebook you should not only list the leaves you identify, but note and describe the trees on which the leaves grow. Make a check sheet to take with you in your field work. For each specimen note the environment, shape, size, bark, and flowers or fruit. Since you want to make your collection as large and complete as possible, write to friends or relatives living in different sections of the country. Ask them to send you pressed leaves from trees indigenous to their area.

Student: Do we have to write those letters?

Teacher: No, that was merely a suggestion.

Student: Aren't we supposed to do some photography?
Teacher: Yes. You are going to photograph leaves. Drawings of leaves are not always accurate. There is such fine detail in some leaves that it is tedious work; often, the effort is out of proportion to the result. Leaves do not make a practical collection as they are very fragile.

Student: Are we supposed to have a camera?

Teacher: You do not need a camera. These pictures will be taken without a camera; you will not even use a lens. We reproduce the leaves in their exact size and with complete detail of venation and margins.

Student: I would like to see that.

Teacher: You are not only going to see it; you are going to do it. Read the references on making contact prints, and the developing of photographic papers.

The making of the prints should not be undertaken until the collection and pressing of specimens is completed, identification finished, and the notebook up-to-date on this phase of the work.

Student: We have read the references on photography. If you will help us, we would like to get started. Where can we make a dark room?

Teacher: There is a storeroom down the hall without any windows so there will be no light coming in from the outside. You can make it light tight.

Student: We masked the door cracks with black cloth, and made a "no admittance" sign to hang on the door while we are developing prints. Can we print some of the pictures at home?

Teacher: Yes, if you wish to go to the expense of buying the equipment. Such an investment is unwise unless you wish to do photography as a hobby. We have materials here for you to use in school, but you cannot take them home with you.
Student: We have decided that we will do the printing here.

Teacher: You can mix your chemicals here in the laboratory. Follow the directions given on the packages. It is best to mix them in the bottles in which they will be stored; one bottle for the print developer, one for the short-stop, and the third for the hypo. You will note that there is a temperature recommended for the water at the time of mixing and another recommended for the working solution. Use a thermometer to check the temperature. As the temperature for mixing is higher than for working, do not use the chemicals for printing immediately after mixing. Let them cool to the proper temperature. If you are in a hurry, you can cool them by running cold water over the outside of the bottles. Notice that the bottles are brown. Only one solution must be stored in a brown bottle, but it is customary to store all in brown bottles.

Student: We have mixed the chemicals. It was a hard job because they clumped up and formed masses which were difficult to dissolve. Why?

Teacher: You did not follow the directions accurately. The water was not at the proper temperature, and you did not add the chemicals slowly and with continuous stirring. Did you discover which of the three solutions must always be stored in a dark bottle?

Student: Yes. The print developer must be stored in a dark bottle because if light falls on the solution, it will cause a change in the chemicals. Then, the solution will not develop the emulsion on the paper.

Teacher: Here are three enameled trays. Use one for the print developer, one for the short-stop, and the third for the hypo. When you put the trays on the work table, set them at least three inches apart. This will help to avoid contamination of the different solutions when you move the paper from one tray to another.
Fill the print developer tray and the short-stop tray no more than one-third full as the two solutions will not be used again. Allow for the displacement of the printing papers and fill the hypo tray.

Student: The instructions for the developer and short-stop state that they can be used again.

Teacher: That is true; they can be used again when ordinary snapshot prints are desired. The prints that you are going to make will form part of a permanent collection, and you should try to make them perfect prints. If you were going to learn film development as well as print development, you would have to sacrifice perfection for speed in order to complete the work in the given time. Since you are learning only paper development, strive for quality, not quantity.

Student: What is this thing that looks like an empty picture frame?

Teacher: That is a printing frame. It is used in contact printing.

Student: A printing frame? How do we use it?

Teacher: You load the frame with printing paper and a leaf. The leaf should be centered artistically. There must be no folds in it. If you have a fold, no detail will show at that place as the light will not be able to penetrate through the leaf to the paper.

Student: I see how you take the frame apart, but what do we put down on the glass?

Teacher: Place the leaf on the glass; then, the paper with the emulsion side toward the leaf and glass. Put on the back press, and lock it at all four points. This entire procedure has to be done in darkness as the paper would come out of the developer totally black if exposed to light.

Student: That will be hard to do in the dark. I don't think we can do it. If we can't see the paper,
how can we distinguish its emulsion side?

Teacher: Practice loading the printing frame in the light. To distinguish the emulsion side of the paper, even in the light, is difficult. You will use the same method in the dark that you have to use in the light. Feel a corner of the paper; the emulsion side is concave; the convex side has no emulsion on it. It is surprising how delicate our sense of touch is. If you are still uncertain, place a corner of the paper between your teeth and bite lightly; the side that adheres slightly to your teeth is the emulsion side.

Student: According to the books, the density of the negative and the speed of the paper determine the length of exposure and the amount of light. How can we tell the density of the negative when we are not using one? What is the speed of the paper?

Teacher: Technically, you are using a negative to make a negative. The leaf is your negative. You have to experiment with the length of the exposure and the amount of light necessary because the amount of light transmitted through the average leaf is too small to permit accurate readings on a light meter. The speed of the paper is determined by the emulsion, and is of no importance here. The print on the paper is a negative also, for the light areas of the leaf will be dark and the dark areas will be light. Your picture will be what is known as a "paper negative." It could be used to make a positive print, but you would lose detail in reprinting.

Student: You said to use a sixty watt lamp in a reflector for the source of printing light. How far do I stand from the light when holding the frame for the exposure?

Teacher: The answer to this question involves one of the laws of physics. The intensity of the light varies inversely as the square of the distance from the light source. If you find, upon development, that the picture is too dark
after an exposure of ten seconds while holding the frame two feet from the light, you could either give the paper less exposure or stand further from the light. However, if the picture is too light, you can either give a longer exposure or step nearer the light.

Student: Do you have any suggestions about developing the pictures that are not given on the pamphlet enclosed with the chemicals?

Teacher: Yes. Through experience, I have learned that certain points should be emphasized to students before they proceed. The time that the print remains in the developer depends upon the time recommended by the manufacturers of the developer and the paper. Generally, this is from two to three minutes. The prints should be agitated constantly during the time they are in the print developer. Use the print tongs in transferring prints from one solution to another as some people are allergic to photographic chemicals. The print should not be in the short-stop more than thirty seconds, nor in the hypo more than twenty minutes. Then, place the prints in a pan of cold water in the laboratory sink and wash them in cold running water for at least forty-five minutes. A longer washing period is recommended. If you have to leave for your next class before the washing is completed, tell me when to set them aside. You can dry them later. Now, we shall make one print together.

The teacher demonstrates the procedure from the loading of the printing frame to the drying of the prints. The students will have failures, but must learn through the trial and error method from this point on.

