This is to certify that the

thesis entitled

Teaching Flowering Plant Anatomy and Physiology
Using a Student-Conducted Research Investigation
of the Wisconsin Fast Plants

presented by

Michael Scott Hoekwater

has been accepted towards fulfillment
of the requirements for

MA degree in Bio. Sci.

Kenneth D. Wadler
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Date July 17, 1996

TEACHING FLOWERING PLANT ANATOMY AND PHYSIOLOGY USING A STUDENT-CONDUCTED RESEARCH INVESTIGATION OF THE WISCONSIN FAST PLANTS

By

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A THESIS

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Division of Science Education

1996

ABSTRACT

TEACHING FLOWERING PLANT ANATOMY AND PHYSIOLOGY
USING A STUDENT-CONDUCTED RESEARCH INVESTIGATION
OF THE WISCONSIN FAST PLANTS

By

Michael Scott Hoekwater

I designed a plant unit in which students, taking on the role of plant researchers, conducted controlled experiments using the Wisconsin Fast Plants. The unit included methods for assessing students' understanding of flowering plant anatomy and physiology as well as their attitudes toward performing the long term research project. I taught the unit to ninety students in three biology classes at a private, religious high school. I used a pre-test to measure students' prior knowledge. At the conclusion of the unit, I used a post-test to measure students' understanding of key concepts. To measure how well students followed the Scientific Method and recorded their results, I evaluated their research reports. Using a written survey, I assessed students' attitudes toward the research project. The results from these assessment tools indicated that this method of teaching is educationally effective, and helps to increase students' interest in class.

To my patient and supportive wife Janey.

ACKNOWLEDGMENTS

This thesis would not have been completed without the assistance of many people. I would like to thank the biology students who served as "guinea pigs" as I taught the plant unit. Their excitement was encouraging, and their feedback was helpful.

I could not have had this opportunity to obtain a Master's Degree if this program had not been developed by Dr. Clarence Suelter and the Division of Science Education. I would especially like to thank Merle Heidemann and Ken Nadler for their assistance as I did my research while developing this unit.

I was able to report statistics concerning students' test scores with the help of Dave Brummel, Computer Center Director at Calvin College. Also, Brenda Banga provided constructive criticism of my grammar and punctuation, for which I am grateful.

I would like to thank my wife Janey for her encouragement when I wanted to quit, and her patience when I did not want to quit.

Finally, I am thankful to God for giving me the opportunity to show students the miracle of His Creation.

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INTRODUCTION

I hear, and I forget.
I see, and I remember.
I do, and I understand.
Chinese Proverb

Teaching is leading students to understanding. The key responsibility of a classroom teacher is designing instructional activities which effectively bring students to the point of understanding. After seven years of classroom teaching, I am convinced that true understanding can only be achieved when a student is actively involved in his or her own learning both physically and mentally. This thesis contains a description of a unit I designed in plant biology which actively engages students in the study of plants. Students take on the role of plant researchers in this unit, growing their own plants, running controlled experiments, recording and analyzing data, and summarizing their results. They learn to use the Scientific Method. In the process, they not only learn much about flowering plant growth and development, physiology, reproduction, genetics, and ecology, but they also observe how a model organism exhibits the common characteristics of all living things.

I use the Wisconsin Fast Plants (rapid-cycling *Brassica rapa*) in the unit. My interest in the Wisconsin Fast Plants began when a colleague at my school introduced them to me.

After I grew the plants myself, I knew they would make an ideal teaching tool in my biology class.

The Wisconsin Fast Plants grow from seed to seed in 35 days. Originally developed as a research tool for scientists by Dr. Paul H. Williams, Department of Plant Pathology, University of Wisconsin-Madison, the rapid cycling *Brassicas* have since become important instructional tools at all educational levels. The Wisconsin Fast Plants Program includes a manual for the high school level as well as one for elementary classrooms. The teaching materials and laboratory supplies needed for conducting exercises with the Wisconsin Fast Plants are available from Carolina Biological Supply Company. Once a basic set of materials is purchased, much of it can be re-used for many years.

I. Reasons for Developing a Plant Unit

The primary reason I chose to use the Wisconsin Fast Plants as the basis for this unit is that it would involve students in a hands-on, long term research project. Because students grow their own plants, they have a sense of ownership in the project. It forces them to be actively involved in their study of plants. Students like growing their own plants. I am not sure if it is because they have a natural interest in gardening or because they enjoy the competition of comparing their plant heights with their neighbors' plant heights.

Other reasons for my developing a unit on plants include my own interest in botany, the reliability of the Wisconsin Fast Plants, and the lack of botanical topics in the typical biology class.

Teaching is more enjoyable when I am teaching a topic in which I am interested. I have always had an interest in botany. I enjoy gardening and tending to rose bushes. Thus, it was natural for me to use plants as the basis of this unit. Generally, students in my biology classes want to do experiments with animals. They think plants are boring. I want to show them that plants are interesting organisms.

Besides my own interest in plants, I chose to use the Wisconsin Fast Plants in my unit because they are a reliable organism for investigation. As a typical science teacher I have experienced frustration using experiments which did not give predicted results. This has not been my experience with the Wisconsin Fast Plants. If students follow the directions carefully, the plants give expected results at the predicted time (e.g. germinate, emerge from the soil, develop true leaves, flower, and develop fruits and seeds).

One example illustrating the reliability of the Fast Plants is the results I get in my genetics study. Students grow first generation (F_1) seeds from a parental cross between a normal (wild-type) Fast Plant and a Fast Plant with a recessive trait called yellow-green, a trait giving the leaves and stem a yellowish color. When these first generation plants flower, students cross-pollinate them in order to produce second generation (F_2) seeds. When students plant these seeds and observe the color of the second generation plants, they will find a ratio very close to the expected ratio of three wild-types to every one yellow-green.

Finally, in an article in the American Biology Teacher, Gordon E. Uno (1994), an Associate Professor of Botany and Microbiology at the University of Oklahoma, describes the lack of botanical instruction occurring in pre-college classrooms. Uno suggests one reason is that plant-related activities recommended in many state guidelines are boring. Also, teachers and biology textbooks often focus on animal and human examples to explain biological concepts and ignore plants, even though plants can be used to illustrate most biological concepts. Uno suggests that teachers try to include hands-on student-conducted plant growth and development projects in biology class as one way to increase student interest in botany. Such projects may also give students a new appreciation for the importance of plants. I think the plant unit I developed helps to address some of Uno's concerns about the lack of botanical education at the high school level.

II. **Comparing the New Approach to the Old Approach**

Before I developed this plant unit for my biology classes, students grew the Wisconsin Fast Plants as a separate activity during the school year. It did not coincide with a specific plant study. The main purpose in having students grow the plants was to teach them the life cycle of flowering plants and to illustrate that a plant exhibits certain characteristics because it is a living organism (e.g. grows, develops, reproduces, responds to the environment). Students grew the wild-type plants. They kept records in a journal of their plants' progress including making sketches, writing descriptions, and taking plant height measurements. Basically, I followed the format described in the Wisconsin Fast Plant Manual (1989).

In developing this new plant unit, I made several major changes. First, I changed the way I teach plant biology. Second, I developed a Wisconsin Fast Plants guide which the students follow as they grow the plants. The guide describes the format students are to use as they keep records of plant growth. Finally, I modified old activities and added new ones.

Rather than teaching plant topics at different times throughout the year, I pulled many of these major topics together to be taught while the students grow the Wisconsin Fast Plants. Now I teach plant growth and development, plant hormone regulation and tropic responses, and flowering plant reproduction while students are growing plants, allowing them to see these processes first-hand. I spend approximately three and one-half weeks on the unit. The plants take five weeks to fully develop, so I finish the unit before students collect seeds from the first growing cycle. Also, students use the seeds they collect to grow a second generation of plants. Students grow the second generation plants for one week to complete the genetics study.

In addition to consolidating plant topics and teaching them together, I also modified the format students use to keep records of plant progress. Students keep a detailed lab report in a notebook. This report must include an introduction, several hypotheses, daily records, and a summary of the results once their investigation is complete. Students hand in their report which is equivalent to one test grade. The reason I require this format is because it is patterned after a scientific research journal. I want students to view their work with the Wisconsin Fast Plants as being their own research project.

Finally, I modified some of the old activities and added new ones to the plant unit. These activities are listed here. A detailed description of each activity is included in "The Plant Unit" section.

The first change I made to the plant growing project was to have students use F_1 seeds from a wild-type and yellow-green parental cross rather than wild-type seeds.

This way the students can identify how the plant-color trait is inherited in the first generation. When these plants are cross-pollinated, an F_2 generation is produced. By growing these seeds, students can identify how the trait is inherited in the second generation.

The second change I made was adding a new ecology investigation to the plant unit. I adapted this investigation from an article by Marian Smith (1991). I wanted to have the students do an experiment testing the influence of an environmental factor on plant growth. I have students test the effect of rubbing on plant growth. In the future I hope to test the effect of other factors on plant growth including overcrowding, varying amounts of fertilizer, salt concentration, and acid precipitation. Each year or two I hope to change the ecology experiment that students conduct.

The third change I made was adding new activities and demonstrations throughout the plant unit. For example, I added a controlled experiment testing the environmental requirements of seed germination. I also developed a demonstration which identifies the gas released by germinating seeds. In addition, I demonstrate the uptake of oxygen by germinating seeds using a seed respirometer. Finally, I require students to sketch a seedling including the primary root and root hairs.

As the Wisconsin Fast Plants are growing, students measure plant height and primary leaf length. The students also count the number of hairs on the primary leaf margin. Using this data, students construct frequency histograms to graphically represent these characteristics in a population of plants.

After completing the rubbing experiment, students construct a line graph showing the change in average height of the plants receiving different amounts of rubbing. The average height is a class average. In addition, students construct a bar graph of the class averages.

Students also conduct tropism studies. Before developing this plant unit, students completed a gravitropism experiment in which they observed the orientation of a seedling in a horizontal film canister. Students also completed an experiment testing the effect of different color lights on seedling growth. I kept these two activities in the plant unit and added an experiment. It is a demonstration of Charles and Francis Darwin's investigation with seedlings bending in response to unidirectional light.

During the flowering and pollination segment of the plant unit, I added several activities. I added a section on flower anatomy study using the Wisconsin Fast Plants flower. Also, I have the students tape and label the flower parts to a 3 by 5 note card.

To show students pollen tubes, I added a demonstration of germinating pollen grains to the plant unit. To illustrate double fertilization, I now include an interesting demonstration using Legos.

I added two activities to the fruit development section of the plant unit. First, students study embryogenesis using a microscope-camera hooked to a TV. Second, students read an article about seed dispersal (De Jonge 1989) and construct a concept map of the main ideas.

Finally, throughout the entire plant unit I have incorporated the use of visual aids using the Bio-Sci II videodisc software published by Videodiscovery Inc., Seattle, Washington. My school purchased a laser disc player for the science department in the Fall of 1995, just in time to be used for my new plant unit! Using still frames as well as motion clips, I am able to show the students various plant structures and developmental processes studied in the plant unit.

III. Classroom Demographics

I teach in a suburban private, religious high school. There are approximately 550 students in grades 9 through 12. The majority of the students come from white middle-class families.

Our students are tracked into one of two tenth-grade biology classes based on their success in ninth-grade physical science. The courses are titled Biology A and Biology B. Students earning an A or B in physical science must be in Biology A. Students earning a C can choose to be in either class. Students earning a D in physical science must be in Biology B.

While implementing the plant unit this past year, I taught three sections of Biology A and two sections of Algebra. There were 90 students in the three Biology A classes, 45 girls and 45 boys. I taught the plant unit in the same way for all three classes.

IV. Where the Plant Unit Fits in the Curriculum

Currently, I teach the following topics in my Biology A classes. They are listed in chronological order. Time spent on each topic varies.

1. Biology as a Science
2. Biochemistry
3. Cell Structure and Function
4. Respiration and Photosynthesis
5. Plant Unit
6. Cell Reproduction
7. Genetics
8. DNA Structure and Protein Synthesis
9. Vertebrate Reproduction and Development
10. Fetal Pig Dissection and Systems Overview
11. Evolution
12. Classification
13. Ecology

I intended to teach the plant unit immediately following a study of respiration and photosynthesis. However, due to scheduling conflicts I actually taught the plant unit right after teaching respiration, but before I taught photosynthesis. This turned out to be a good thing. The plant unit nicely leads into a study of leaf structure and photosynthesis. Students encounter some photosynthesis concepts in the plant unit. For example, students grow Wisconsin Fast Plants seedlings in chambers allowing three different color lights (red, blue, green) to enter. The results from this experiment lead into a discussion of what wavelengths of light plants absorb. This is good background knowledge for a study of photosynthesis.

I teach the plant unit toward the beginning of the year, but not first thing. Students must have good microscope skills and lab techniques before they begin the plant unit. The advantage of teaching the unit toward the beginning of the year is that I can draw on aspects of the Wisconsin Fast Plants study throughout the rest of the year.

In addition, our genetics study with the plants takes place before the students have studied Mendelian principles. Once they tabulate the results from their F_2 plants, students develop a model to explain them. I think this is a an educationally effective method of having students study genetics. Students encounter the problem of phenotype expression in offspring in a manner similar to the way

Mendel encountered the problem. They do not know ahead of time what to expect.

One final advantage in doing the plant unit earlier in the school year is to raise student interest in biology class. Since the unit involves much student activity, their interest level in the class is high. Hopefully, I can maintain this throughout the rest of the year.

SCIENTIFIC PRINCIPLES TAUGHT IN THE PLANT UNIT

The plant unit highlights the major events occurring in the life cycle of a flowering plant. Topics covered in the unit include seed structure and germination, plant primary and secondary growth, hormone control and tropic responses, plant responses to mechanical stimulation, flowering plant reproduction, embryogenesis and seed maturation, fruit development and seed dispersal, and Mendelian genetics.

A seed consists of a seed coat, stored food, and an embryo. A seed is alive but carries on life processes including cellular respiration at a very slow rate. The growth of the embryo from the seed is called germination, and is dependent upon certain environmental factors including water, oxygen, and heat. Although some seeds require exposure to light for germination, Wisconsin Fast Plants seeds (*Brassica rapa*) do not.

A dormant seed is very dry (water makes up only 5 to 20 percent of total weight). As a seed imbibes water, enzymes are activated which begin digesting stored food in the seed. As cellular respiration rate increases, oxygen is used and carbon dioxide is released. Photosynthesis will not occur in the cells of the embryo until chlorophyll is produced. The first structure to emerge from the seed is the radicle, or primary root. Root hairs as well as lateral roots grow off the primary root, increasing the uptake of water and minerals.

As a plant grows, new tissue is formed at regions called meristems. Apical meristems occur at the tips of roots and shoots and are involved in the increase in length of these structures. This is called primary growth. Lateral meristems produce secondary tissues including xylem, phloem, and cork, which make up wood and bark. Wisconsin Fast Plants have no lateral meristem. The seasonal growth of tissue from vascular cambium in woody plants produces annual rings which can be used to estimate the age of a woody stem.

Plant growth is regulated by hormones. The work of Charles and Francis Darwin as well as Frits Went showed the importance of naturally occurring auxin (indoleacetic acid) in the bending of seedling stems toward light (Raven, Evert, and Eichhorn 1986). A growth response involving bending of a plant part toward or away from an external stimulus is called a "tropism". Plant stems show positive phototropism and negative gravitropism. In phototropism, migration of auxin to the dark side and the subsequent increase in cell length is responsible for stem bending toward the light source. The bending upward of a stem and downward of a root in response to gravity appears to be caused by hormonal gradients triggered by the movement of amyloplasts (starch-containing plastids). In stems the accumulation of auxin on the lower side of the stem causes cell elongation here, and bending of the stem upward. In roots, the accumulation of auxin on the lower side inhibits cell elongation. Thus, cells on the upper side increase in length, causing the root to bend downward (Raven, Evert, and Eichhorn 1986).