Student: Making these prints is discouraging. We made three good prints yesterday, and left them to dry between blotting sheets over-night. When we looked at them this morning before school, they had some ugly brown stains on them. Since they were fine yesterday, there is no reason why they should be ruined today.
Teacher: This discourages me more than it should you. Your last remark is illogical, isn't it? There is always a reason for failure if you search for it. Nothing is ever completely static. What was there on the paper that could cause staining?

Student: The emulsion?

Teacher: All of the printing paper has an emulsion on it. The staining must be due to something in contact with it.

Student: We had the paper in chemicals.

Teacher: Did you take the paper directly from the hypo solution and dry it?

Student: Oh no, we washed it.

Teacher: You did? The stains were caused by your failure to wash all of the hypo out of the paper. You did not follow directions very well. Look up your instructions now. Find the place where you are told to wash the prints in cold running water for at least forty-five minutes. Do you have it?

Student: Yes, it's here all right, but I didn't think this direction was very important.

Teacher: I noticed yesterday that you finished developing the prints so late in the period that you had only ten minutes to wash them. After a ten-minute wash, you put them between blotting sheets to dry.

Student: We came back after school to change the blotting sheets. The prints were all right then. Why didn't you say something about it to us?

Teacher: The actual reacting of chemicals is not necessarily visible. I knew that the prints would probably stain, but I wanted you to learn from personal experience that laboratory directions must be followed accurately for successful results.
Student: This mistake helps to make believers out of us. We won't be so careless next time.

Teacher: You have just one week now to complete as many good prints as you can. Remember quality is more important than quantity. Only good prints will be added to the collection.

The teacher supervises the selection and mounting of the prints. A typewritten label, giving the genus, species, and common name of the leaf, is pasted at the lower right of each mount. Average students, working in partnership, should complete five or six good photographs. The class demonstration includes the notebook, the pressed leaves, the photographs, and a display of the equipment. In the report the student summarizes the procedure and the results of the project.

Student: We collected fifty-two leaves, then started working on the pressing, identification, and check list of the tree characteristics. We could recognize quite a few of the leaves at once. We learned how to use a key for those that we had to identify. At first, it was more difficult to use a key than to compare our leaves with the pictures in the reference books. However, we found that the key was a great help in identification when there were several similar leaves in a family. The photography was the hardest but most interesting part of the project. When we learned how to do it successfully, we had time for only six prints that were acceptable for the permanent collection. I would like photography for a hobby if I could earn enough money for the equipment. After working with leaves so much, I can identify most of them on sight.
PLATE V

PHOTOGRAPH OF A REDBUD LEAF
**Materials and Equipment**

Blotting paper sheets or newspapers  
Contact paper  
Glass stirring rods  
Hypo  
Leaves  
Manila folder or vasculum  
Press  
Print developer  
Printing frame  
Print tongs  
Rubber cement  
Safe light, optional  
Salon mounts, optional  
Short-stop  
Sixty watt bulb in a reflector (Reflector can be made by students)  
Thermometer  
Three brown bottles, gallon size, with plastic screw tops  
Three enameled trays  
Turtox Key Cards for Leaves I, Extremities and Margins, Subject No. 24.41  
Turtox Key Cards for Leaves II, Types and Venation, Subject No. 24.42
Bibliography


CHAPTER VII

TERRARIA

This project is flexible and can be adapted to the slow student. The association with good students in group work and the actual contact with living plants and animals are stimulating to the student who has no interest in formal laboratory work. A corresponding improvement in classwork and in general attitude is often the result.

Procedure, Difficulties, and a Student's Summary

Teacher: A number of students who could not decide on a project have asked me to assign one to them. The terraria project is ideal for this group because of the variety of living plants and animals involved and of its interest to the entire class when completed.

Student: Are we going to have living plants and animals?

Teacher: Yes. Biology is a study of life. While your textbook is essential, and the dissection of preserved forms is very important, we should have the opportunity of observing and studying some of the living plants and animals we read about.

Student: What is a terrarium?

Teacher: A terrarium is a glass case containing a small plot of earth in which are growing plants. In this container we can reproduce, on a miniature scale, different environments, a woodland, a bog, or a desert. If the case is large enough,
the animals which can live in the environment may be placed there.

Student: Can we make a woodland terrarium?

Teacher: I suggest that you make three terraria, a woodland, a desert, and a bog. Since there are seven of you in the group, two students could work on each terrarium, and one student could be responsible for the care of the animals.

Student: Is there a lot of reading in this project? I don't like to read, especially anything uninteresting. I can't understand the hard words in the science books, and I can't spell them. My mother says that no one in our family can spell. I would like to take care of the animals.

Teacher: There is not as much reading in this project as in some of the others. You will read the references listed in the second part of the bibliography in order to get the directions for making the terraria. Then, as you progress in the work, you will want to find out about the animals and plants in your care. You have an idea that science books are not exciting. Many of the common little garden insects around you live "believe it or not" lives. There is nothing as strange in fiction as the insect-eating plant, the Venus flytrap, or the little horned toad which isn't a toad at all and which squirts blood from its eyes to frighten its enemies. Did you know that the ability to spell is a result of observation and effort, and is not an inherited trait? You can learn to spell whether your parents can spell or not. Make a list of all of the new words you find in this project. Write them correctly and practice spelling and defining them. This can be a part of your science notebook.

Student: Do we all work together or separately?

Teacher: You will be responsible for your individual terraria and personal notebooks, but in the collection of specimens and supplies you will
work as a group. In this way you will know something about the other terraria and have an interest in all of them. Read The Book of Wild Animal Pets by Clifford Moore, and the pamphlet, Feeding Aquarium and Terrarium Animals, for necessary information.

Student: We have decided among ourselves who is to do each terrarium, and we have read and discussed the reference, The School Terrarium. Do you have the cases for the terraria?

Teacher: We have three large aquaria that are fine for this work. How have you divided up the responsibility for the supplies?

Student: We have made a list of everything we need, and we are going to keep a record of the students who bring supplies. What animals live peacefully together in a woodland terrarium?

Teacher: Not all of the specimens will live peacefully together as some provide food for others. Make your field trips before frost. Gather the plants for the terrarium. When it is ready, collect frogs, toads, salamanders, snakes, insects, and garden spiders.

Student: We have fixed the soil for the woodland terrarium as the instructions directed. We have planted Boston and maidenhair ferns and an elm seedling. Half of the soil we have covered with moss and the rest with blue grass. We are going to get some small leaved ivy and try to find some plants that will bloom.

Teacher: In the spring hepaticas, Dutchman's-breeches, Jack-in-the-pulpit, and violets make nice specimens for the terrarium. In the fall household plants, the African violet, cyclamen, dwarf geranium, and succulents will do very well. Liverworts are not flowering plants, but they are very interesting. Look them up in the references and try to find some.

Student: We have the desert terrarium started. It looks rather bare and dry. We have planted five different prickly cacti that we bought
at the dime store, but we don’t know their names.

Teacher: There is an excellent book in the references that deals only with cacti. You will want a Christmas cactus or some other spineless form for the lizards to climb. Make a reflector for a light bulb. Suspend it over the terrarium. Warmth and light are necessary if desert animals are to be healthy and active.

Student: There aren’t any desert animals in this vicinity. Where can we get some?

Teacher: Find out what animals are native to a desert environment, and which of these are suitable for your terrarium. Then, find if they are available in the catalogue of the biological supply house. We can order a few specimens.

Student: The bog terrarium is filled with the acid soil, but we don’t have any plants or animals yet.

Teacher: Read the leaflet, Field Collecting Hints—Botany. Search the bogs around the rivers and lakes. Collect any small plants you find in these areas. You can identify them later. You may also send to the biological supply house for a Venus flytrap, a sundew, and a pitcher plant. These plants are not found in Nebraska, but their adaptation for food-getting is so peculiar that most textbooks discuss them. You will have them to explain and show to the class. As for the animals, when your terrarium is planted, you can keep successfully any of the amphibians. If you wish to provide a pan of water, you can include a crayfish, a minnow, and some duckweed.

Student: I am going to take care of the animals. I have read about the food habits of all of the animals the other students have or are going to order. I have some meal worms started, and I am going to paste a diet and feeding schedule on each terrarium.

Teacher: It is important to remember in feeding animals in the laboratory that they sometimes must be
trained to eat. The best food for them is their normal diet in the wild state if you can supply it. If this is not available, you can try the substitutes suggested in your references. Since the animals you have are cold-blooded, do not worry if they do not eat immediately. They can live without food for long periods of time without harm. The salamander and toad will adapt readily to captivity, but they will cause some damage to the plants in the terrarium by burrowing. When handling the animals, especially the snakes, be patient and deliberate in all of your movements. Some of them sense indecision and fear very quickly, and become restless and frightened. None of the animals should be bothered when feeding. Under no condition is any teasing to be allowed; this form of cruelty is harmful both to the animals and to those who indulge in it. In all cases you want to avoid the necessity for forced feeding as this will damage your specimens. If you are industrious and persistent in your efforts, you will be able to solve the feeding problems.

Student: Our woodland terrarium is completed. On a field trip over the week end we caught some frogs, toads, and garter snakes. Shall we put them all in the case?

Teacher: One toad and a garter snake are sufficient for a terrarium. It is important not to overcrowd it because you want the plants and animals, which are dependent upon each other for life, well balanced. In a well planned terrarium the number of plants and animals is so apportioned that the terrarium is a self-sustaining unit. The extra specimens can be used in other terraria.

Student: I don't understand how plants are dependent upon animals.

Teacher: Look up the process called photosynthesis and the carbon cycle in your textbook.

Student: Are there any other animals that we can add?
Teacher: Yes. Some of the smaller forms such as land snails, insects, and spiders should be collected. The black and yellow garden spider makes a beautiful orb web and readily takes food in captivity. About this time of year the females lay their eggs and spin a silk cocoon around them.

Student: I don't like spiders and I am afraid of snakes. I won't touch a slimy snake; they are dangerous and bite with their tongues. Our terrarium is pretty now, and all of the snakes, spiders, and toads will just spoil it.

Teacher: If your woodland is to be natural you will want some little woods creatures to inhabit it. Your ignorance of these animals is the reason you fear them. When you see the garden spider spinning her web, watch the cricket chirp, observe the brilliant golden eyes of the frog and all of the other interesting characteristics of these animals, you will lose your fear. Garter snakes are harmless. If you frighten them, they may try to protect themselves and bite. Their bite feels like a needle prick and cannot hurt you if you disinfect the little puncture in your skin. When you hold them, you will find that the scales are waxy smooth and agreeably cool. The snake's tongue is so delicate and its function so unusual that I want you to learn from observation or from your references exactly what it does. It is not for biting.

Student: I caught fifteen grasshoppers, and placed them in the terrarium because I wanted to make a special study of them. They ate the foliage and my partner threw them out.

Teacher: Did the grasshoppers eat the foliage from every plant?

Student: The geranium was the only plant they didn't eat.

Teacher: Here is an interesting "why not?" question. Evidently the geranium has some means of protection. Perhaps you can find out what it is. As for the terrarium, it was overstocked with
grasshoppers and the balance of nature in it was upset. The plants could not grow as fast as the insects ate them. You can make insect cages to house the grasshoppers. You will find the directions and suggestions for studying grasshoppers, crickets, cockroaches, and others in A Source Book of Biological Nature-Study by Elliott Downing.

Student: The bog terrarium has some mold in it. What shall I do?

Teacher: Remove the mold that is visible, drain the terrarium, and dust it lightly with sulphur. Take the glass cover from it for a few days. Mold is a plant. Get a hand lens and study it. Find out why it cannot make its own food.

Student: Every morning the woodland terrarium is covered on the inside with a film of moisture. It sweats like ice pitchers do in the summer. What can we do to prevent this?

Teacher: Before you can prevent anything from occurring you have to know what is the cause. Find out what transpiration is and why an ice pitcher sweats, and I will trade information with you.

A drop of glycerine smoothed over the glass on the inside of the terrarium will prevent this clouding and allow more accurate observation. However, this information should not be given until the students have noticed and discussed the reasons for the clouding.

Student: The plants and lizards that we ordered have arrived and are in the terraria.

Teacher: After the animals have become accustomed to the desert terrarium, place a few live flies in it and sprinkle water on the leaves of the Christmas cactus. What happens?

Student: We followed your directions, and nothing is happening.
Teacher: Turn on the light bulb over the terrarium and warm it up. The animals may be cold or just frightened. Immobility is often a protection to them in strange surroundings. Let us observe them now.

Student: Look, the chameleon on the green plant is changing from a dull gray to a green color.

Teacher: Here is an unusual activity. Have you ever known of an animal that could change its color?

Student: Arctic hares and weasels change from brown fur to white during the winter season. We studied protective coloration in animals and this change is an example of it. The chameleon is trying to match the color of the plant.

Teacher: So it seems, but are you certain of your conclusion? The chameleon remained in the same position for some time before any change was noticed. Why did it change color at this particular time?

Student: We didn't do anything but turn on the light over the terrarium. Could the light have affected the animal?

Teacher: How could you find out? Perhaps, it was affected by a rise in the temperature.

Student: We should plan some experiments. I saw an octopus in an aquarium in California that changed its color. The attendant told me that it changed very rapidly when angered. He said that the animal's feelings had something to do with this. You know, people show emotion by blushing. We don't know what it is that enables the chameleon to make the different colors. I think it would be interesting to find out about this.

Teacher: You will want to be very careful in planning your experiments in order that you may be sure just what factor you are testing.

Student: The insectivorous plants are in the bog terrarium. I put some flies in with them.
Teacher: These plants will have to recover from the shock of transplanting and root before you will see any activity.

Student: Since they eat insects, how can they live without food?

Teacher: What color are the plants?

Student: Mostly green.