Many plants are also influenced by mechanical stimulation. M.J. Jaffee (1973) demonstrated that gently rubbing young seedlings reduced stem elongation by as much as 45 percent, resulting in shorter and thicker plants. Such a response may help a plant survive by reducing the chance that the stem falls over or breaks when encountering natural mechanical stimulation such as the wind, rain, and animal movement.

The flower is the reproductive structure of angiosperms, the flowering plants. The Wisconsin Fast Plants flower contains four sepals and four petals which protect the inside flower parts. The petals also serve as a beacon and landing pad for pollinators. The stamen is the male structure which produces pollen grains within the anther. Pollen grains produce two sperm from a generative cell. The female pistil contains ovules within the ovary. Ovules contain the eggs (Raven, Evert, and Eichhorn 1986).

Pollination is the transfer of pollen from anther to stigma, the top of the pistil. For many flowering plants, including the Wisconsin Fast Plants, this is accomplished by honey bees as they visit many flowers, collecting pollen and sipping nectar. Pollen tubes grow from compatible pollen grains on the stigma down through the style to the ovules in the ovary. One sperm fertilizes the egg, forming the zygote. A second sperm fuses with the two polar nuclei to form a triploid cell. This will become the endosperm, food for the growing embryo within the seed (Raven, Evert, and Eichhorn 1986). For this reason, fertilization in flowering plants is called double fertilization.

Within the ovule the embryo undergoes certain developmental stages, called "embryogenesis". The outer layers of the ovule (integument) develop into a seed coat. The ovary wall matures, forming the fruit. The fruit of the Wisconsin Fast Plants is a pod. The fruit is useful in dispersing the newly formed seeds, thus ensuring the continuation of a new generation of plants.

Inheritance of traits can be studied using the Wisconsin Fast Plants. As is true for the pea plants Mendel used in his investigations, Wisconsin Fast Plants have discrete characteristics which are inherited according to Mendelian principles.

OUTLINE OF THE PLANT UNIT

Before beginning the plant unit, each student takes a pre-test (Appendix A). The pre-test is useful in assessing students' prior knowledge and misconceptions. A student's performance on the pre-test does not affect his or her grade for the plant unit. I grade the students' success on the plant unit using three items--a post-test (Appendix B), their Wisconsin Fast Plants Lab Report, and the graphs they construct during the unit.

In designing the plant unit, I tried to use activities which would lead students to understand the major concepts of a plant's life cycle. Although I used several resources in developing the unit, the most important resource was the Wisconsin Fast Plant Manual (1989). Also, I receive Fast Plants/Bottle Biology Notes twice a year from the Wisconsin Fast Plants Program. This newsletter has also been an important source of ideas in the development of this unit.

The major component of the unit involves pairs of students growing their own Wisconsin Fast Plants and performing the necessary activities with them. These activities are all contained in the lab guide which I designed entitled "The Wonderful Wisconsin Fast Plants Project" (Appendix C).

In addition to the work they do with the Fast Plants as they follow the lab guide, students conduct separate investigations and watch demonstrations intended to extend their understanding of certain plant topics. An outline of the unit is given below:

I. Seed structure and Germination

Main Questions: What is a seed? What is necessary for seed germination? What occurs during germination?

Wisconsin Fast Plants Activities from "The Wonderful Wisconsin Fast Plants Project":
observe, measure, and sketch seeds; plant F_1 seeds; observe and sketch emerging shoot; calculate germination rate; record number of wild-type and yellow-green offspring; thin and/or transplant seedlings; measure and sketch root system

Additional Activities:
"What Does a Seed Need to Germinate?" investigation (Appendix D); "What are Those Germinating Seeds Doing?" demonstration (Appendix E); Seed respirometer investigation (Appendix F); Bean seed sketch; root hair sketch; view germinating seed pictures and movie from Bio-Sci II videodisc

II. Vegetative Plant Growth

Main Questions: How does a plant grow? What influences plant growth?

Wisconsin Fast Plants Activities:
sketch and label growing plant; measure plant height and primary leaf length; construct frequency histograms of data; count hairs on margin of primary leaf; perform rubbing experiment on plants

Additional Activities:
"Plant Responses to Light and Gravity" investigation (Appendix G); Darwins' Seedlings demonstration; horse chestnut branch study; secondary growth/annual ring study

III. Flowering Plant Reproduction

Main Question: How does a plant accomplish the production of the next generation?

Wisconsin Fast Plants Activities:
pollination with bee-sticks; flower anatomy study; pollen grain and ovule observations; "Pollen Germination" demonstration using TV. and microscope-camera (Appendix H); "Model of Plant Fertilization" demonstration (Appendix I); flower anatomy worksheet (Appendix J) and fertilization worksheet (Appendix K); honey bee study; "Brassicas and Bees: A Partnership in Survival" article (Appendix L) and worksheet (Appendix M); discussion of bee parts using overhead transparency (Appendix N)

IV. Fruit and Seed Development

Main Question: What happens to the parts of the flower after fertilization?

Wisconsin Fast Plants Activities:
measure and sketch seed pods; observe and sketch immature embryo; embryogenesis study (Appendix O); measure and record seed collection data

Additional Activities:
construct concept map of seed dispersal using seed dispersal article (De Jonge 1989); view fruit examples on Bio-Sci II videodisc

V. The Second Generation

Main Questions: What is the ratio of wild-type and yellow-green plants in the F_2 generation? How can these results be explained?

Wisconsin Fast Plants Activity:
grow the F_2 seeds, record the color of the offspring, try to develop a model which explains the results

THE PLANT UNIT

I. Background

The first homework assignment I give to the students is to read through "The Wonderful Wisconsin Fast Plants Project." I want them to get an idea of what will be expected of them as they perform the tasks described in the guide. I also want them to preview some of the topics they will be studying during the next few weeks.

The lab guide explains how the students are to keep records of their work. Their lab report must include an introduction giving an overview of the project. The students are asked to write hypotheses stating their predictions of how the plants will respond to mechanical stimulation and how the yellow-green color will be expressed in the first generation plants. Each day they work with their plants they record the date, the days since planting, the purpose for working in the lab, the procedure they use in the lab, and any data collected. After completing their study of the F_1 plants growing cycle, students must write a summary of their results. I have tried to pattern the lab report after that of a scientific research paper.

After students read the guide and write the introduction to their lab report, I explain to them how the F_1 seeds we are planting were produced. The seeds are available from Carolina Biological Supply Company. In order for students to see what color the original parents of the F_1 seeds were, I grow samples of wild-type and yellow-green Wisconsin Fast Plants. Students must write three hypotheses concerning what fraction of plants in the first generation will be green and what fraction will be yellow-green. I have them choose the hypothesis with which they are most confident, and star it. Having students write more than one hypothesis forces them to think about the many outcomes that could occur.

II. Planting

The first activity the students do is to become familiar with the Wisconsin Fast Plants growing apparatus. The students work in pairs. Each pair receives a quad, a square foam growing pot with four compartments called cells. The students plant the seeds by placing a diamond shaped cloth wick in the bottom of each cell. The cells are filled half-way with moist soil. Three slow-release fertilizer pellets are added to each cell. Then the cells are filled to the top with soil. Three seeds are sown in each cell. Students write their names on a label which they place in one of the cells of the quad. The quads are then placed on a watering platform with a large cloth mat saturated with water from a reservoir below. The cloth mat keeps the wicks moist, continuously providing water to the soil in each cell. The platforms with prepared quads are placed under florescent lights which remain on twenty-four hours a day.

III. Seed Structure

Before students plant the Wisconsin Fast Plants seeds, they observe them, using a dissecting microscope. This allows them to measure the average width of three seeds as well as to sketch the external structure of the seed.

Fast Plant seeds are small, averaging between one and one and one-half millimeters. Thus, I use soaked bean seeds to study seed anatomy. On a sheet of notebook paper students sketch a bean seed and label the seed coat, hilum, and micropyle. I explain the origin of these structures. After removing the seed coat, the students sketch the internal parts of the seed including cotyledons, epicotyl, hypocotyl, and radicle. Using a needle, the students cut up a cotyledon and add iodine. The color change indicates the presence of starch. I discuss with the students why the embryo needs this food source.

Before giving the pre-test to my students, I wondered if observing the outside and inside structure of a seed was an important activity. But on the pre-test only 57% of students answered "True" to the True/False statement "A seed contains a small plant inside of it." Seeing this, I decided to keep the activity in the unit. On the post-test, 92% of students correctly answered "True" to the same question. (Although it does make me wonder what the other 8% of students were doing when we opened up the bean seed and clearly saw the young plant!)

IV. Germination and Seedling Structure

To study germination, the students perform the investigation "What Does a Seed Need to Germinate" (Appendix D). They also observe the demonstrations "What Are Those Germinating Seeds Doing?" (Appendix E) and "Comparing Dormant and Germinating Seeds" (Appendix F). Students must answer analysis questions included with each activity. Students view germination video segments from the laser disc player to see how the process occurs. Finally, using the seedlings emerging in their quad, students sketch a seedling shoot, and they calculate germination rate.

On the pre-test 64% of students thought that soil was required for Wisconsin Fast Plants seed germination. Seventy five percent of students thought sunlight was required. Only 55% of students knew that heat was necessary. Rather than tell the students that the Wisconsin Fast Plants seed requires water and heat and not sunlight or soil to germinate, I have them do the investigation "What Does a Seed Need to Germinate?"

In this investigation students use three empty film canisters labeled A, B, and C. The students cut pieces of blotting paper to fit the canister lids. The blotting paper is moistened in the lids of canisters A and B but kept dry in canister C. Three seeds are placed on the blotting paper in each lid. The bottoms are snapped on to the lids. Canisters B and C are kept at room temperature while canister A is placed in the refrigerator. After two or three days students check the canisters for germinating seeds.

Only seeds in canister B germinate. Seeds in canister A imbibe water but they do not start growing. Seeds in canister C remain dry. Students observe that water is needed for germination as well as a temperature above a few degrees Celsius. They also observe that light and soil are not needed for Wisconsin Fast Plant seed germination.

This investigation does help to change students' misconceptions about what is needed for seed germination. On the post-test 92% of students chose both soil and sunlight as items not required for Wisconsin Fast Plants seed germination. Also 93% correctly chose heat as being required for germination.

While I think this investigation is useful, I may modify it slightly. I may use Grand Rapids variety of lettuce seeds in addition to Fast Plant seeds. I would add a fourth canister which has moist blotting paper and a transparent bottom. This would demonstrate that some seeds do require light in order to germinate.

An additional investigation I am thinking about doing is measuring the effect of solutions with varying pH values on Wisconsin Fast Plants seed germination. This would show the ecological effect of acid rain.

After performing the seed germination experiment, I have students use canister A to sketch a seedling as it first emerges from the seed. I draw their attention to the root hairs which many students mistake for mold. I tell the students about the study done on 4-month old rye plants in which it was calculated that the plant has 14 billion root hairs with a combined surface area of 401 square meters and which, if placed end to end, would measure over 10,000 kilometers (Raven, Evert, and Eichhorn 1986). These statistics surprise most students.

Gas exchange in germinating seeds is a confusing concept to students. Many students think that because seeds are plants they must take in CO_2 and release O_2 during germination. On the pre-test 58% of students thought CO_2 was required for seed germination. 33% did not think O_2 was needed for germination. I perform two demonstrations to address these misconceptions.

The first demonstration is "What Are Those Germinating Seeds Doing?" which also can be performed as a student investigation. It is adapted from <u>A Sourcebook for the Biological Sciences</u> (1966), a handy book for biology teachers. In this demonstration, four large test tubes are filled with water and bromothymol blue (BTB) so they are 1/4 full. A smaller test tube is placed inside the larger test tube. One smaller test tube contains dry seeds, one contains soaked seeds, one contains boiled seeds, and one contains no seeds. The smaller test tubes are plugged with cotton. The larger test tubes are corked. Students then predict the color they expect the BTB solution in each test tube to be after 24 hours. If students have not worked with BTB before this investigation, I will demonstrate how it changes color when exhaled breath is blown into the solution.

The next day students check the color change in each test tube. The only test tube that should have a color change is that containing the soaked seeds. As they respire they give off CO_2. As CO_2 is added to water carbonic acid is formed, causing the pH to drop and BTB to turn yellow. The other tubes should show no color change in 24 hours.

Interestingly, when I performed this demonstration, the BTB solution in the boiled seeds test tube did change to yellow. This led to an interesting class discussion about why the solution in this test tube changed color. When I removed the cork, a terrible smell came from inside. The seeds were decomposing. I was able to lead students to conclude that it was probably the respiration of bacteria, and not the boiled seeds, that had caused the color change. The seeds I used had been boiled two days prior to the day I did the demonstration. Bacteria had begun growing on the seeds.

The second demonstration illustrating gas exchange during seed germination involves the assembly of seed respirometers. The investigation I use is titled "Comparing Dormant and Germinating Seeds" from the Glencoe lab manual Investigating Living Systems (Kaskel et al. 1994). I use the lab exactly as it is written except I add a fourth test tube with boiled seeds. This demonstration nicely follows up the previous one because the four test tubes used in this one contain the same seed conditions--one test tube contains dry seeds, one contains soaked seeds, one contains boiled seeds, and one contains no seeds.

In addition to the seeds, one-half teaspoon of soda lime (a carbon dioxide gas absorber) is added to each test tube. A cotton plug separates the soda lime from the seeds. A second cotton plug is inserted over the soda lime to keep it in place when the tubes are inverted (see diagram in Appendix F).

The four test tubes are rubber-banded together and inverted in 30 ml of colored water in a small beaker. The height of the water column in each test tube is measured. After 24 hours, the height of the water column is again measured.

The test tube showing the greatest change in water column height indicates the seeds that are undergoing respiration at the greatest rate. The only tube showing a significant change in water level is the soaked seeds. As these seeds respire they use oxygen and release carbon dioxide. The amount of carbon dioxide released is equal in volume to the amount of oxygen used. However, the carbon dioxide given off is absorbed by the soda lime. Thus the volume of gas in the tube decreases, resulting in the movement of water into the tube.

Again, when I performed this demonstration we got unexpected results in the test tube with boiled seeds--a significant rise in water level. I had used the same two-day old boiled seeds in this test tube. This time the students quickly determined that the water rise was probably due to oxygen consumption by bacteria. A quick sniff inside the tube confirmed their suspicions.

I think these two demonstrations help to change students' misconceptions concerning gas utilization during seed germination. On the post-test 89% of students responded that CO_2 is not required for germination. 89% of students also answered correctly that O_2 is required.

These demonstrations also illustrate that germinating seeds are using stored food as an energy source. On the pre-test when asked "As a seed germinates where does it get the necessary energy?", 23% of students chose photosynthesis, 32% chose sunlight, 20% chose soil (!), and only 25% chose respiration. However, on the post-test 88% of students chose respiration for the same question, while 6% chose photosynthesis, 7% chose sunlight, and no one chose soil.

To help students see the process of seed germination, I use still frames and a germination movie from the Bio-Sci II videodisc. Frames 20312 to 20317 show corn seeds germinating as well as bean, pea, and radish seedlings. The radish seedling frame nicely shows root hairs. Frame 20865 begins a movie showing corn seed germination using time-lapse photography. Students love to see time-lapse movies of growing plants. These pictures and movies are very effective in displaying seed germination and early seedling growth.