Teacher: Look up the process called photosynthesis in your text and you will find that the answer to your question depends upon the color of the plants.

Student: Shall we make some drawings as the students in the other projects are doing?

Teacher: Yes. A record of all the activities in your terraria should be kept, and a properly labelled drawing of each plant and animal should be made. Notice the effects that such environmental factors as food, temperature, and moisture have upon these plant and animal associations.

Student: Are there any experiments we can do with the terraria?

Teacher: The carbon and oxygen cycles can be demonstrated by sealing the glass top of the woodland terrarium with tape for a period of three or four days.

Student: Won't the plants and animals die without fresh air?

Teacher: Try it and see.

Student: I sealed the terrarium three days ago and both the plants and animals are getting along fine. I don't understand it.

Teacher: If you remember, I told you that this experiment demonstrated the carbon and oxygen cycles. Did you refer to your textbook?
Student: No. I read about them before, but I didn't understand them.

Teacher: Bring your group to the blackboard and we will explain by diagrams why the plants and animals can live in a sealed, balanced terrarium.

Student: Shall we explain this to the class when we demonstrate the terraria?

Teacher: Study it thoroughly so that you can present it accurately.

The terraria made by this group can be kept after the project work is completed. They are valuable for classwork and the various activities of the plants and animals are always interesting to the students. Each member of the project should make a short report displaying his terrarium. One student should be selected to make a general summary.

Student: I am going to repeat some of the things that other members of my group told in their reports. Students who were afraid of animals, particularly snakes, became accustomed to handling them. We learned that nature invented camouflage for the frog and chameleon long before man discovered its use for war purposes. Many of our group read more reference books than were on the required list. Several of us used our projects as subjects for themes in our English classes. An art student made a good grade on a design of cacti that she worked out from the drawings in her project notebook. The students working with the bog terrarium had their insectivorous plants written up in the school paper. Our terraria and some of the other projects were displayed for the Parent-Teachers' Association meeting at the school. We learned that in the process of photosynthesis the leaves of green plants act as food factories, and also resemble water fountains in their transpiration activity. The facts, that it takes life to support life and that all organisms are interdependent, became
clear to us in our study of the terraria. Nature seems extravagant producing so many different forms of life, but nothing in the world is wasted.
Materials and Equipment

Animals: crayfish, frogs, toads, salamanders, snakes, lizards, insects, garden spiders

Hand-lens
Light bulb with reflector

Plants: mosses, ferns, flowering plants, tree seedlings, insectivorous plants, cacti

Soils: acid soil, loam, sand, gravel

Three glass aquaria with two glass covers and one screen top
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CHAPTER VIII

PLANT EXPERIMENTS

This project involves simple procedures which any high school student can perform satisfactorily. It is adapted to a group of six or eight students. Besides the fundamental study of seed germination, a number of plant experiments may be completed, and if cooperative observations are encouraged, a general study of the functions and structures of plants will result.

Procedure, Difficulties, and a Student's Summary

Teacher: Several students may be assigned this project. The first portion of the time is devoted to making a collection of fruits. These are to be properly labelled with the names and the methods of seed dispersal. When the collection is checked as satisfactory, the germination of seeds will be studied. The last portion of the project time is spent performing experiments with plants.

Student: This project does not seem as interesting as some of the animal projects.

Teacher: You are interested in animals because they are like yourself, and you know more about them. Most plants are rooted to one place and they do not possess sense organs; so you think they are inactive and have no reactions to their surroundings. However, they are living organisms even as we are. They must have food, water, and a suitable place in which to live. They reproduce themselves and they die.
Sometimes, sharp spines and disagreeable tastes protect them from their enemies. Often, they produce nectar and sweet odors which attract insects to pollinate their flowers and develop luscious fruits which entice animals to disperse their seeds. When you become familiar with the activities and life stories of plants, and realize that the entire animal world would starve without them, they will no longer seem dull and unimportant to you.

**Student:** Won't it be difficult to mount the apples, pears, and other fruits that we are to collect?

**Teacher:** You have a limited idea of the meaning of the word "fruit." A fruit, according to botanists, is a matured ovary of a flower, including its one or more seeds and any part of the flower which may be closely associated with the matured ovary. This definition includes grains, bean and pea pods, acorns, tomatoes, maple keys, and many others which are not fruits in the popular sense. In Part V of the list of plant experiments, a number of fruits are suggested for collection. If the fruits are mounted in cellophane envelopes on show card sheets, there is space for a large number of specimens, and the cards are excellent for demonstration purposes. However, the mounting method is an individual matter.

**Student:** I have completed the fruit collection and would like to have it checked so that I can start the seed germination.

**Teacher:** As your collections are completed, bring them to me. When they are marked satisfactory, you may start the seed study. During any free time that you may have, read the references listed in the bibliography of this project. Since some of you are almost ready for the next section, I will give the instructions and you may note the procedure at this time. Bring to school six jars with screw-top lids, some seeds, and a strip of muslin, approximately one foot wide and three feet long. You may bring as many different seeds as you wish, but include
among them lima beans, radishes, and corn. Soak a few of the lima beans and the corn overnight in a jar of water. Take them out the next day, examine, and draw them. Use your text to help you find and label all of the structures.

**Student:** Why do we soak the seeds in water?

**Teacher:** That is to make them swell. The seed coats are softened and the seeds can be dissected easily. The bean and the corn were selected because they are types of classes of seed plants. The bean is a dicotyledonous seed without endosperm, and the corn is a monocotyledonous seed in which there is a large endosperm. In the appendix of your textbook you will find a comparison of Monocotyledones and Dicotyledones. Use this reference while you are studying the seeds. At the same time as you prepare the seeds for soaking, cover the bottoms of the other jars with cotton, saturate it with water, and place several seeds of the same kind on each piece of cotton. Screw the lids on the jars and label each one with your name, the kind of seed it contains, and the date. Place the containers on the window sill. The object of this experiment is to bring about the germination of the seeds. Germination is the growth and development of the tiny plant in each seed. Can you tell me some of the conditions required for sprouting seeds?

**Student:** Moisture, air, and light.

**Teacher:** Very well. You will supply the seeds with moisture and air. If you place them in the window, they will have light.

**Student:** I think that seeds need a certain amount of warmth before they will start to grow.

**Teacher:** Yes, heat is necessary; it is a variable condition and the amount required depends upon the kind of seed. For instance, a maple seed will germinate on a cake of ice. The majority of seeds, however, grow most freely between
sixty and eighty degrees Fahrenheit. The temperature in the laboratory will meet this requirement.

Student: I don't think that light is necessary to germinate seeds. Seeds planted in the ground do not have light.

Teacher: Since one of the other students believes that light is important in growing seeds, how can we prove who is right?

Student: We could place a jar containing the same kind of seeds in a locker. If the seeds develop in the dark, then light is not necessary.

Teacher: In that case it might be claimed that different temperatures affected the growth of the seeds.