Finally, students observe the plants in their quads. Within two or three days after sowing the seeds, cotyledons emerge from the soil. I point out to students the connection between these structures and the same structures they observed in the bean seed.

By counting the number of seedlings emerging, and comparing it to the number of seeds sown, students can calculate the germination rate. The Wisconsin Fast Plants seeds usually show between 70% and 100% germination rate.

When the seedlings emerge, students thin them to one plant per cell. Cells without a plant receive a transplant. We discuss the reasons for thinning the plants. In the future I plan to have students investigate what happens when the plants are not thinned.

Finally, students measure and sketch the root system of a Wisconsin Fast Plants seedling so they can see the extent of root growth in a young plant.

V. Analyzing the Transmission of Plant Color in F_1 and F_2 Plants

Within the first week after planting the F_1 Wisconsin Fast Plants, students can determine if they are showing the normal green color (wild-type) or the mutant yellow-green color. I have students count the number of wild-type and yellow-green plants in their quads before they thin them. This way all seedlings are included in the data analysis. Students record their own data and class totals of plant phenotypes. I also give students combined totals from all Biology A classes. Having students record data from a small sample (their quad) and larger samples demonstrates the technique of using large sample sizes when analyzing statistics.

Based on Mendelian principles, the expected phenotypic ratios for these F_1 plants is 100% wild-type and no yellow-green. In my three classes we recorded 362 wild-type and 4 yellow-greens (99% wild-type and 1% yellow-green). The students were a little surprised by the results. On the pre-test only 13% of students thought the expected phenotypic ratio of first generation plants would be 100% green and 0% yellow. 43% of students chose 75% green and 25% yellow, 42% chose 50% green and 50% yellow, and 2% chose 0% green and 100% yellow. I do not tell the students why we would expect 100% green. I tell them that they will have to wait until our genetics unit, or produce a model on their own to explain the results.

After students have studied genetics and they understand the principles used to explain the F_1 phenotypic ratio, I ask the students why we did not get exactly 100% wild-type plants in the F_1 generation. This helps to illustrate experimental error. For example, one F_1 plant which a student thought was a yellow-green plant was actually an un-healthy plant. Students are able to come up with other reasons that the actual results did not exactly fit the expected results.

While growing the F_1 plants, students cross-pollinate them. The seeds produced are the F_2 generation. Students collect these seeds and plant them. After one week students are able to identify and count wild-type green and yellow-green plants. In my three classes we recorded 293 wild-type and 110 yellow-green plants (73% wild-type and 27% yellow-green).

Again, many students cannot explain these results until we study genetics. Educationally, I think this is very effective. Normally, the way we structure activities in a science class is to explain what to expect first, and then have students do the investigation. In this case, students do not know ahead of time what to expect. Once they tabulate their results, they are forced to try to explain them. If this is disconcerting for students, they will want to have an explanation. Once given one, they are more likely to remember it.

John Dewey, the educational philosopher and teacher who taught at Teachers College, Columbia University, described the process of learning as the "complete act of thought" (Childs 1939). According to Dewey, learning begins with a person encountering a confusing or problematic situation. When people are confused by something they see or hear, they seek to resolve the conflict that the situation causes in their mind. Resolving the conflict involves defining the problem and attempting to explain it. Through observation and research, people test whether or not the explanation they have developed is sufficient. If the explanation is supported by the evidence collected, they are satisfied. They have learned something.

Dewey's work has influenced my methods of teaching. When I approach a biological concept, I think about how I can have the students experience a problem related to the concept which creates confusion for them. They are more willing to listen to the explanation because, according to Dewey, they want to eliminate this confusion in their minds. This is why I like to have students encounter the problem of phenotype expression with the Wisconsin Fast Plants before we study genetics.

I am very pleased with the results of our genetics study using the Wisconsin Fast Plants. It is wonderful to have a reliable organism to use for genetic studies. One activity I plan to add to the plant unit related to the genetics portion is to have students do a Chi-square analysis of the results. I think it would be worthwhile to have students understand how scientists judge the significance of experimental results. In addition, I think students need more work with statistics.

VI. Vegetative Plant Growth

As students watch their quad plants develop true leaves and grow taller, they undertake several activities that will teach them about population statistics, plant responses to mechanical stimulation, hormonal control of tropic responses, and secondary growth.

When the Wisconsin Fast Plants are one week old, students count and record the number of hairs on the margin of the first true leaf of each plant and calculate an average. I adapted this activity from the article "Hairy's Inheritance: Getting a Handle on Variation" in the Spring, 1993, edition of Wisconsin Fast Plants/Bottle Biology Notes. I ask students to think about why Wisconsin Fast Plants' leaves have these hairs. It is one example of a trait showing variation in the plant population. Some plants have no hairs. Some have as many as 50 or more hairs on the first true leaf margin.

Students also measure the height of each plant and the length of the first true leaf of each plant. Using the measurements for every plant in class, students construct frequency histograms for these characteristics. This is an excellent way for students to see the normal distribution of a variable trait in a population. Students also record the number of plants in the sample (N), the mean, and the range. This activity is adapted from the article "Getting a Handle on Variation: Quantifying Differences in Plant Height" from the Spring, 1992, edition of Wisconsin Fast Plants/Bottle Biology Notes.

Using students' graphs, I discuss variation in populations. I ask students to think about how the population might change if only the tallest plants were cross-pollinated, introducing the idea of artificial selection. I discuss with students how artificial selection will change the normal distribution of the population.

After students measure their plant heights, they begin investigating the effects of mechanical stimulation (rubbing) on plant growth. I adapted this activity from "Plant Growth-Responses to Touch--Literally a 'Hands-On' Exercise" by Marian Smith (1991). In the article she describes how to use bush bean plants to investigate the effect of rubbing on plant growth. I use the same procedure with the Wisconsin Fast Plants. Each day the students rub the plants by gently rubbing up and down the stem with their thumb and forefinger. The plant in cell B is rubbed 10 times, the plant in cell C is rubbed 20 times, and the plant in cell D is rubbed 30 times. The plant in cell A receives no treatment. Each day the heights of the plants are measured and class averages are calculated. At the end of one week students construct both a line graph and a bar graph of class average plant heights.

Before we begin this investigation, I have students write three hypotheses about how the Fast Plants will respond to rubbing. They indicate with a star which one they think is the best. The majority of students predict that rubbing will increase plant growth. On the pre-test, 55% thought that plants rubbed 30 times a day would grow taller than plants not rubbed.

According to Marian Smith, the more a bean plant is rubbed the shorter it is and the slower it grows. Plants rubbed 30 times should be shorter and have a slower growth rate than plants rubbed 20 times, and so on. After continuing the rubbing treatment on the Wisconsin Fast Plants for one week, my students found the average height of all four treatment groups to be similar--plants receiving no treatment had an average height of 74 mm, plants rubbed 10 times per day averaged 70 mm, plants rubbed 20 times per day averaged 60 mm, and plants rubbed 30 times per day averaged 71 mm.

After completing the rubbing experiment, we compared our results to the bush bean data reported by Marian Smith. We discussed reasons for difference in the data. Some students commented that the plants in their quad appeared to show more noticeable differences in height later in the growth cycle.

When I repeat this experiment, I will make two changes. First, I will continue the treatment for two weeks instead of just one. Second, I will have students use some object other than their fingers to rub on the plants, possibly a cotton swab or toothpick. Because the plants are quite small and fragile when students begin the rubbing experiment it is difficult for them to rub the plants without damaging them. With these changes I hope to get results with the Wisconsin Fast Plants which more closely resemble the bush bean data. If I do not get satisfactory results, I will use bush bean plants.

VII. Hormonal Control of Tropic Responses

At the same time students are performing the rubbing experiment, they investigate plant tropic responses using Investigation I from "Plant Responses to Light and Gravity," a lab included in the <u>Wisconsin Fast Plant Manual</u> (Appendix G).

In the first experiment students grow seedlings in a film canister which has three holes drilled in the side. Each hole is covered with a different color plastic, either red, blue, or green. After 78 hours students record the window toward which the seedlings are growing.

The majority of seedlings grow toward the blue window. When we performed the experiment, we recorded the following data: 32 seedlings toward blue; 9 seedlings toward green; 7 seedlings toward red; 12 seedlings could not be determined. Using the data, I discuss with students why Fast Plants might prefer the blue. This leads to the questions of which wavelengths of light are reflected from a plant and which wavelengths of light are absorbed.

Many students do not predict that most of the seedlings will grow toward the blue window. On the pre-test, only 27% thought the majority of seedlings would grow toward the blue. Students also do not understand that green light is reflected from plants. When asked "Why are plants green?" on the pre-test, only 34% chose the option "Because they reflect green light." Among the other choices, 18% chose "Because they absorb green light," 35% chose "Because they reflect blue and yellow light," and 13% chose "Because they reflect blue and red light."

This 3-color canister experiment, along with the follow-up discussion, helps students understand that plants absorb blue light and reflect green light. On the post-test, 93% chose the blue window when asked toward which window most seedlings would grow. Also, 86% knew that plants were green because they reflected green light.

The other tropism experiments that I have students perform involve plant responses to gravity. In one investigation, seedlings are grown in a film canister which is placed on its side. In the other, a Wisconsin Fast Plant seedling is cut at soil level and its cotyledons are stuck to moistened blotting paper in the lid of a film canister. The bottom is snapped to the lid, and the canister is placed horizontally. In both experiments, the seedling stems bend upward, opposite the pull of gravity.

The outcome of the second gravitropism experiment surprises many students. On the pre-test when asked to choose how the cut end will look after a few hours, 59% of students chose pointing down. When asked why they chose this answer many students responded that it is because the cut end is where the roots were, and roots grow down. I love it when an experiment turns out differently from what students predict. This confusing situation sets the stage for our discussion of auxin and its role in plant bending.

Students do remember the outcome of this experiment. On the post-test, 93% of students knew that the seedling stem would point upward.

After students complete the gravitropism investigations, I have them read from their textbook about Charles and Francis Darwin's experiments with wheat seedlings and Frits Went's experiment showing the effect of auxin on plant stem bending.

To illustrate the Darwins' experiment I use several film canisters with a hole drilled in one side to allow unidirectional light into the canister. I grow three Wisconsin Fast Plant seedlings in each canister. When the seedlings are about 5 mm tall, I clip the top off one seedling, cover the top of the second with an aluminum foil cap, and do nothing to the third. After two days I show students the results. The untreated seedling is the only one bending toward the light.

This demonstration reinforces the idea that the tip of the seedling is responsible for detecting light and causing the bending of the stem. In the future I may have students do this experiment in pairs and omit one of the other tropism experiments.

VIII. Secondary Growth

A final topic I examine with my students related to plant growth is tree branch anatomy and annual ring production. Students sketch a horse chestnut branch on paper and label some of the external features as I point them out. I show students the terminal bud, lateral buds, bud scars, leaf scars, bud-scale scars, and lenticels. I describe to students how a branch grows, and how the scars are formed. After showing students how to estimate the branch's age, I assign them the task of estimating the age of a branch that they find in their yard. The main reason I do this branch study is to give students some "nature knowledge" which we will apply later in the year when we visit a wooded area near school.

To investigate secondary growth, I show students sections of a tree trunk. I ask them to estimate how old the tree was when it was cut down. I then explain how the vascular cambium produces new phloem and xylem tissue, increasing the width of the stem.

I generally do not spend more than one class period doing this branch and secondary growth study.

IX. Flower Anatomy and Physiology

Of all the activities completed with the Wisconsin Fast Plants, the two that get mentioned most often at the end of the plant unit as being a student's favorite activity are pollination and the honey bee study. The Wisconsin Fast Plants provide a dynamic and interactive method for studying flower anatomy, flower physiology, and the mutualistic symbiosis between flowering plants and honey bees.

Before the F_1 Wisconsin Fast Plants flower, students construct bee-sticks by gluing the thorax of a bee to the end of a toothpick. This activity can cause students to wonder why they are gluing dead bee parts to a toothpick. Once the flowers open, students eagerly use their bee-sticks to visit many of their friends' flowers, picking up pollen and transferring it to their own flowers. I tell students that some buzzing helps the pollination process. They readily follow the suggestion, buzzing as they fly their bee-sticks around the room.

Students pollinate the flowers before they study flower structure, which generates interest in flower anatomy. It also causes students to question why pollination is necessary, setting the stage for our flower study. Students are more interested in finding out what is really happening when a bee visits a flower.

Most students know that bees pick up pollen as they visit flowers. On the pre-test, 78% finished the question "Insects play a part in the reproduction of flowering plants by..." with the answer "spreading pollen." Yet many students do not know what flower parts are involved in this process. Only 22% knew that during pollination, pollen is transferred from the anther to the stigma.

To study flower structure, students remove a flower from one of their Wisconsin Fast Plants. Using a dissecting microscope, they sketch the parts of the flower. As they read the description of each flower part in the "Wonderful Wisconsin Fast Plants Project" guide, they label that part on their sketch and give its function. Students then tape the parts of the flower on to a 3 by 5 note card, which I grade. I allow the students to use their card to study for the post-test.

I think this method of studying flower structure is effective. On the pre-test, only 45% of students could identify the stigma, only 42% could identify an anther, and only 33% could identify the sepals. However, on the post-test, 98% of students correctly identified the stigma, 97%

correctly identified an anther, and 93% correctly identified the sepals.

To aid students in viewing pollen grains, I have them make a wet mount of pollen by smearing an anther in a drop of water on a slide. Using a light microscope, students can observe and sketch pollen grains.

The ovules of the Wisconsin Fast Plant flower are very small and difficult to see. Instead, I have students use a larger flower like a snapdragon to view ovules.

In the Wisconsin Fast Plants guide I give students a description of how fertilization occurs in a flower after pollination is accomplished. On the pre-test only 43% of students knew that sperm reach the egg by way of a tube.

To help students visualize this process, I use two demonstrations. One which I adapted from the article "Pollen Germination with Fast Plants" (1990) shows pollen grain germination (Appendix H). The other demonstration illustrates double fertilization (Appendix I). This activity I modified from a model of double fertilization described in the Wisconsin Fast Plants Manual.

Once a pollen grain adheres to the stigma, it begins to germinate, growing a tube which passes through the style to an ovule in the ovary. Wisconsin Fast Plant pollen grains can be stimulated to germinate *in vitro* when placed into a solution of sucrose and mineral salt.

I show students germinating pollen grains using the microscope-camera and TV. This method saves time and assures that all students see what they are supposed to see. The microscope-camera has been an invaluable tool in my biology class for demonstrations like this.

The double fertilization demonstration is simple yet effective in helping students understand the process. I use a plastic bag to represent an embryo sac, and a rolled up overhead projector plastic sheet to represent a pollen tube. Inside the bag I place three Lego pieces, two attached together. The solitary piece represents the egg. The two connected represent the polar nuclei (fusion nuclei). I drop two additional Lego pieces through the overhead sheet into the bag. These represent sperm. One "sperm" Lego piece connects to the polar nuclei pieces forming the triploid endosperm. The other "sperm" Lego piece connects to the "egg" piece forming the diploid zygote. Although students laugh at me when I take out the parts to this model, it does help them remember the process.

In addition to watching these two demonstrations, I have students fill out a worksheet on flower structure (Appendix J) and a worksheet on double fertilization (Appendix K).

Besides teaching students about flowering plant reproduction, the Wisconsin Fast Plants can be used to illustrate the mutualistic symbiosis between flowering plants and honey bees. To study this relationship, students first study bee parts. Students sketch and label the three main body parts of the bee. They also locate the proboscis, the mouth-part the bee uses to sip nectar. By placing a wing and a crushed abdomen on a slide, students can study wing and stinger structure using the light microscope. Students seem to enjoy viewing these parts with the microscope.

A fascinating aspect of our bee study involves observing the special pollen-collecting structures on the bee legs. I use the microscope-camera connected to the TV to show students the antenna cleaner on the foreleg, the spur and pollen brushes on the midleg, and the pollen comb, pollen press, and pollen basket on the hindleg. After viewing these structures, I have students predict how the bee uses each of them.

As a homework assignment after viewing the bee legs, students read the article "Brassicas and Bees: A Partnership in Survival" (1987) (Appendix L) and answer questions about the article from a worksheet (Appendix M). The article describes pollination and explains why bees associate with flowers. It also identifies how a bee uses its leg structures to collect and store pollen. The next day I discuss the article, using an overhead transparency showing a bee inside a flower and the bee legs (Appendix N).

Students enjoy learning about bees. One student commented that our study of bees gave her a new appreciation for "a seemingly simple and boring organism."

X. Fruit and Seed Development

The Wisconsin Fast Plants are an excellent organism for examining fruit development. Many students do not know that fruits develop from the flower ovary. On the pre-test only 16% of students knew that fruit develops from a flower ovary. After completing the plant unit one student described her prior misconception about flowers and fruit in this way: "Before, I thought a fruit was a fruit while a flower was a whole separate unrelated thing."

When students grow the Fast Plants, they can actually watch the fruit develop from the flower ovary. A day or two after pollination students can observe the sepals, petals, and stamens shriveling up and falling off the flowers. At first this causes distress for some students. I hear the comment, "Our flowers are dying!" I usually respond by asking if all of the flower parts have fallen off or if there is a part still remaining. It is enjoyable seeing some students finally make the connection between fruits and the flower that preceded it.

Seeing the development of pods from Wisconsin Fast Plant flowers does help students make the connection between the flower ovary and fruit development. On the post-test, 89% of students correctly identified the flower ovary as the structure from which the fruit develops.

When pods first begin developing, students measure the length and sketch one. When the pods are fully mature, students re-measure and re-sketch them. This allows them to identify how the seed pod changes during its development.

In addition to fruit development, students also study embryogenesis. I adapted this activity from the article "Embryogenesis" in the Fall, 1989, edition of Wisconsin Fast Plant Notes. I again use the microscope-camera for this demonstration. I cut open an immature seed approximately 10 days after pollination and another seed 14 days after pollination. When this is done, the liquid endosperm spills out and the immature embryo can be seen. While students are sketching the embryo, I explain how it processes the endosperm, converting it into food stored in the cotyledons. I use an overhead transparency of embryogenesis to aid in the discussion (Appendix O).

One function of fruit is aiding in seed dispersal. Students read "Slingshots, Parachutes, and Propellers" (De Jonge 1989) which discusses seed dispersal. Although written for younger students, the article does a nice job of illustrating the role of fruit in seed dispersal. As they read, students construct concept maps of the methods of dispersal described in the article.

When I discuss the article in class, I use the Bio-Sci II videodisc to show students examples of fruits. Some of the fruits I show include "floating" fruits such as cottonwood and milkweed, sticky fruits such as cocklebur and bur, and exploding fruits such as jewelweed.

This study of seed dispersal is adequate. Yet, I would like to use an investigation which requires students to run a controlled seed dispersal experiment. I want to make this study of seed dispersal more inquiry-based and not just descriptive.

When the F_1 Wisconsin Fast Plants are 35 days old, the quads are removed from the water to allow the plants to dry. Five days later the seeds can be removed from the seed pods. On "harvest day" students measure the length of the pods produced by their quad plants and calculate the average pod length. They also calculate the average number of pods produced by their plants. Once all the seeds are collected and counted, students calculate the average number of seeds produced per pod and per plant for their quad.

The collected seeds are the F_2 generation in our genetics study. The plants need only to grow for five days after being planted before their phenotype can be determined and tabulated in the genetics study. This is the only thing we do with the F_2 plants.

ANALYSIS OF EFFECTIVENESS OF UNIT

I. Evaluating the Wisconsin Fast Plants Report

When students complete their study of the F_1 Wisconsin Fast Plants life cycle, they must write a summary of their work. The summary must include a comparison of their hypotheses regarding the effect of rubbing and the phenotypic ratio of the F_1 to the actual results. It must also include an evaluation of what aspects of the Wisconsin Fast Plants Project worked well for them and which aspects did not work well. Finally, students mention what they liked and did not like about the plant project.

I strongly encourage students to use a word processor to make the finished copy of their Wisconsin Fast Plants Report before they hand it in. I also suggest that they make their sketches neat. Some students use color pencils on their sketches.

I designed a grading sheet to make the grading of the report manageable and fair (Appendix P). The total number of points a student can earn on the report is 100. I deduct 5 points for every day the report is late. I add points for very neat work. The report is worth one test grade.

Results of students' Wisconsin Fast Plant reports are given on the following page:

Total number of students = 90

Number of students handing in a report = 90

Mean score = 94 (94%)

Median score = 96 (96%)

Highest score = 105 (105%)

Lowest score = 60 (60%)

Number of students earning an A or A- = 56

Number of students earning a B+, B, or B- = 26

Number of students earning a C+, C, or C- = 4

Number of students earning a D+, D, D-, or F = 4

I was very pleased with the students' Wisconsin Fast Plant reports. I gave very high grades on the reports because the students earned them. I told the students that they should be very proud of their finished report. It represents their ability to use the scientific method in doing basic research on a living organism. Most of the students put their Fast Plant Report in their portfolio.

II. Results of Pre-test and Post-test

In addition to evaluating students' Wisconsin Fast Plants reports, I measured how much they learned from the unit using a post-test.

The post-test I used this past year is a slight modification of the pre-test. I removed question 16 dealing with the elements in fertilizer. I had not discussed this topic with students during the plant unit. Also, I dropped the five questions dealing with the horse chestnut branch and annual rings (questions 26 - 30). In one of my biology classes I did not have time to do this lesson due to a schedule conflict. Therefore, to be fair, I removed these questions from the post-test. I added nine new questions to the post-test.

The pre-test results given below are for the 41 questions that also were on the post-test and do not include the 6 questions omitted on the post-test. The post-test results given are for the same 41 questions and do not include the 9 additional questions.

Results of pre-test:

Number of Respondents = 88

Number of Test Items = 41

Mean score = 17.7 (43.2%)

Median score = 17 (41.5%)

Standard Deviation = 4.31

Highest Score = 28 (68.3%)

Lowest Score = 10 (24.4%)

Results of Post-test:

Number of Respondents = 90

Number of Test Items = 41

Mean Score = 35.2 (86.0%)

Median Score = 36 (87.8%)

Standard Deviation = 4.88

Highest Score = 41 (100.0%)

Lowest Score = 21 (51.2%)

The frequency distribution of pre-test and post-test scores are given in Figure 1 on the following page.

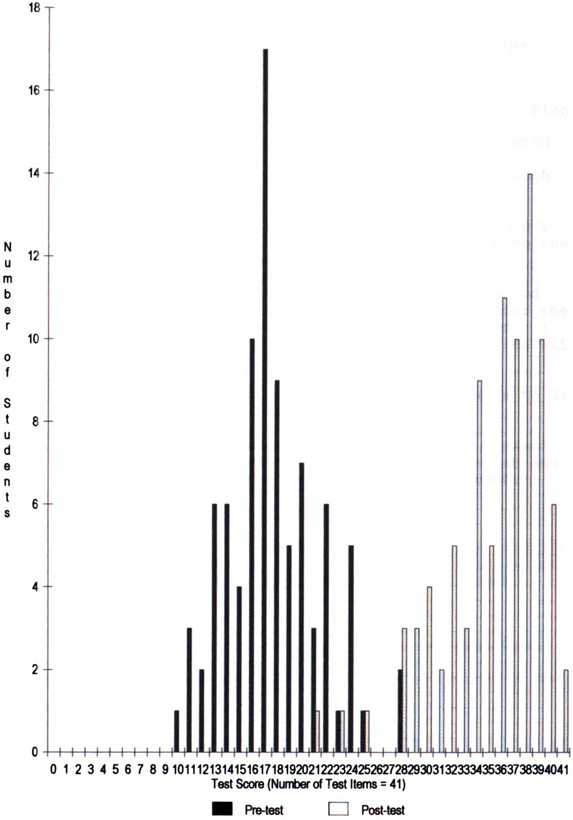
I am very pleased with the students, scores on the post-test. I think that many of the plant unit activities help students remember and understand the main concepts. Based on these results, I would consider the plant unit activities to be educationally effective.

It is difficult to compare the students' post-test scores with scores from students taught the "old" way before I developed this plant unit. The plant unit pulls together several topics which I previously taught in separate units throughout the school year. Much of the plant unit is new material which I did not teach before. I do think that after completing this plant unit students remember the material for a longer period of time than students taught the same topics in the "old" way.

II. Student Attitudes Toward the Plant Unit

After completing the plant unit I asked all students to write down what they liked about the plant unit and what

Figure 1 - Frequency Distribution
of Pre-test and Post-test scores



they did not like about it. Two common remarks were reported. First, students said that they enjoyed it. Second, students stated that the activities helped them learn the main concepts of the plant unit.

Most of the students stated that they enjoyed the plant unit. Some of the comments I read included the following:

> "This was a really fun and interesting project, much better than lectures or book-reading."

> "What I liked about this experiment was the chance to plant and raise my own brood of plants and to have them actually live to reproduce. That was cool!"

> "It was fun to make the bee-sticks and to go around pollinating the flowers. Looking at the bee under the microscope was probably my favorite thing we did. I thought it was amazing how the bee collects pollen with all the special tools."

> "The graph-making was cool. It gave me a chance to use my computer in a way I haven't before."

> "At first I thought that the idea of rubbing a plant was ridiculous, but it was fun to go into the lab and see how much our plants had grown just overnight."

> "It was fun, yet educating."

> "This project will be remembered as one of my favorite projects I ever did in school. It was not only a lot fun, but it taught me some valuable things about plants."

Other students stated that they liked the fact that they gathered the information rather than me giving it to them:

> "What I liked about this project was that it taught all these things about plants without just having us take notes in class. Most of what we learned was information we gathered ourselves."

> "I liked that we went to the lab almost every day and had hands on work. It made our group figure things out for ourselves instead of rushing to a book or the teacher."

I think the independent work of the plant unit helps students work together to solve problems. One student described how she and her partner solved one problem:

> "(We) ran into a few problems but they either did not matter or we were able to solve them. One problem we had was that our plant in quad cell B was growing slower than the others. It developed leaves and flowers later than the rest of the plants. Another problem we had was that the soil in quad cell A kept drying out. We solved this problem by keeping the soil moist by adding water regularly."

Many students observed that the hands-on nature of the project helped them understand the concepts better:

> "It is nice to work with something that is living and that you can actually see and understand what is happening."

> "I thought what worked well was being able to actually see, touch, and even smell what I was studying. It's always great to be able to interact with what you are learning about."

> "I think that because of the things I did and saw I understood and remembered things more than if I had just read or heard about them."

> "The reason that this project was so good is because we used actual plants to learn about the plant cycles and processes instead of learning it all out of a book or from diagrams and pictures. I like 'hands-on' learning instead of just listening to a teacher tell us about it."

Not all students liked everything about the plant unit. A few students thought the plant growing went on for too long. Some students commented that they did not like having to record so much data. Others said that they did not like having to write up all their work as a report. They said that it took too long to do this.

Overall, I am satisfied with the students' attitudes toward the plant unit. It appears to be a valuable and enjoyable learning experience for most students.

CONCLUSION

Designing this plant unit required much work. However, considering the students' well-written Wisconsin Fast Plant reports as well as their success on the post-test, I think it was worth the effort.

A benefit of growing the Wisconsin Fast Plants during this unit is that many students used them for an independent research project I have students do each year.

Every year in February my school holds an open house for the community. At this open house students display projects they have done in their classes. I treat this open house like a science fair. Pairs of students design and complete independent investigations related to some aspect of biology.

This past year I encouraged students to use the Wisconsin Fast Plants for their experiments. About half of the students did so. Some of the experiments students did with the Wisconsin Fast Plants included measuring the effects of acid rain on plant growth and measuring the effect of different amounts of fertilizer on plant growth. One group of students used a mutant form of Wisconsin Fast Plants called "rosette" which do not produce gibberellic acid and remain short. They measured the effects of gibberellic acid on the wild-type and rosette plants. Some students even measured the effect of different soft drinks on plant growth. The advantage of using Wisconsin Fast

Plants for these experiments is that students already have experience growing them. They are an ideal organism for students to use for such independent projects.

I am glad my colleague introduced the Wisconsin Fast Plants Program to me. I am also thankful that I spent the time to develop this plant unit. Teaching this unit convinces me that when students hear, they forget. When students see, they remember. But when students do, they understand.

APPENDICES

APPENDIX A

APPENDIX A

PLANT UNIT PRETEST Name____________________________________

NOTE: THIS IS A PRETEST. HOW YOU DO ON THIS TEST WILL NOT INFLUENCE YOUR GRADE AT ALL!!
PUT ALL OF YOUR ANSWERS ON THE SCANTRON SHEET. USE A #2 PENCIL AND FILL IN THE CIRCLES COMPLETELY. ERASE COMPLETELY.
ANSWER ALL OF THESE QUESTIONS AS BEST YOU CAN. IF YOU DON'T KNOW AN ANSWER, GUESS!

Use the following key for the first six items.

A. Is required for Wisconsin Fast Plant seed germination.
B. Is NOT required for Wisconsin Fast Plant seed germination.

1. carbon dioxide

2. oxygen

3. soil

4. sunlight

5. heat

6. water

For the next 2 items use the following key: A. True B. False

7. A seed contains a small plant inside of it.

8. A seed is alive.

----

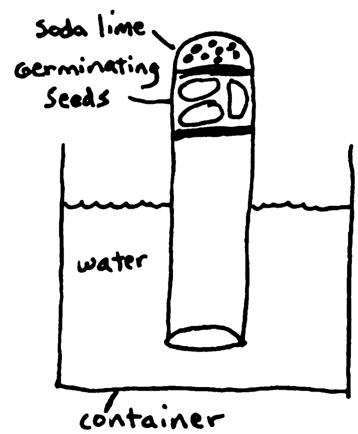
9. As a seed germinates, where does it get the necessary energy? A. photosynthesis B. sunlight C. respiration D. soil

10. As a seed germinates, which gas is given off? A. oxygen B. carbon dioxide C. both oxygen and carbon dioxide D. nitrogen

11. The first structure to emerge from a germinating seed is the A. cotyledon(s) B. radical (root) C. stem (shoot tip) D. true leaves

12. When the Fast Plants first emerge from the soil during germination, what is the first structure to be visible above the soil? A. cotyledons B. radical (root) C. flower bud D. true leaves

13. A test tube containing germinating seeds and some soda lime (a carbon dioxide absorber) is placed into a container of water such that the trapped air in the tube prevents water from moving up into the tube. As the seeds germinate, what will occur in the test tube? A. water will move out of the tube as respiration occurs. B. water will move out of the tube as photosynthesis occurs. C. water will move in to the tube as respiration occurs. D. water will move in to the tube as photosynthesis occurs.