Student: We could exclude the light from the jar by painting the outside of it black. Then, we could place it on the window sill beside the other jar.

Teacher: You must use a scientific approach to the problem, and meet all of the requirements for a good experiment. In a check experiment the purpose is to test the correctness of a conclusion. Every condition must be the same with the exception of the one factor which you wish to test. The same kind of seeds are placed in the same conditions of temperature, moisture, and air with the variable factor, light. Use several seeds so that any that are non-viable will not confuse your results. The more often the experiment is repeated the greater the accuracy of the test, and the less chance there is for a claim of false conclusions from incomplete evidence. Often, experiments are simply methods worked out to prove or to disprove a theory. You have just developed a method of either proving or disproving your theory that light is necessary for the germination of seeds. If you will keep in mind the rules for a good experiment, you can devise ways in which to test other ideas you have about plants.
Student: How long will it take for the seeds to germinate?

Teacher: The seeds will germinate at different rates of speed. You must examine them every day and make accurate drawings of every state of growth. During the time that you are waiting for the germination of the seeds, prepare a rag doll test. You will find the directions for this experiment in the pamphlet Seed Corn Testing.

Student: The seeds in my jars are not germinating. They are molding.

Teacher: Instead of the proper conditions for the development of the seeds, your jars must have conditions best suited to the growth of mold. What are those conditions? Compare your jars with those of the other students. Find in what respects yours differ. Scrape some of the mold from the seeds, and examine it under a hand-lens. Molds of various kinds, such as penicillin and streptomycin, are much in the news now, and you should know something about this flowerless plant. Why is it growing on the seeds? What is the fine dust that comes from the culture? Find and include all of this information in your notes. After you know why the mold is growing instead of the seeds, change the conditions and start some new seeds.

Student: There was air in the jars when we started these experiments, but we tightened the lids of the jars. How can the plants grow in air-tight jars when air is needed by all living things for respiration?

Teacher: Study the process called photosynthesis. You will find the answer to your question, and also, why the existence of animals is dependent upon that of plants.

Student: I read the references on soilless gardening. Can we do this experiment next?

Teacher: I am sorry that we do not have the laboratory space in which to do this experiment. I
included it in the references in the hope that some of you might become interested in hydroponics. If you are willing to undertake this problem and carry it to a successful conclusion in your home, I will supply you with the chemicals needed for the nutrient solutions. It will require a long period of work and much attention before any of the plants will bloom and bear fruit.

Student: Ever since you told the class about the Westinghouse Science-Talent Search, I have been planning to enter the contest when I am a senior. I would like to use hydroponics for the project and the essay which I have to submit.

Teacher: Since you are in the upper one-fourth of your class and are majoring in science, your plan is a good one. Besides hydroponics, there are many other experiments you can perform with the plants you grow, such as studies in plant food deficiencies. Start your project with tomatoes and Calendulas, and when they bear, bring a flower and a fruit to me together with snapshots of your equipment for your final project grade.

Student: I believe that I have completed the section on seed germination. What shall I do next?

Teacher: When I have checked your drawings and notes, you may select two plant experiments from each section on the list. When you have made your choice, sign your name opposite the questions you intend to answer. Read the procedures carefully before you make your decision as you will not be allowed to change your mind. No experiment will be duplicated until all of them have been assigned. Write up each experiment in your notes giving the materials, procedure, observations, conclusion, and a diagram of the equipment. Observe the work being done by your group so that you will have a general knowledge of all of the experiments performed.
The list of experiments in the form of questions with their reference pages is appended to this chapter.

**Student:** Where do we get the supplies for these experiments?

**Teacher:** Some of them you can bring from home, such as bottles, jars, flowers, and seeds. The rest of the equipment including chemicals, thermometers, microscopes, and dissection instruments are available here for your use.

The class demonstration for this project includes a display of the fruit collections and diagrams of the seed germination. Students demonstrate a few of the outstanding plant experiments. Short oral reports are given by the members of the group, and one student is selected to give a summary of the work.

**Student:** Most of our group completed their project. Two of us reported difficulty with molding and decaying of seeds. We learned that the conditions required for germination of seeds are moisture, heat, and air in proper proportions. We found that light is not a necessary factor. Three general stages were noted in the development of all of the seeds: (1) the breaking of the seed coats, (2) the penetration of the supporting medium, (3) the lifting of the young leaves into the air to produce food for the plant. We made three large diagrams of the seed germination for class study. To a botanist, many of the vegetables, nuts, and grains are fruits. Some of the fruit collections made by members of our group were extensive and showed originality in their mounting. The experiments that were demonstrated for the class were: (1) the method of determining how much force seeds exert in bursting the seed coats, (2) the effect of moisture on the direction of growth of roots, (3) the paths water travels in the stem, (4) the collection and testing of the gas given off by a water-plant in sunlight. According to scientists,
Plants existed on earth before animals. Plants are vital to man producing his food, clothing, and shelter. One of the steps in civilization is the change from the hunting to the farming occupation. In our own country the story of corn is the story of a culture. Seed plants have developed a most efficient means of providing for their reproduction. In the tombs of ancient Egyptians, grain is found that will still germinate. As we become aware of the importance and value of the plant world, its study becomes more interesting to us.
PLATE VI

SEED GERMINATION

Dicotyledon Lima Bean

Monocotyledon Corn

DRAWING OF SEED GERMINATION I
PLATE VII

STAGES of GERMINATION
Squash

DRAWING OF SEED GERMINATION II
PLATE VIII

HYDROPONICS EXPERIMENT

Photograph Taken in Student's Home
Experiment questions

I. Roots

1. What is the function of the root? Pp. 87-88.

2. In what direction should the main root grow, to do its work most effectively? Pp. 88-90.


II. Stems


2. How are the conditions for growth of stems tested? Pp. 252-53.

3. Does the stem use up oxygen and produce carbon dioxide as germinating seeds, roots, and leaves do? Pp. 278-79.

III. Leaves

1. Of what use are the seed leaves? Pp. 163-64.


3. Do the foliage leaves, like the seed leaves, contain food? Pp. 181-82.

4. Is the starch in the foliage leaves manufactured there, or does it come from the supply stored in the seed leaves? Pp. 182-83.