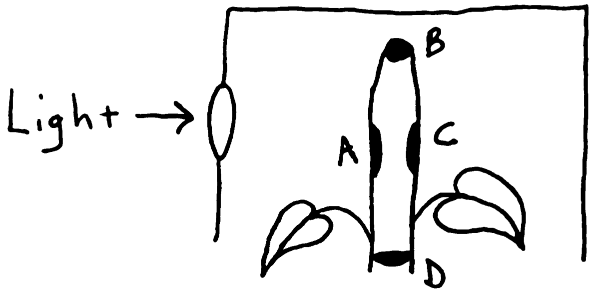
14. A seed contains a food supply. Which type of seed, germinating or dormant, carries on the process of converting this food supply into usable energy at a slower rate? A. germinating seeds. B. dormant (dry) seeds C. They do this at the same rate. D. Neither seed does this. They both only undergo photosynthesis.

15. If a "normal" color green Fast Plant ("wild type") is cross-pollinated with a recessive mutant yellow-green Fast Plant (with yellow color leaves), what would be the expected percent of green plants and yellow plants in the first generation (F_1)? A. 100% green, 0% yellow B. 75% green, 25% yellow C. 50% green, 50% yellow D. 0% green, 100% yellow

16. What 3 elements are found in plant fertilizer? A. Nitrogen (N), Carbon (C), Potassium (K) B. Carbon (C), Phosphorous (P), Potassium (K) C. Nitrogen (N), Phosphorous (P), Potassium (K) D. Calcium (Ca), Phosphorous (P), Potassium (K)

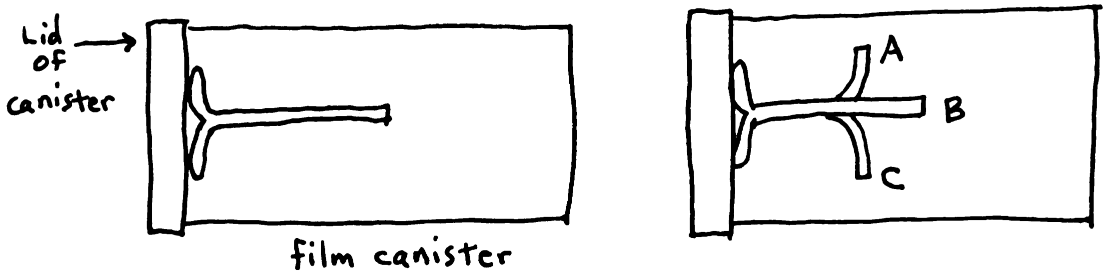
17. A class of students is growing Fast plants. Each group has 2 plants growing. One plant (plant A) is not rubbed at all on the stem. The second plant (plant B) is rubbed 30 times up and down on the stem for 5 days. At the end of the 5 days, how will the average height of the plants compare? A. The avg. height of A will be taller than B. B. The avg. height of B will be taller than A. C. The avg. height of A will be the same as B. D. This cannot be determined.

18. The figure below shows the top part of a plant growing in a dark chamber with a hole for light to enter on one side. Which of the shaded areas indicates the area on the stem where auxin will accumulate under these conditions?



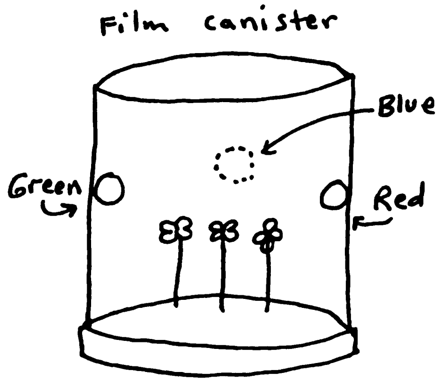
19. Which of the following best describes how auxin works? Auxin A. makes cells divide more slowly. B. makes cells divide more rapidly. C. makes cells elongate (increase) in length. D. inhibits cells from elongating.

20. A small plant is cut at soil level (roots cut off) and stuck to the lid of a film canister. The film canister is placed on a table horizontally as shown on the left below. At right, which letter indicates what the plant stem will look like after a few hours?



21. Which of the following best explains why the plant stem will appear as you've drawn it in number 20. A. Auxin accumulates on the upper side, causing cells to elongate. B. Auxin accumulates on the lower side causing cells to elongate. C. Auxin accumulates on the upper side, inhibiting cell division. D. Auxin accumulates on the lower side, inhibiting cell division.

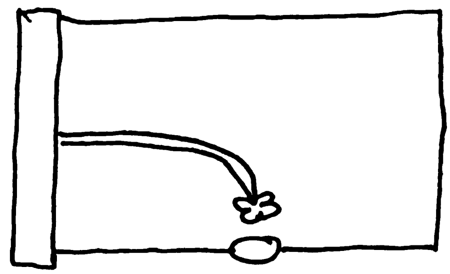
22. 100 plants are grown in film canisters (3 per canister) with three windows as shown at right. Toward which window will the majority of the plants grow? A. green. B. blue C. red D. all three windows equally



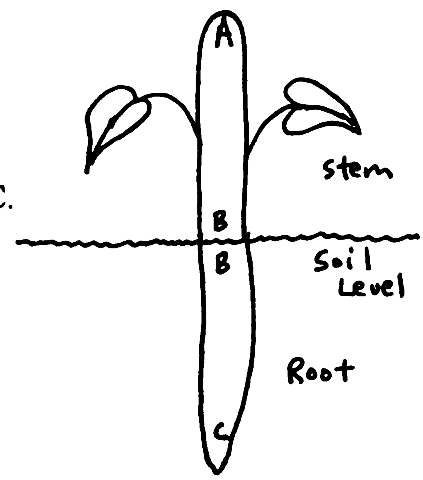
23. Why are plants green? Because A. they absorb green light. B. they reflect green light. C. they reflect blue and yellow light. D. they reflect blue and red light.

24. If a seedling is growing in a light-proof box with a hole at the bottom, the shoot will grow downward. This suggests that :

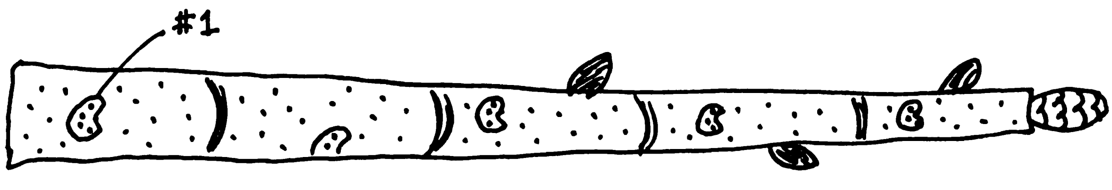
A. Positive gravitropism is a stronger influence on shoot growth than positive phototropism
B. Positive phototropism is a stronger influence on shoot growth than negative gravitropism
C. Negative gravitropism is a stronger influence on shoot growth than positive phototropism
D. Negative phototropism is a stronger influence on shoot growth than positive gravitropism



25. The plant at right is growing taller and the root is growing longer. Which of the areas of the plant are areas where most of the growth is taking place. A. In area A. B. In area B. C. In area C. D. Both in areas A and C.



The branch below was pulled off a tree. Answer the following questions.



26. How many terminal buds are shown? A. 1 B. 2 C. 3 D. 4

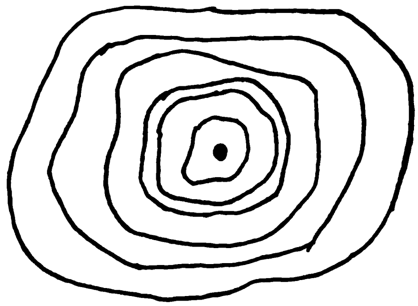
27. How many lateral buds are shown? A. 1 B. 2 C. 3 D. 4

28. What is the structured labeled #1? A. terminal bud scar B. lateral bud scar C. lateral bud scale scar D. leaf scar

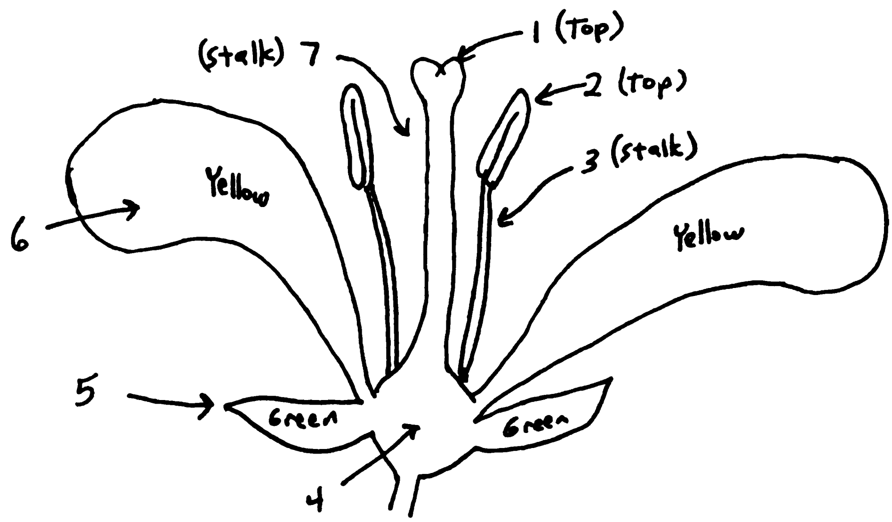
29. How old is this branch? A. 3 years B. 4 years C. 5 years D. 6 years

30. The tree below was cut at the end of the summer 1994. What year was the driest growing season?

A. 1990
B. 1991
C. 1992
D. 1993



Use the diagram of a Fast plant flower below to answer the next 3 questions.



31. What is structure 1? A. stigma B. style C. anther D. sepal

32. What is structure 2? A. stigma B. style C. anther D. filament

33. What is structure 5? A. petal B. sepal C. stamen D. pistil

34. In a flowering plant, fertilization occurs within the: A. cotyledons. B. ovary. C. seed. D. stigma.

35. Which part of a flower produces the pollen? A. pistil B. petal C. sepal D. stamen

36. Where is sperm contained in a flower? A. within the ovules. B. within the pollen. C. within the pistil. D. within the seed.

37. How do sperm reach the egg of a flowering plant? A. by swimming B. by gravity C. through the air D. through a tube

38. Insects play a part in the reproduction of flowering plants by: A. eating pollen B. scattering seeds C. helping fertilization D. spreading pollen

39. What is the relationship between pollination and fertilization in flowers?
A. Fertilization and pollination are the same event.
B. Fertilization must occur before pollination can.
C. Pollination must occur before fertilization can.
D. Pollination is sexual, fertilization is asexual.

40. From which part of a flower does the fruit develop? A. pollen B. ovary C. anther D. stigma

41. From which part of a flower do seeds develop? A. pollen B. ovules C. sepals D. stamens

42. Which of the following does NOT occur as a seed matures following fertilization? A. The embryo develops and matures. B. Food is produced and stored. C. A seed coat develops. D. The fertilized egg is stored until the seed germinates.

Use the following key for the next 4 questions:

A. fore-leg B. mid-leg C. hind-leg

Which of the bee legs listed above contains the following adaptive structures:

43. antenna cleaner

44. pollen basket

45. pollen comb

46. pollen brush

---

47. Which of the following best completes the blanks? During pollination, pollen must be transferred from the --?-- to the --?--. A. anther, ovary B. stigma, anther C. filament, anther D. anther, stigma

APPENDIX B

APPENDIX B

PLANT UNIT TEST **Name**___________________________________

PUT ALL OF YOUR ANSWERS ON THE SCANTRON SHEET. USE A #2 PENCIL AND FILL IN THE CIRCLES COMPLETELY. ERASE COMPLETELY.

Use the following key for the first six items.

A. It is required for Wisconsin Fast Plant seed germination.
B. It is NOT required for Wisconsin Fast Plant seed germination.

1. carbon dioxide

2. oxygen

3. soil

4. sunlight

5. heat

6. water

For the next 2 items use the following key: A. True B. False

7. A seed contains a small plant inside of it.

8. A seed is alive.

---

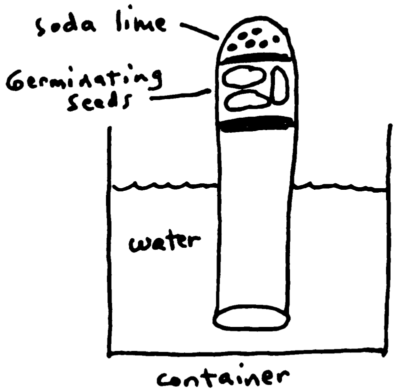
9. As a seed germinates, where does it get the necessary energy? A. photosynthesis B. sunlight C. respiration D. soil

10. As a seed germinates, which gas is released? A. oxygen B. carbon dioxide C. both oxygen and carbon dioxide D. nitrogen

11. The first structure to emerge from a <u>germinating bean seed or Fast Plant seed</u> is the A. cotyledon(s) B. radical (root) C. stem (shoot tip) D. true leaves

12. When the Fast Plants first emerge from the soil during germination, what is the first structure to be visible above the soil? A. cotyledons B. radical (root) C. flower bud D. true leaves

13. A test tube containing germinating seeds and some soda lime (a carbon dioxide absorber) is placed into a container of water such that the trapped air in the tube prevents water from moving up into the tube. As the seeds germinate, what will occur in the test tube? A. Water will move into the tube as respiration occurs. B. Water will move into the tube as photosynthesis occurs. C. Water will move into the tube as CO_2 is used by the seeds. D. Both B and C are correct.



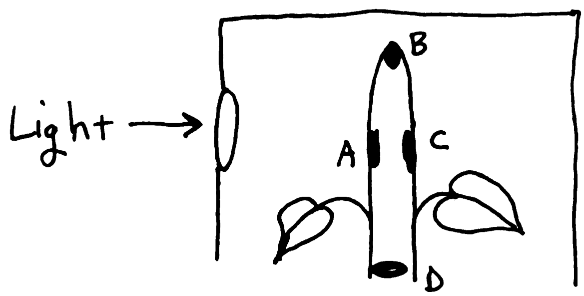
14. Which type of seed, germinating or dormant, carries on the process of converting food into usable energy at a slower rate? A. germinating seeds. B. dormant (dry) seeds C. They do this at the same rate. D. Neither seed does this. They both only undergo photosynthesis.

15. If a "normal" color green Fast Plant ("wild type") is cross-pollinated with a recessive mutant yellow-green Fast Plant (with yellow color leaves), what would be the expected percent of green plants and yellow plants in the first generation (F_1)? A. 100% green, 0% yellow B. 75% green, 25% yellow C. 50% green, 50% yellow D. 0% green, 100% yellow

16. As a Fast plant seed germinates, what supplies the growing embryo with food needed for energy? A. The embryo makes it by photosynthesis. B. The embryo absorbs food from the soil. C. The embryo gets food from the water it absorbs. D. The embryo gets food from the cotyledons.

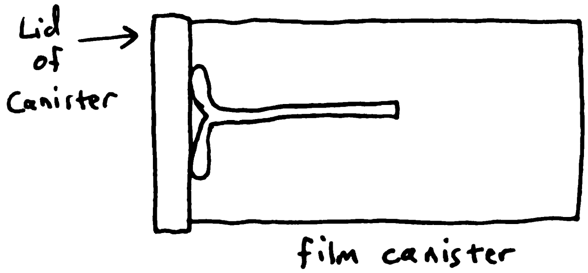
17. A class of students is growing Fast plants. Each group has 2 plants growing. One plant (plant A) is not rubbed at all on the stem. The second plant (plant B) is rubbed 30 times up and down on the stem for 5 days. At the end of the 5 days, how will the average height of the plants compare? A. The avg. height of A will probably be taller than B. B. The avg. height of B will probably be taller than A. C. The avg. height of A will be about the same as B. D. Plant B will die because of the rubbing.

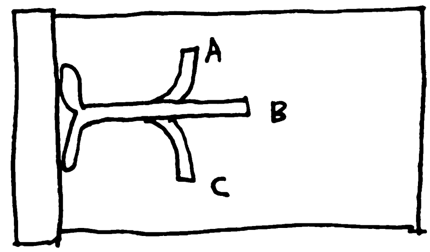
18. The figure below shows the top part of a plant growing in a dark chamber with a hole for light to enter on one side. Which of the shaded areas indicates the area on the stem where auxin will accumulate under these conditions?



19. Which of the following best describes how auxin works in the plant stem shown above? Auxin A. makes cells divide more slowly. B. makes cells divide more rapidly. C. makes cells elongate (increase in length). D. inhibits cells from elongating.

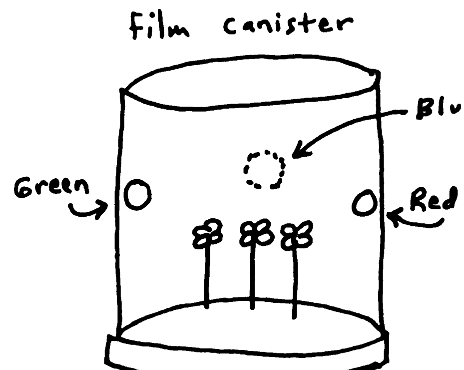
20. A small plant is cut at soil level (roots cut off) and stuck to the lid of a film canister. The film canister is placed on a table horizontally as shown on the left below. At right, which letter indicates what the plant stem will look like after a few hours?





21. Which of the following best explains why the plant stem will appear as you've drawn it in number 20? A. Auxin accumulates on the upper side, causing cells to elongate. B. Auxin accumulates on the lower side causing cells to elongate. C. Auxin accumulates on the upper side, inhibiting cell division. D. Auxin accumulates on the lower side, inhibiting cell division.

22. 100 plants are grown in film canisters (3 per canister) with three windows as shown at right. Toward which window will the majority of seedlings grow?
A. green B. blue C. red
D. all three windows equally



23. Why are plants green? Because A. they absorb green light. B. they reflect green light. C. they reflect blue and yellow light. D. they reflect blue and red light.

24. If a seedling is growing in a light-proof container with a hole at the bottom, the shoot will grow downward. This suggests that :
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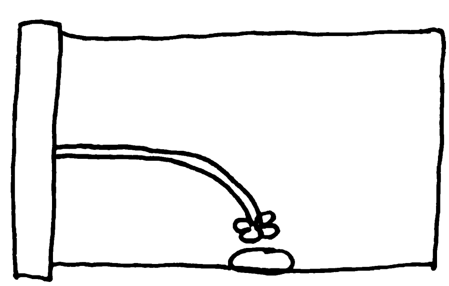
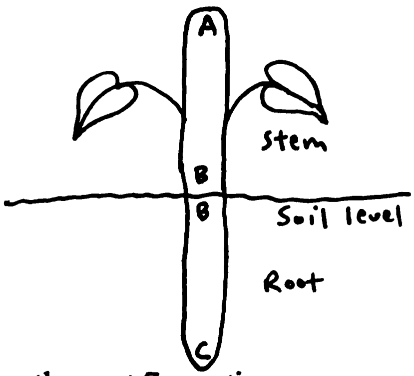
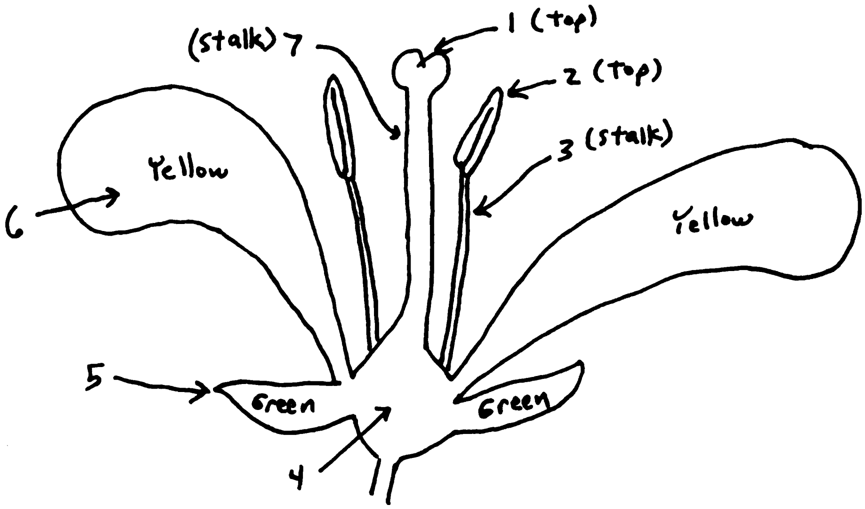


25. The plant at right is growing taller and the root is growing longer. Which of the areas of the plant are areas where most of the growth is taking place. A. In area A. B. In area B. C. In area C. D. Both in areas A and C.



Use the diagram of a Fast plant flower below to answer the next 7 questions.



26. What is structure 1? A. stigma B. style C. anther D. sepal

27. What is structure 2? A. stigma B. style C. anther D. filament

28. What is structure 3? A. sepal B. style C. anther D. filament

29. What is structure 4? A. style B. pistil C. ovule D. ovary

30. What is structure 5? A. petal B. sepal C. stamen D. pistil

31. What is structure 2 and 3 together? A. stamen B. style C. sepal D. anther

32. What structure contains ovules? A. #2 B. #4 C. #7 D. #1

---

33. What honey bee structure is used to make a beestick? A. abdomen. B. head C. thorax

34. In a flowering plant, fertilization occurs within the: A. pollen grains. B. ovary. C. seed. D. stigma.

35. Which part of a flower produces the pollen? A. pistil B. petal C. sepal D. stamen

36. Where is sperm contained in a flower? A. within the ovules. B. within the pollen. C. within the pistil. D. within the seed.

37. How do sperm reach the egg of a flowering plant? A. by swimming B. by gravity C. through the air D. through a tube

38. Insects play a part in the reproduction of flowering plants by: A. eating pollen B. scattering seeds C. helping fertilization D. spreading pollen

39. What is the relationship between pollination and fertilization in flowers?
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B. Fertilization must occur before pollination can.
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41. From which part of a flower do seeds develop? A. pollen B. ovules C. sepals D. stamens

42. Which of the following does NOT occur as a seed matures following fertilization? A. The embryo develops and matures. B. Food is produced and stored. C. A seed coat develops. D. The fertilized egg is stored until the seed germinates.

Use the following key for the next 4 questions:

A. fore-leg B. mid-leg C. hind-leg

Which of the bee legs listed above contains the following adaptive structures:

43. antenna cleaner

44. pollen basket

45. pollen comb

46. pollen brush

47. Which of the following best completes the blanks? During pollination, pollen must be transferred from the --?-- to the --?--. A. anther, ovary B. stigma, anther C. filament, anther D. anther, stigma

48. About how many ovules does an orange blossom (flower) contain? A. 1 B. 5-10 C. 50-100 D. 500-1,000

49. What does a honey bee use the spur on its mid-leg for? A. To sting another organism. B. To hold unto a flower or its hive. C. To kick pollen out of the pollen basket. D. To hold onto another bee during mating.

50. A honey bee can usually sting a person many times. A. true B. false

APPENDIX C

APPENDIX C

The Wonderful Wisconsin Fast Plants Project

Introduction

Part of your work in biology class this year will involve doing some basic investigation and research with special plants commonly referred to as "Wisconsin Fast Plants". These plants are given this name because a team of biologists at the University of Wisconsin, headed by Dr. Paul Williams, developed them. They did this by carefully guiding the reproduction of certain plants of the species *Brassica rapa*. Other varieties of plants closely related to the Fast Plants include the wildflower black mustard and many common vegetables including Chinese cabbage, turnips, brussels sprouts, cauliflower, and broccoli. Some of these varieties are shown in Figure 4 * below.

The careful work of these scientists resulted in the development of a plant which grows well under artificial light and goes from seed to seed in just thirty-five days.

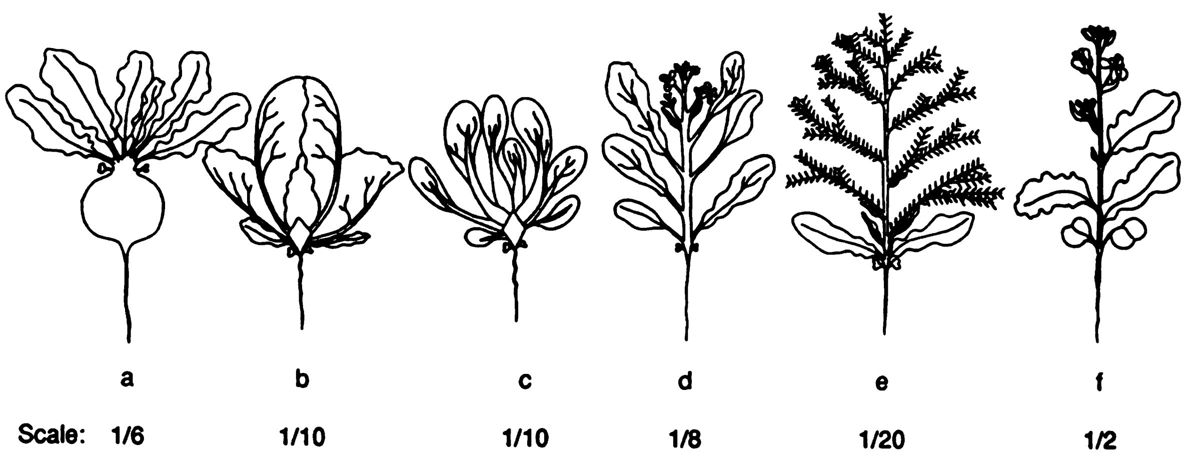

Figure 4. Forms of *Brassica rapa* representing various cultivar groups: (a) *B. rapa*, turnip group; (b) *B. rapa*, Chinese cabbage group; (c) *B. rapa*, pak choi group; (d) *B. rapa*, saichin group; (e) *B. rapa*, turnip rape group; and (f) *B. rapa*, rapid cycling.

We will be growing the Wisconsin Fast Plants this year in order to study plant growing techniques, plant anatomy and physiology, flowering plant reproduction, and heredity (the transmission of traits from parents to offspring).

*All figures from Wisconsin Fast Plants Program (1989), Wisconsin Fast Plants Manual (Madison, Wisconsin: Wisconsin Alumni Research Foundation, North Carolina: Carolina Biological Supply Company).

I. Lab Report Guidelines

Throughout this investigation you will be performing lab activities which are meant to answer certain questions about a plant's growth, development, and reproduction. Questions will be asked in this manual, and then you will complete certain procedures which will help you answer those questions.

Correctly reporting the results of a scientific investigation may be as important as the investigation itself. In this investigation, you are the scientist and you will want to keep up-to-date and accurate records of your work and results. You should keep written records of your work either in a notebook or on loose-leaf paper kept in your three-ring binder. We will be working with these plants frequently over the next 3-4 weeks so bring your records every day. After the project is complete, you will hand in your report with all of the information described below. Most students will want to re-write or type up their work to make it look very neat. <u>The Wisconsin Fast Plants Project lab report will be worth one test grade</u>.

The general format of your lab report should include the following:

1. An **introduction** explaining the project and purpose it is being done. You will need to read through this manual, focusing on the "Key questions" given periodically, to help you in writing your introduction.
2. An **hypothesis** which predicts what you expect will happen in the experiment. In this investigation you will be asked to make several hypotheses concerning different aspects of the plant's growth, development, and reproduction.
3. **Daily records** which include the following: **date, days since planting**, the **purpose** for the day's lab work, the lab **procedure** for that day (record **exactly** what you did to **your** plants and include any **new material** used that was not mentioned in a previous daily entry), any **data** collected, and **answers** to any questions given in this manual for that particular day or set of days.
4. A **summary of your results** including a decision concerning whether your purpose for doing this project was accomplished and whether your hypotheses were correct. It should also include an evaluation of what worked well in the investigation, what did not work well and what you think went wrong, and how the investigation could be improved.

Finally, describe what you liked and disliked in this plant project.

II. Growing the Fast Plants - The First Generation

Before we begin growing the plants you need to know a few things about these seeds. These seeds are the first generation of seeds (called the F_1 generation) from 2 parent Fast Plants which were slightly different from each other. One of the parents was a "normal" color green Fast Plant (called the "wild-type") and the other was a yellow-green color (which we will call "yellow"). Your teacher will show you examples of these Fast Plants so you can see the difference.

Knowing that these seeds are the offspring of two different color parents, write 3 hypotheses about what color(s) you think these first generation plants will be and what

fraction of the total population will be that color. For example, one hypothesis could be stated like this:
"If a wild-type Fast Plant and a yellow Fast Plant are crossed, then the first generation will contain _____% normal green color plants and ______% yellow plants."

After you have written 3 hypotheses, choose the one that you think is the best one and put a star next to it.

A. Day 1 - **Planting**

Key Questions: What apparatus is used to raise the Fast Plants? What do the Fast Plant seeds look like? How are the seeds planted?

Setting-up:

1. The basic growing unit is a "quad"--a square Styrofoam pot with four compartments called cells.
2. A small wick goes into the bottom of each cell. This is necessary to keep the soil constantly moist.
3. Seeds will be sown in specially tested soil mix.
4. Slow release fertilizer pellets will be added to each cell. These pellets will release nitrogen (N), phosphorus (P), and potassium (K) into the soil for the plants.
5. The quads with the wicks sticking partially out of the bottom are placed on a watering platform with a large cloth mat in such a manner that water passes from the reservoir below the platform to the cloth mat, to the wicks and into the soil.
6. A plastic label with students' names and class period is placed in one cell for identification.
7. The platforms with prepared quads are placed under florescent lights which are on twenty-four hours each day.

When completed, the set-up should look like Figure 1 below.

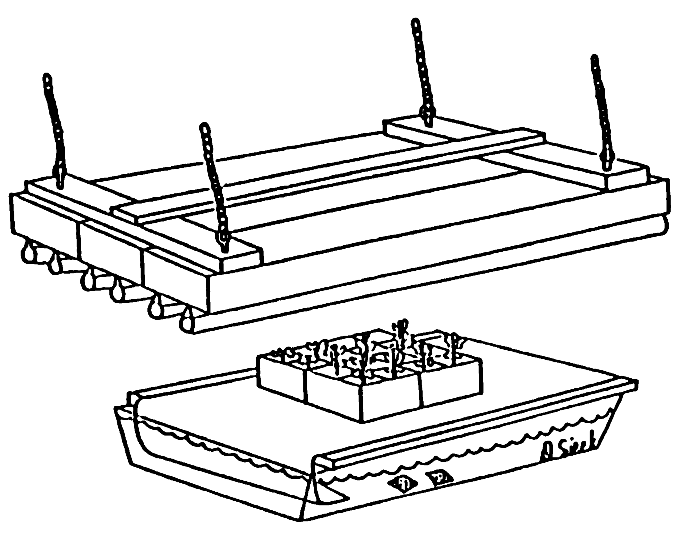

Figure 1 Wisconsin Fast Plants™ growing system.

Planting:

1. Observe the seeds using a dissecting microscope.
   DATA to collect:
   -In your lab records, carefully sketch the structure of the seed. Include its color and any markings.
   -Measure the size of 3 seeds in mm. Then calculate and record an average seed size.
2. Plant the seeds as demonstrated by your teacher. Put 3 seeds in each cell. Record the actual number of seeds sown. Then place your quad on a watering platform.