6. What is the nature of the openings in leaves through which air passes? Pp. 196-203.

7. Do leaves lose water rapidly by evaporation when they are growing on the plant? Pp. 203-04.

IV. Flowers

1. Can you dissect and name the structures of a simple flower?

2. Can you dissect and name the structures of a composite flower?

V. Fruits

1. Do you have any of the following fruits in your collection?

   Beggar's tick
   Clematis
   Dandelion puff
   Grains: corn, rye, wheat
   Grape or raisin
   Larkspur
   Legume pods: bean, pea
   Linden
   Maple key
   Milkweed pod
   Pine
VI. Seeds

1. Do seeds in their dormant condition contain water? PP. 7-8.


6. How does the depth at which the seed is buried affect germination? PP. 38-42.


8. How much force does the seed exert in bursting the seed coats? PP. 48-54.

9. Do you find any devices to make escape from the seed coats easy? PP. 54-60.

10. How much opposition can the seed stem overcome in forcing its way upward? PP. 72-77.

11. What happens if a seed stem meets an obstacle which it cannot push aside? PP. 79-81.
Materials and Equipment

I. Supplied by the school

Chemicals: iodine, lime water, nitric acid, sodium hydroxide, litmus
Cotton
Dissection instruments
Hand-lens
Microscopes
Thermometers


II. Supplied by the student

Flowers
Fruits
Jars with screw top lids
Mounting materials for collection
Muslin strip, approximately one foot wide and three feet long
Seeds: lima beans, corn, radishes and others

III. Not all of the equipment used in the plant experiments is listed, as much of it was made by the students from scrap material secured from the laboratory and from home.
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"Hydroponics: Growing Plants in Nutrient Solutions without Soil," Turtox News, XIX (October, 1941), 140.


Propagating Plants," Turtox News, IX (March, 1931), 35.


Laboratory work should be adapted to the students' abilities. The preceding projects were selected because they were readily adaptable to poor, average, and good students. Too often in our educational system there is little provision made for the brilliant student. This project is included in the series as an example of work which offers a challenge to superior students. The power of observation, laboratory technique, ingenuity, and persistence are required for the successful pursuit of this problem. Dr. Leslie Arey, speaking of the value of embryology, says, "A general conception of how man and other animals develop from a single cell by orderly and logical processes should share in the cultural background of every educated mind."

**Procedure, Difficulties, and a Student's Summary**

Teacher: The project on embryology should not be attempted unless you are especially interested in science, and an excellent student. Besides the regular laboratory periods, it requires

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considerable outside preparation and library reference work.

Student: After we start the problem, if we find that it takes too much of our time, may we transfer to another project?

Teacher: Since I have indicated that it is difficult work and demands extra time, you should not select it unless you are prepared to accept these conditions.

Student: My friend and I want to do this project.

Teacher: I will tell you later if this problem is assigned to you.

Since an average student or an emotionally unstable student is not able to carry this project to a successful conclusion, it is important that the teacher consider the student's qualifications before assigning it.

Teacher: You may work on chick embryology. The Turtox publications are available in the laboratory. For the other references listed in the bibliography and for further information, consult the files of the public library. We have an incubator made from a packing box, light bulbs, and a thermometer. It is insulated and maintains a fairly constant temperature.

Student: We are testing the incubator. It can be improved. We are going to make wire screen shelves to hold the eggs.

Teacher: Place a beaker of water in the incubator to serve as a humidifier. How many eggs are you going to incubate?

Student: We haven't decided yet. Before starting the incubation, we thought that we should get infertile and fertile eggs and study their structures. One of the references suggested this method of procedure, and gave instructions for distinguishing between the two kinds of eggs.
Teacher: You can practice opening the eggs and removing the contents. Carefully puncture the shell towards the larger end of the egg. Using scissors, cut through the shell and about three-fourths of the way around the egg. Allow the contents to float out into a saucer of water. Later, on you will use a normal salt solution instead of water. Cut around the white germinal spot on the upper surface of the egg and float it into a watch glass. If the egg is fertile, this spot is the embryo. There is a fine membrane covering the spot and this membrane should be removed with a camel's hair brush.

Student: I believe I understand the directions. What is a normal salt solution and why do we have to use it?

Teacher: It is a salt solution of a concentration similar to that in which body tissues live. When it is warmed to the incubating temperature of one hundred and three degrees Fahrenheit, it will keep the tissues in a normal condition for a short time.

Student: If we are going to use it, shouldn't we prepare a supply now?

Teacher: Yes. Measure out six-tenths of a gram of sodium chloride and dissolve it in enough distilled water to make one hundred cubic centimeters of solution.

Student: I can't follow those directions. I don't know what sodium chloride and distilled water are, and I don't recognize the measuring units.

Teacher: Look up the metric system of measurement and the meaning of the other terms you don't understand. Then, I will show you how to use the chemical balance and make up the solution.

Student: We have made a diagram of the contents of an egg and labelled it according to an embryology text. Will you go over the labels with us and pronounce the terms?
Teacher: Yes, and when you can pronounce the names of structures, use them so that they will become a part of your vocabulary. Have you made arrangements to get the fertile eggs?

Student: Yes. The temperature in the incubator varied considerably. We found, by adding an extra light bulb of low wattage in the late afternoon, that no drop in temperature occurred during the night. We are going to start thirty eggs tomorrow.

Teacher: I believe that a trial run with five or six eggs might prove more satisfactory. You can test the performance of the incubator and develop a method of studying the embryos.

Student: We are going to write on each egg the date and time that it is placed in the incubator. We have arranged a schedule for taking the eggs out, and we have a list of the stages that we want to study. We would like to have passes for some of our study periods. Can we get into the laboratory whenever we have to remove eggs from the incubator?

Teacher: The school hours are from eight to four. However, if you will let me have a copy of your schedule, we can make arrangements so that you can remove the specimens when necessary and preserve them. I shall be glad to give you passes to the laboratory during your study periods if you do not neglect your other work.

Student: What will we do about the eggs over Saturday and Sunday?

Teacher: We can leave the incubator going over the weekend.

Student: Our trial run of three days was fairly successful. The incubator worked, but one of the embryos did not grow. Why?

Teacher: I do not know. There are a number of possible explanations. The egg may have been infertile. Can you think of other reasons that would prevent its development?
Student: If it was fertile, maybe the embryo died.

Teacher: Good. It is possible that through some faulty hereditary factor it could not develop. This problem suggests other questions. How old is the embryo of a fertilized egg when it is laid by the chicken?

Student: When laid, the egg is at least eighteen hours old. I was surprised to learn that we never eat fresh eggs.

Teacher: How much time did you allow for heating the eggs before counting the hours of embryo growth?

Student: We started counting time from the moment we put them in the incubator.

Teacher: You must allow between ten and eleven hours for the eggs to become thoroughly heated. I see from your schedule that you have listed sixteen, twenty-one, twenty-four, thirty-eight, sixty, and seventy-two hour embryos. Why did you select these hours for study?

Student: We found some good pictures that have every structure labelled, and we knew that it would be much easier to find the parts of the chicks if we had some guide to follow.

Teacher: That is an excellent reason. However, your collection will be more interesting if you include some older specimens. They may be stored in jars containing 70 per cent alcohol. It is possible that all of the eggs may not develop and that the ages you estimate for the embryos may be inaccurate. Since part of this project work includes the preservation of specimens, I suggest that you allow one embryo for study and one for preservation for every hour you schedule. Make a summary in your notebook of the structures and development you observe in each embryo.

Student: The first embryos are so small that we can't see any more than the germinal spot. How can we study them?
Your project has progressed so well that there is time to make permanent microscopical slides of the early embryos. The slides can be studied under the microscope and projected on a screen by our microprojector. The making of slides is not required, but would you like to try?

Yes. I don't know if we could make any good ones, but we could try.

Read, in the references on microtechnique, the methods for fixing and hardening tissues. When you are ready to start, let me know.

Which fixative is the best for our purpose?

Bouin's fluid is the most generally used fixative. It is rapid and the embryos will not be injured if left in the reagent overtime. Since your regular laboratory time is limited, this is an important factor. We have the chemicals in the storeroom, and it is not difficult to make. You must follow the directions exactly, and, after fixing, transfer the embryos directly to 70 per cent alcohol. Wash out the reagent with repeated changes of the alcohol. To complete the hardening and to remove the water from the tissues, it is necessary to place the embryos in a series of alcohols of increasing strength. You can find the details and directions for this procedure in your references.

We have prepared jars of the fixing reagent and the various alcohols, but we don't have all of the instruments and containers that we need to do this work.

Beyond a few chemicals and your intellect, you don't need any specialized equipment. Just because you do not have all of the implements and supplies mentioned in the books does not mean that you cannot do the work. The results may have faults, but you are learning, and probably wouldn't do better with professional equipment. Scientists do not always start out in expensive, perfectly appointed laboratories. Those who do research work
often have to design and make their own equipment. Make what you have do, or make what you have into what you need. Saucers and shallow bowls can substitute for low stender dishes; jelly jars for tall stenders; a needle stuck into a wooden stick for a tool. Make a slide rack by bending a piece of spring wire into a suitable shape. Use your imagination and develop your ingenuity.

Student: We are starting to incubate the eggs this afternoon, and if all goes well, will have a sixteen-hour embryo to fix tomorrow morning.

Teacher: Fine. Remember to turn the eggs over twice a day.

Student: I have seen hens turn their eggs and wondered about it. Is it important?

Teacher: If they are not turned, the membranes which surround the chick and the yolk become attached to the shell membrane, and sometimes grow to the shell itself.

Student: That is another reason why embryos may not develop.

Teacher: Now, you are ready to clear the embryos.

Student: Yes. It seems complicated; will you go over the process with us?

Teacher: First, transfer the hardened and dehydrated embryos to a mixture of equal parts of 95 percent alcohol and creosote-xylol. As the embryos begin to clear, pour off this mixture and add pure creosote-xylol. The creosote-xylol should be changed at least once for best results. Keep all of the containers tightly covered to prevent evaporation. Refer to your references for specific directions.

Student: We destroyed three of our specimens in the process. Those that remain are clear. What do we do next?

Teacher: Infiltrate the embryos with balsam. You will find this procedure discussed on pages 93 and
94 in *The Essentials of Practical Microtechnique* by Albert Galigher. Let me see the specimens before you mount them.

**Student:** We are ready to mount the embryos now.

**Teacher:** Clean the new slides and cover glasses in 95 per cent alcohol. Put a drop of balsam in the center of a clean slide, slip a needle under the embryo, and place it in the drop. The chick embryos are thick but delicate, so the cover slips will need to be supported with glass rods. I will show you how to draw glass tubing to the required fineness. Balsam shrinks as it dries. To prevent bubbles of air in your mount, add enough balsam to spread beyond the edge of the cover glass. Any excess can be removed before the balsam hardens.

**Student:** We started with seven embryos and we finished with four slides. Three of the slides are clear.

**Teacher:** You have done very well. As I told you, this project requires laboratory technique and persistence. Spend the remaining time studying the specimens and preserving the older embryos for your collection. Compare your notebook summaries of the embryonic stages with this list.

**Sixteen hour embryo**
1. Primitive streak

**Twenty-one hour embryo**
1. Head fold
2. Notochord (primitive backbone)

**Twenty-four hour embryo**
1. Development of head region in advance of lower embryo
2. Block-like, distinct segments
3. Blood islands

**Thirty-eight hour embryo**
1. Head more distinct showing three vesicles of brain
2. Increased number of segments
3. Tubular heart visible
Sixty hour embryo
1. Head bent and body curved
2. Distinct eye and ear
3. Segments almost complete
4. Definite tail end

Seventy-two hour embryo
1. Head and tail of embryo approach
2. Cerebral hemisphere distinct
3. Eye showing lens and retina
4. Heart large and farther from head
   (Heart often beats spasmodically after embryo removed from shell)
5. Blood vessels prominent
6. Upper and lower limb buds appear

Seven day fetus
1. Externally, fetus resembles a bird
2. Neck separates head from thorax
3. Beak with nostrils
4. Eye still very large
5. Forelimbs are wing-like
6. Feather markings appear

Student: Does this list include every structure and all development?

Teacher: No. Use it as a general check list. For your class demonstration, display the embryos, slides, and equipment. Prepare an outline of your own from your summaries of the embryo development. This outline may be placed on the blackboard for the class.

Student: This project was absorbing but difficult work. Our equipment was not always satisfactory although we did learn to contrive fairly adequate substitutes for things we did not have. We devoted much more time to our problem than was required because we wanted to make as complete a collection of embryos as we could. All of the eggs did not develop. We made three acceptable slides and preserved twelve other chick embryos. We found that the embryos did not look much like chickens to us until they were about eight days old. We were hoping to hatch a chick from our incubator, but we were unable to get any specimen older than eighteen days. You
might think that after our study we would know how a chicken develops from a single cell. We do know more about how embryos look and something about the manner in which they grow, but the whole process of their development appears to us even more incredible than it did. This project has taught us that animal life develops according to an orderly, miraculous plan.
PLATE IX

CHICK EMBRYOS
Materials and Equipment

Camel’s-hair brush
Chemical balance
Chemicals
  Balsam
  Beechwood creosote
  Ethyl alcohol
  Formalin
  Glacial acetic acid
  Picric acid
  Sodium chloride
  Xylol
Cover glasses
Dissecting instruments
  Forceps
  Needles in wooden sticks
  Scissors with fine blades
Fertile eggs
Glass tubing
Glassware
  Jars
  Saucers
  Specimen bottles
  Watch-glasses
Gummed labels
Incubator
Medicine droppers
Microprojector
Microscope
Slides

Bouin’s Fluid
  Formalin ......................................................... 25 c.c.
  Glacial acetic acid ........................................... 5 c.c.
  Picric acid, saturated aqueous solution ..................... 75 c.c.

Creosote-xylol
  Equal parts of xylol and beechwood creosote
Bibliography


CHAPTER X

CONCLUSION

The study of living things transforms idle curiosity to active curiosity and inspires a freshness and vigor of thought that develops character as well as knowledge. Probing the secrets of nature's smallest entities proves that all phenomena appear in a connected, orderly fashion. Knowledge, which is not acquired in a logical way, adds little to our adjustment to living. It is superficial and soon forgotten. In science we learn that certain consequences follow certain antecedents as surely as night follows day, and that if we disobey nature's laws, whether we understand them or not, we must pay.