B. Days 2-4 - **Germination and Shoot emergence**

Key questions: When do the seeds germinate? When do they emerge from the soil? What do the seedlings (young plants) look like?

1. Be sure to water gently (approx. 5 drops per cell) from above with a pipet for these three days to insure adequate moisture during germination.
2. DATA: Note the date of the first shoot emergence. What plant part is first visible above the soil?

C. Day 5 - **Seedlings**

Key questions: What color (wild-type green? yellow?) are the first generation plants? How does this compare with your original hypotheses? What must be done with the seedlings now that they have emerged?

DATA:

1. Record the number of wild-type green plants and yellow plants in your quad. If necessary, use the sample plants your teacher has available to compare colors. Write this information on the board. Record class data when it is available. How does the data compare to the hypothesis you chose as being the best? Try to explain why these first generation offspring plants turned out the way they did.
2. Sketch a "typical" day 5 seedling. The first "leaves" to appear are the *cotyledons* or "seed-leaves". These were part of the seed and they furnish the emerging plant with food for energy until the true leaves are formed and the plant can produce its own food from photosynthesis. <u>Label</u> the stem, cotyledons, and first true leaves (if present) on your sketch.
3. Record the total number of seedlings that emerged. Divide this number by the number of seeds sown on day 1 and multiply by 100. This gives the germination rate (as a percent). Record this rate.
4. Thin the seedlings to ONE per cell by removing the extras with a tweezers or your fingers. If pulling out a seedling will damage the roots of one you are keeping, cut the seedling off near the soil with a scissors. Why must we thin the seedlings like this?
5. Any cell lacking a plant should receive a transplant from another cell with extras.
6. Place one of the extra plants into a small pool of tap water in a watch glass and observe it with a dissecting microscope. Sketch the root system and record its length in mm. Your teacher will tell you what to do with the extra seedlings.

D. Days 8-15 - Vegetative plant growth

Key Questions: Just how fast are these Fast Plants anyway (What is the rate of plant growth)? Will mechanical stimulation (touching) influence the rate of plant growth? What is the structure of the adult plant?

Make a prediction of how fast you think the Fast Plants grow (without any mechanical stimulation) and record it. Give the rate in mm/day.

Do you think it is possible to change the rate of plant growth by touching the plant regularly as it grows? To find out, we will try an experiment with our Fast Plants. Each plant in your quad should receive a different amount of rubbing. The plant in **cell A** should **not be rubbed** at all (and be careful when you measure its height!), the plant in **cell B** should be rubbed **10 times**, the plant in **cell C** should be rubbed **20 times**, and the plant in **cell D** should be rubbed **30 times**. The rubbing should be gently done with your thumb and fore-finger up and down the plant stem.

Write 3 hypotheses about what effect you think the rubbing will have on the plant's growth (or height). ("If a plant stem is rubbed, then it will . . . ") Put a star next to the hypothesis you think is the best.

DATA:

<u>Day 8</u>

NOTE--try to minimize the amount of touching done to the plants while collecting data over the next week.

1. Sketch and <u>label</u> a "typical" day 8 plant.
2. Count and record the number of <u>hairs</u> on the <u>margin</u> of the <u>first true leaf</u> of each plant and calculate the average. Why do you think Fast Plant leaves have these hairs? Give at least one idea in your records.
3. Measure and record the length of the first true leaf (in mm) from the stem to the tip for each plant and calculate the average. Your teacher may have you write this information on the board in order to collect class data.
4. Measure the height of each of the four plants in your quad cells in millimeters from soil level to the tip of the plant (called the apex). Don't measure to the tip of the leaf. The cells are labeled A-D in order for you to distinguish the plants and keep separate records for each plant. Record each plants' height in your records and on the board. Copy from the board the height of every plant in the class. This information will be used to construct a graph. Also, 2 students will be asked to calculate the average height of all the "cell A" plants (and "B", "C", and "D" plants) in your class. Record these averages when they are available. They will be used for a graph to be constructed on day 12 or 15.
5. With your thumb and fore-finger, gently rub up and down on the stem of the plants in cells B, C and D the correct number of times.
6. If your plants fall over they can be supported using sticks and rubber rings. These will be available throughout the rest of this project. Use them as needed.

7. Construct the following graph using graph paper from your teacher or a computer:

Height Variation in a Population Graph (Frequency Histogram)--Using class data for plant heights on day 8, construct a histogram (bar graph) showing the number of plants that have a certain height. Notice these measurements were taken before rubbing was done on the plants. "Height (in mm)" should be on the horizontal axis and "Number of plants (frequency)" should be on the vertical axis. Bars should be made at each millimeter mark (unless no plants have that height). Underneath the graph, write the following information: 1) the number of plants (N) that were counted; 2) the average height of all the plants (mean); 3) the range of heights (difference between shortest and tallest plant).

(Extra Credit) Length of First True Leaf Frequency Histogram. Using class data for lengths of first true leaves, construct a frequency histogram similar to the one already described. "Length of First True Leaf (in mm)" will be on the horizontal axis and "Number of plants (frequency)" will be on the vertical axis. Make sure you are making a bar graph with the bars positioned at each millimeter mark. Underneath the graph give the number of plants (N), the mean, and the range.

Days 9, 10, 11

1. Measure the height of each plant. Write this on the board. Record your plant heights
and the class averages in your records. You do not have to record the height of every plant in the class as you did on day 8. Only the average height for each cell is needed.
2. Gently rub the plants in cells B, C and D the correct number of times.

Day 12

1. Measure the height of each plant. Write this on the board. Record heights and the class averages in your records. Your teacher may have you use the plant height information through today to make graphs, or you may need to wait until day 15 to do this. If you are waiting until day 15, then gently rub the plants in cells B, C and D the correct number of times.
2. Count and record the total # of leaves (incl. cotyledons) for each plant and calculate the average.
3. Sketch and label a "typical" day 12 plant. Observe the very tip of the plant. The structures developing are flower buds. Observe the buds with a magnifying lens and sketch several examples.
4. Make 2 beesticks which will be used to pollinate the Fast Plant flowers when they have developed. Instructions for making beesticks:
   a. Obtain two bees and two toothpicks.
   b. Remove the head and abdomen from the thorax of each bee.
   c. Place a drop of glue on the end of a toothpick and gently insert the end of it into the indentation in the thorax caused by removing the head or abdomen. Remove the wings and legs from the thorax. Repeat with the second toothpick.
   d. Place both toothpicks into the soil of one of the quad cells.

Day 12 or 15 (depending on the teacher's judgment)

1. Measure the height of your 4 plants. Write this information on the board. Record your plant heights and class averages.

2. Design and plot the following graphs either on graph paper supplied by your teacher or on a computer.

a. Plant Height Line Graph. Using the **class average plant height data for days 8-12 (15)**, plot the change in average height (line graph) for the plants in **cell A, B, C, and D**. "Time (in days)" should be on the horizontal axis and "Plant height (in mm)" on the vertical axis. Use a different color for each average. Using the graph, compare your hypothesis concerning the effect of rubbing the plants on their height with the actual results. Did it turn out the way you predicted?

Calculate the average growth rate of the Fast Plants in each cell (A-D) from day 8 to day 12 (15)(in mm/day). Take the average number of millimeters a plant grew from day 8 to day 12 (15) and divide that by the number of days (4 days or 7 days). Compare the average growth rate for cell A plants (which received no rubbing) with your prediction on day 8. How close were you?

b. Plant Height Bar Graph. Using the class average plant height data for only day 12 (15), make a bar graph for the plants in cell A, B, C and D. "Number of times rubbed" should be on the horizontal axis and "Plant height (in mm)" should be on the vertical axis. Spread the bars out on the graph.

E. Days 15-19 - **Flowering and Pollination**

Key Questions: How are flowers protected before completely opening? Where on the adult plant are flowers produced? What do the parts of the Fast Plant flower look like and what is their function? What is pollen and where is it produced? What do pollen grains look like? Why do bees associate with flowers and how does each benefit? What important adaptive structures do bees have on their legs and what is the function of these structures?

DATA:

1. Note the day on which open flowers first appear on your plants this week.

2. If the Fast Plants were growing outdoors bees would naturally be attracted to the flowers. In the process the bees help to pollinate the flowers. We will be discussing this process in a few days. Since we are growing the plants indoors we will need to artificially pollinate the flowers using our beesticks. Use the following instructions to assist you:

Gently touch the inside parts of the flowers of one of your plants using a twirling motion. You should be able to see a yellow powder collecting on the bee thorax. This is pollen. Then using the same motion, deliver the pollen to the flowers of a plant in a different quad cell. Use Figures 12 and 13 below as a guide.

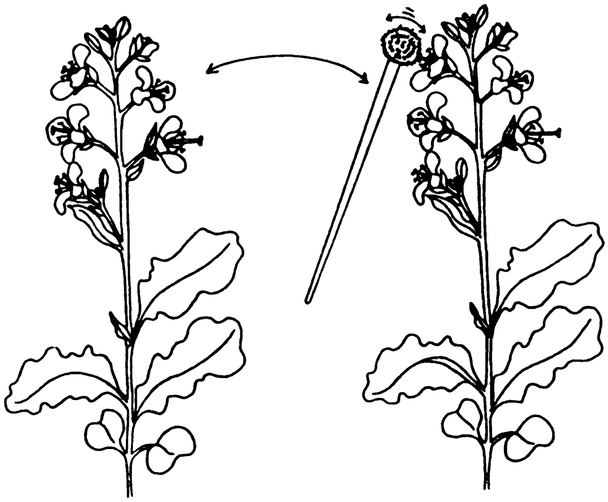

Figure 23. Cross-pollination.

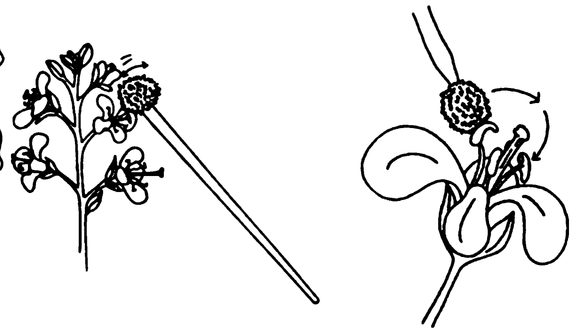

Figure 22. Pollen transfer to bee stick.

This is called "cross-pollination" because pollen from one plant is being delivered to the flowers on another plant. Repeat this procedure until you have delivered pollen to the flowers of plants in each of the four cells. Notice we are spreading pollen between various members of our first generation of plants.

Pollinate your flowers on days 15 - 18

3. On day 16 and/or 17 (as determined by your teacher) study the Fast Plant flower and the honey bee by doing the following:

a. Cut off a flower from one of your plants and put it under the dissecting microscope. Carefully sketch the flower. Notice that the flower has 4 "whorls" or layers to it. Label the following **bold-lettered** parts in you sketch and write the function of each part next to the label. If these descriptions are not enough, use your textbook or one of the other textbooks in the room to help you.

1) The outer-most layer contains small green leaf-like structures. These are called **sepals**. Where did you see these structures before? What do you think is their function?
2) The next layer contains yellow leaf-like structures. These, of course, are the **petals**. What do you think is their function?
3) Just inside the petals is a ring of stalk-like structures. You should be able to see the yellow dust (pollen) on the tops of these. How many do you see? The entire structure is called a **stamen**. The top part which produces pollen is called the **anther**. The stalk which holds it up is the **filament**.
4) The stamens surround a stalk-like structure in the middle of the flower. This is called the **pistil**. The top of the pistil may have a thick sticky liquid on it. This top is called the **stigma**. What do you think is the function of this sticky top? Below

the top is a long slender stalk called the **style**. At the bottom of the style is an enlarged base. The stamens, petals, and sepals are all connected to this base which is called the **ovary**. Later you will cut open an ovary to view the inside.

If you look very carefully at the ovary where the stamens are connected to it you can see small knobs which may be secreting a drop of liquid. These knobs are called **nectaries** and the liquid they secrete is nectar. Honey bees poke a long mouth part called a proboscis into a nectary and sip out nectar.

b. After you have labeled your sketch, carefully pull apart the flower keeping all the parts. Tape the parts onto a 3 by 5 note card and label them. Also write how many of each part there is (for example "4 petals"). Put your names on your note card.

c. Using a forceps, pull off an anther from another flower on one of your plants. Smear the anther in a drop of water on a microscope slide. Pollen from the anther will be suspended in the water. Add a coverslip and observe with high power of a microscope. In your records sketch and label examples of **pollen grains**.

d. Your teacher will have available ovaries from other flowers for you to cut open. Using a razor blade, carefully cut the ovary in half and put both halves under the dissecting microscope. Inside you should see many small oval-shaped structures. These are called **ovules**. Sketch and label examples of ovules inside the cut ovary. Other flowers were used for this procedure because the Fast Plant ovules are very small and quite difficult to see.

e. <u>Read this brief overview of sexual reproduction in flowering plants</u>:

The flower is the sexual reproductive part of a plant. In sexual reproduction, 2 different types of sex cells (called male and female gametes) carry genetic material from two different sources and come together to produce offspring. This joining of sex cells is called **fertilization**.

In flowers, the male gametes (sperm) are produced inside the pollen grains after they have been delivered to the stigma of the flower. This delivery of pollen grains to the stigma is called **pollination**.

The female gametes (eggs) are produced in microscopic structures contained inside the ovules found inside the ovary.

If the sperm is contained inside the pollen grain stuck to the top of the pistil and the eggs are contained deep inside the ovary at the base of the pistil, how do sperm get to the eggs? To give you an idea, your teacher will show you some pollen grains on the TV.

In flowering plants, fertilization is a bit different than in other sexually reproducing organisms. Fertilization normally involves one sperm fertilizing one egg. However, in flowering plants, two sperm formed from one pollen grain will fertilize two different cells inside an ovule. One of the cells is the egg. The other is a special cell called the **fusion nucleus** cell. When fertilized, the egg will become the offspring plant and the fusion nucleus will become food for the young plant. Since two cells are fertilized, this is called **double fertilization**. Your teacher will illustrate this process using toys.

f. As you have read, pollination must occur if reproduction is to proceed. For the Fast Plants, pollination is accomplished naturally by honey bees. As a bee moves about on a flower some of the pollen grains will stick to its hairy body. When it visits other flowers, some of these pollen grains will contact and adhere to the stigma. When this occurs, pollination has been accomplished. (See the handout from your teacher for more information on bees and pollination).

DATA:
1) Observe a honey bee using a dissecting microscope. Sketch the bee and label the three main body parts: head, thorax, and abdomen. Look for the proboscis on the head.

2) Place a bee wing on a microscope slide. Also crush the hind end of an abdomen to try to reveal the stinger and place it on the same slide. You will not need a drop of water. Put a coverslip over these parts and try to locate them under low power of the microscope. Sketch and label these parts.

3) The bee has three pairs of legs: forelegs, midlegs and hindlegs. Your teacher will show you all three examples on the TV. Sketch each type of leg. On the foreleg, sketch the antenna cleaner. On the midleg sketch the spur and the brushes. On the hind leg sketch the pollen basket, pollen comb and pollen press. Think about how the bee might use each of these structures.

4. On day 18 (or 19 depending on instructions from your teacher) perform the following:

a. Pollinate the flowers.
b. Remove any unopened flower buds by cutting them off with a scissor. Remove buds from the top and from the tip of any side shoots. Why do you think we are doing this?
c. Count and record the number of flowers (some which have probably fallen apart by now) which are on each plant and calculate the average.

F. Days 19-34 - **Seed pod formation**

Key Questions: What happens to the flowers after pollination? Which part of the flower does not fall off but actually enlarges? Where and how are the new seeds produced? What does the young plant (embryo) look like as it develops inside the developing seed?