Each student develops a philosophy of life. His natural ability to learn and to understand from the teaching of others determines the value of his philosophy in everyday living. Life in the mental world is intelligence. Life in the physical world is force. An understanding teacher combines both intelligence and force in creating an educational ideal in which defects of memory, reasoning, and environmental handicaps are absorbed.
in the sheer joy of doing. To do something and achieve results has made a passable student of many a dullard.

Science is a challenge to the mind. A student's mental habits are shaped according to the age in which he lives, and his every thought is stimulated by the color and restlessness of this scientific age. Today's students are not satisfied to stop where preceding generations left off, but feel that their generation should surpass those that have gone before in scientific achievement that will benefit all mankind. It is the teacher's privilege to encourage this social consciousness.

When a student's motive in education can be pointed toward seeking a good way of life, the study of biology releases many impulses in terms of beauty, law, and order which create true judgment and develop a reasoning human being. He discovers what he can do with what he knows. In his project he proves that education does not begin and end merely with books. The eye and the hand require training no less than the ear and the mind.

In many high school courses the teacher is the active thinking force while the student sits, listens, and agrees. He may absorb details in quantity as a sponge, and he may be able to pour them forth in the same fashion as they were absorbed, but since he has
exerted no personal effort, he will acquire no personal wisdom. Memorizing of words does not make a thinker or enrich experience. Active participation in learning encourages the student to combine his natural energy and creative thought. A good teacher not only reveals problems, but teaches students the patience to solve them. Failure attends all work by and with living organisms. To understand that failure is simply an accompanying factor, not a necessary conclusion, is to develop the adult attitude needed for inner adjustments that overcome adverse circumstances.

A condition which is fatal to one order of life is security to another. Men drown in water and live in air; fish drown in air and live in water. This truism shows us that although environments differ, each organism is well adjusted to its own place in the scheme of the universe. Biology teaches that though superficially different and requiring varied environments, organisms are fundamentally alike in their activities and are interdependent.

Biology projects often become hobby projects. While many school studies end with graduation, hobbies developed from the study of biological projects enrich the years and develop nature-lovers who learn patience and kindness to all living things.
The work with biology projects adapts itself with surprising ease to the individuality and personality of the student. All students can look, but only trained students observe the myriad forms of life in test-tubes of pond water. The realization that all living things come from preceding living forms is an important one.

The social activities found in the ant house create a respect for the instincts which exact obedience and unselfish sacrifice for the welfare of the community.

The dissections of the fish and the frog teach manual dexterity. The amazing complexity of the vertebrate animals surprises and intrigues the students.

Collecting leaves appeals to the acquisitive habits of the adolescent age. The identification and study of leaves and trees make the students aware of the intricate beauty of their surroundings, and foster their appreciation for pattern and design in nature. Photographing the leaves adds interest and permanence to this project besides teaching the importance of following directions.

The acquired fear that many students have of the crawling and hopping creatures is best overcome by handling them and observing their normal activities in the terraria. The animals in their natural habitats reveal the advantage of camouflage, both defensive and offensive.
Experiments with living plants familiarize the students with biological laboratory procedures. A general knowledge of the structures and functions of plant forms is acquired. Students are interested to learn that through biological remodeling of plants the great industry of agriculture was begun less than ten thousand years ago.

The growth and development of a complex animal from a single cell is one of the most incredible yet fundamental facts of nature, and the response of the students to this biological miracle is one of appreciation and awe.

Truth is the beginning and end of all knowledge. The ultimate aim of all science is truth. Biology, as no other science, possesses both truth and heart appeal. All of us are students of "the treatise of life," bios logos, which is biology.
APPENDIX
Practical Projects for High School Biology

1. Frog Dissection
   - Specimen dissected
   - Chart drawn from specimen
   - Bibliography

2. Fish Dissection
   - Specimen dissected
   - Chart drawn from specimen
   - Bibliography

3. Ant-house
   Started May 1943 and no additions made to original colony
   - Bibliography
     Turtox Service Department, "Turtox Service Leaflet No. 35, "Studying Ants in Observation Nests"

Eleanor Rueth
Maulfrey Stewart
Carl O'Beirn
Jack Young

115
4. Insect Collection

(a) Insect nets, mounting boards, pins, boxes
(b) Insects, mounted and classified
(c) Bibliography
   Jacques, "How to Know the Insects," 1941, Harry Jacques, Mt. Pleasant, Iowa
   Lutz, "Field Book of Insects," 1935, G. P. Putnam's Sons

5. Bee Study

(a) Observation bee-hive
(b) Super with comb
(c) Charts of the honey bee
(d) Preserved specimens
(e) Bibliography
   Extension Circular No. 303, "Beginning with Bees in Nebraska," July 1940, University of Nebraska Agricultural College Extension Service, Lincoln, Nebraska
   National Geographic Society, "Our Insect Friends and Foes and Spiders," 1935, Washington, D.C.

6. Leaf Collection

(a) Mounted leaves
(b) Mounted prints of leaves
(c) Printing frames
(d) Bibliography
   King, "Talking Leaves," 1934, Harter Publishing Co., Cleveland, Ohio

7. Plant Germination
   Marion Heiser
   Alita Zimmerman
   (a) Charts drawn from germinating seeds
   (b) Experiments for demonstration
   (c) Laboratory drawings and notebook
   (d) Bibliography
      Extension Circular No. 127, "Seed Corn Testing," Reprinted March 1933, University of Nebraska Agricultural College Extension Service, Lincoln, Nebraska
      Osterhout, "Experiments with Plants," 1908, Macmillan Co.

8. Test-tube Aquaria
   Shirley Stacy
   (a) Test tubes containing pond water samples and Protozoa powder
   (b) Slide mounts of fresh material
   (c) Notebook
   (d) Bibliography
      Turtox Service Department, "Turtox News," General Biological Supply House, Chicago.
      Volume 8, No. 8, August 1930
      Volume 11, No. 11, November 1933
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      Volume 18, No. 11, November 1940
      Ward and Whipple, "Fresh Water Biology," 1918, Wiley & Sons

9. Bird Study
   Barbara Griffin
   Shirley Hasselquist
   (a) Bird paintings
   (b) Migration map
   (c) Feather collection
   (d) Birds' nests
   (e) Mounted bird feet
   (f) Records of bird calls
   (g) Bibliography
Pearson, "Birds of America," 1944, Garden City Publishing Company, Garden City, N.Y.

10. Chick Embryology

Fritz Ware

(a) Incubator
(b) Specimens and microscopical slides
(c) Drawings made from slides
(d) Slide projector
(e) Bibliography

Turtox Service Department, "Turtox News," General Biological Supply House, Chicago
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Student Explanations

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2. Test-tube Aquaria . . . . . . Shirley Stacy
3. Plant Germination . . . . . . Marion Heiser
   Alita Zimmerman
4. Chick Embryology . . . . . . Fritz Ware