DATA:
1. On several different days observe the development of the seed pods. Where did they develop from? Can you see evidence of seeds developing inside? Sketch and label a seed pod.

2. On one or two days your teacher will show you the inside of an immature seed on the TV. Sketch the immature plant (embryo) and notice how it develops during these days.

G. Day 35

Remove the quad from the watering platform. The plants will now be allowed to dry for at least 5 days.

H. Day 40 (or later as determined by your teacher) - **Harvest day!**

DATA:
1. Count and record the number of pods produced by each plant. Determine the average number of pods per plant. Compare this number to the number of flowers recorded on day 18(19). Did all of the flowers produce a seed pod?
2. Measure the length of each pod in mm. Determine the average pod length.
3. Remove the pods from the plants. Remove the seeds from each pod by carefully pulling the pods apart and having the seeds fall onto a white sheet of paper.
4. Record the total number of seeds produced by your plants.
5. Calculate the average number of seeds produced per pod.
6. Calculate the average number of seeds produced per plant.

Place your seeds into an envelope as indicated by your teacher. Dismantle your quads and throw away the soil and dried plant parts. Return the quad, wicks, sticks, rings, and labels to the proper containers as indicated by your teacher.

III. Growing the Fast Plants - The Second Generation

The Fast Plants we just got done growing were the first generation of plants from two different parents which were crossed together (cross-pollinated). One of the parents was the normal green color (wild-type) and the other parent was yellow-green. In the first generation, what color(s) was (were) the offspring? What percentage of the offspring were each color? (Go back to your data for day 5 if you don't remember the answer to these questions.)

When the first generation plants flowered we cross-pollinated them to produce a second generation of seeds. It is these second generation seeds which we will now be planting. As they grow we will determine if they show the normal green color (wild-type) or show the yellow color.

Before you plant your seeds, write 3 hypotheses about what color(s) you think these second generation plants will be and what fraction of the total population will be that color. For example, one hypothesis could be stated like this: "If the first generation plants are crossed, then the second generation will contain ______% normal green color plants and ______% yellow plants."

After you have written 3 hypotheses, choose the one that you think is the best one.

A. Day 1 - Planting
Plant the seeds the same way you did before. Refer back to day 1 of the first generation plants if you need to refresh your memory.

B. Days 2-4 - Germination
Your teacher will make sure the quads stay moist enough for germination.

C. Day 5 (or later as determined by your teacher)
Look at all the seedlings growing in your quad. Record the number of wild-type green plants and yellow plants in your quad. If necessary, use the sample plants your teacher has available to compare colors. Write this information on the board. Record class data when it is available. How does this compare to your hypotheses? Try to explain why the second generation turned out this way. Does this surprise you in any way?

Unless your teacher wants to continue growing the plants, the quads can be dismantled as before and the plant parts and soil discarded. Be sure to save the quads, wicks, and labels and put them in the place designated by your teacher.

We have completed our Fast Plant Project. You must now write a summary and include the items mentioned at the beginning of this manual. Your teacher will inform you when this project is due.

APPENDIX D

APPENDIX D

WHAT DOES A SEED NEED TO GERMINATE?

Introduction
Germination is growth of an embryo from a seed. The process requires certain environmental conditions. This investigation demonstrates what conditions are necessary for germination.

Material (per group)

3 black plastic film canisters with lids	3 pieces of blotting paper (3 cm x 3 cm)
9 Fast Plant seeds (or other small seeds)	small beaker of water
masking tape	thermometer

Procedure
1. Cut the pieces of blotting paper into circles so that they fit into the film canister lids.
2. Soak two of the pieces of blotting paper in a beaker of water until they are completely moist.
3. Place the moist pieces of blotting paper inside two lids. Place the dry piece inside the third lid.
4. Place three seeds on the blotting paper in each lid. Sketch the seeds in the table below.
5. Using masking tape, label one of the film canister bottoms "moist, refrig" and with your name. Snap this bottom on to a lid with moist paper. Bring this canister to your teacher to be put in the refrigerator.
6. Label one of the bottoms "moist, room" and with your name. Label the third bottom "dry, room" and with your name. Place these two canisters in the location directed by your teacher.
7. Record the room temperature and refrigerator temperature in the table below.
8. Sketch what your think the seeds in each canister will look like after 48 hours in the table below. After 48 hours open the canisters and sketch the seeds.

	Seeds (start)	Prediction	Seeds (48 hrs. later)
Moist, refrig. (___C)--			
Moist, room (___C) --			
Dry, room (___C) --			

Questions
1. Which canister or canisters contain(s) germinating seeds?
2. Identify what environmental conditions are necessary for seed germination based on the results.
3. Which film canister or canisters contain(s) seeds which did not germinate? Why might it be an advantage for seeds not to germinate under these conditions?
4. Using the results, identify at least two things which are not required for seed germination.

APPENDIX E

APPENDIX E

WHAT ARE THOSE GERMINATING SEEDS DOING??

Introduction

This investigation is a simple set-up, but it visually demonstrates a process that is occurring as a seed germinates.

Material:

Per group
- 4 large test tubes with corks
- test tube rack
- 4 small test tubes which fit into the large test tubes
- 4 small pieces of cotton
- tape or marking pencil
- 7 soaked bean or pea seeds (soaked overnight)
- 14 dry bean or pea seeds (7 to be boiled and 7 to remain dry)
- Bromothymol Blue solution (BTB)
- water (approximately 30 ml)
- Hot plate with boiling water in large container (or microwave)

Procedure

1. Boil 7 seeds for 5 minutes using the hot plate set-up or a microwave.
2. As the seeds are boiling, use tape or a marking pencil to label four large test tubes. Mark one with a "B" for "boiled", one with a "S" for "soaked", one a "D" for "dry", and one with a "N" for "no seeds".
3. Pour enough water into each of the large test tubes so that they are 1/4 full. Add 5 drops of bromothymol blue solution.
4. Place the 7 soaked seeds into a small test tube and stick some cotton into the top.
5. Place this test tube into the large test tube marked "S". Don't drop it in, it might break! Make sure it does not overflow into the small test tube with the seeds inside. See figure 1.
6. Put the cork into the large test tube.
7. Repeat steps 4-6 using the boiled seeds and the large test tube marked "B", and the dry seeds and the large test tube marked "D". Also put a small test tube with no seeds and some cotton in the test tube marked "N".
8. Record the color of the BTB solution in each test tube under "data".
9. Predict the color the BTB will be after 24 hours in each test tube.
10. Allow the test tubes to sit over night. Check the color of the BTB solution the next day and record.

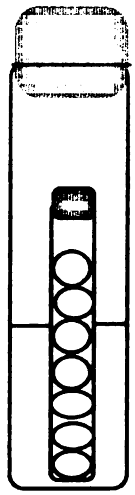

Figure 1

Data

	BTB color (start)	Prediction	BTB color (after 24 hrs)
Boiled seeds --			
Soaked seeds --			
Dry seeds --			
No seeds --			

Conclusions/Discussion questions

Bromothymol Blue is an indicator. It changes color as the pH of the solution changes. BTB is blue or greenish blue in neutral (pH 7.0) and basic (pH > 7.0) solutions, but becomes yellow as the solution becomes more acidic (pH < 7.0). If carbon dioxide is added to water, carbonic acid is formed in the solution, which causes the acidity to increase.

$$H_2O + CO_2 \longrightarrow H_2CO_3 \longrightarrow H^+ + HCO_3^-$$

1. What color was the BTB solution in the test tube with the soaked seeds after 24 hours?
2. What could explain why the color changed?
3. What process is occurring inside the cells of the embryo in the germinating seeds? How do you know?
4. Did the BTB change color with the boiled seeds? Why or why not?
5. Did the BTB change color with the dry seeds? Why or why not?
6. Why was the test tube with no seeds used?

Teacher's Notes:

1. This investigation can be done as a student lab or teacher demo.
2. Bean seeds were used, but other large seeds could be substituted.
3. Make the Bromothymol Blue stock solution as follows:

   Mix 0.5 g bromothymol blue powder with 500 mL of distilled water. (1% solution)
   If the solution appears green, slowly add 0.1N sodium hydroxide one drop at a time until the solution turns blue.

APPENDIX F

Comparing Dormant And Germinating Seeds

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Seeds that are purchased for planting are viable (alive). However, they show no signs of any life processes. Scientists refer to seeds in this condition as being dormant. When dormant seeds are soaked in water, they respond by quickly showing evidence of life processes. Such seeds are said to be germinating.

One of the life processes carried on by seeds is respiration. When respiration occurs, a seed takes in oxygen gas from the air and gives carbon dioxide off into the air in about equal amounts. A dormant seed carries on the process of respiration very slowly. Germinating seeds carry on this process rapidly.

In this investigation, you will
- (a) prepare respiration chambers to measure the amount of oxygen used by seeds.
- (b) compare the rate of respiration occurring in dormant and germinating seeds.
- (c) measure and record the height to which water rises in each chamber to indicate the amount of oxygen used by each seed type.
- (d) predict the amount of oxygen used up by seeds in various experimental situations.

Materials

test tubes—3
soaked bean seeds
dry bean seeds
cotton
metric ruler
soda lime
small beaker
water, colored
teaspoon
masking tape and pen (or glass marking pencil)
rubber band

Procedure

- Place five dry dormant seeds into a test tube.
- Add a small cotton plug just above the beans. Do not pack the cotton too tightly but tight enough so that seeds cannot fall out when the tube is turned upside down.
- Add half a teaspoon of soda lime (a carbon dioxide gas absorber) to the test tube. **CAUTION:** *Do not handle soda lime with bare hands.*
- Insert a second cotton plug over the soda lime as shown in Figure 1.
- Use tape or a marking pencil to label the test tube "dormant." Place the label toward the round or bottom end of the test tube.
- Prepare a second tube in a similar manner. However, put in five soaked germinating seeds instead of the five dormant beans. Label this tube "germinating."

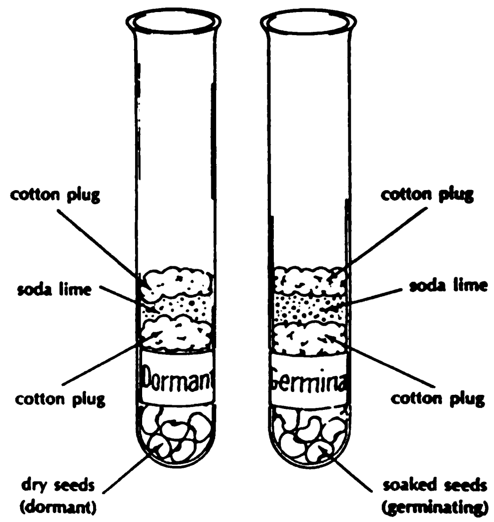

FIGURE 1

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From Kaskel, Albert, et al. (1994), Investigating Living Systems (New York: Glencoe/Mc Graw-Hill) 233-236.

• Prepare a third tube with no seeds. Add only one half teaspoon of soda lime and a small cotton plug just above the soda lime.

• Turn the tubes upside down and place them into a small beaker that contains 30 mL of colored water. A rubber band placed around all three tubes will prevent their tipping over.

• With a ruler, measure in millimeters the height to which the colored water rises in each test tube (Figure 2). Look carefully. Measure the water level in the test tube, not the beaker.

• Record the height for each test tube in Table 1. Record the height as 0 mm if water does not move into a test tube.

• Allow all test tubes to remain undisturbed for at least 24 hours.

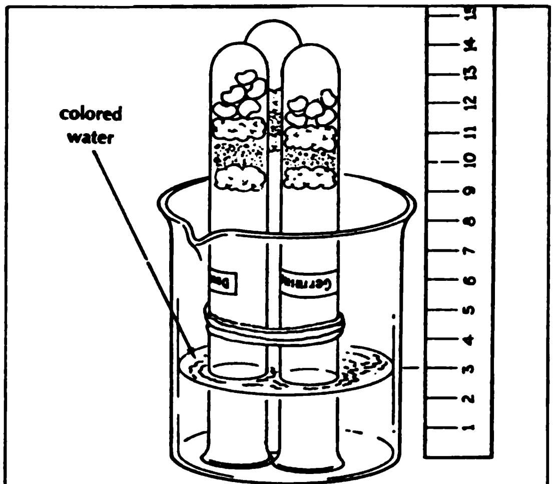


FIGURE 2

• After 24 hours, measure and record the new height of water inside each test tube. DO NOT move the beaker or remove the test tubes from the beaker until you have measured the height of water within each test tube.

• Calculate the difference in water height from start to end by subtracting the height of water in each tube at the start from the height of water in each tube after 24 hours. Record this amount in the last column of Table 1.

TABLE 1. HEIGHT OF WATER IN TEST TUBES

TUBE CONTENTS	HEIGHT OF WATER AT START	HEIGHT OF WATER AFTER 24 HOURS	DIFFERENCE IN WATER HEIGHT
Dormant seeds			
Germinating seeds			
No seeds			

Analysis

1. (a) What is probably trapped within each tube turned upside down in the water? ____________

   (b) What prevents water from moving into each tube at the start of the experiment? ________

   ____

2. If air within a tube is used, water will rise within the tube to replace the missing air.

   (a) Which tube shows the most evidence of air being used in 24 hours? ____________

   (b) What is the evidence? ____________________________

   (c) What specific gas found in air probably is being used? ____________________

Name ______________________________ *Date* ______________

3. What life process is responsible for the uptake or using of this gas? ____________

4. (a) Which seed type, dormant or germinating, carries on this process at a faster rate? ________
   (b) What is the evidence? ____________

5. What does the tube containing no seeds show? ____________

6. Soda lime is a chemical which absorbs or removes carbon dioxide from air.
   (a) **Recalling that seeds use oxygen gas and release carbon dioxide, predict the level of water 24 hours later in all tubes if no soda lime is used.** ____________
   (b) **Explain.** ____________

7. A seed contains a food supply. This food is used during respiration.
   (a) Which type of seed, dormant or germinating, carries on respiration at a slower rate? ________
   (b) What experimental evidence do you have to support your answer? ____________
   (c) Which type of seed, dormant or germinating, would use food at a slower rate? ________
   (d) Explain why using food slowly may be an advantage to the survival of the plants. ________

8. **Suppose you place 20 germinating bean seeds into one test tube and add soda lime. Into a second tube, you place 10 germinating bean seeds along with soda lime. You then invert both tubes into a beaker of water.** Complete Table 2 by providing what you might expect in measurements for the rise in water 24 hours later.

TABLE 2.

	HEIGHT OF WATER 24 HOURS LATER
20 germinating seeds	
10 germinating seeds	

9. Give your reasons for the measurements given in Table 2. ____________

10. Suppose you place 20 germinating bean seeds into one test tube with soda lime. Into a second tube you place 20 germinating bean seeds but no soda lime. You then invert both tubes into a beaker of water. Complete Table 3 by providing what you might expect in measurements for the rise in water 24 hours later.

TABLE 3.	
	HEIGHT OF WATER 24 HOURS LATER
20 germinating seeds with soda lime	
20 germinating seeds with no soda lime	

11. Give your reasons for the measurements in Table 3. ______________________________

____

12. Assume that you boil some germinating seeds for 30 minutes in water. Place these boiled seeds into a test tube with soda lime. Prepare a second tube with unboiled germinating seeds and soda lime. Invert both tubes into water. Complete Table 4 by providing what you might expect in measurements for the rise in water 24 hours later.

TABLE 4.	
	HEIGHT OF WATER 24 HOURS LATER
Boiled germinating seeds with soda lime	
Germinating seeds with soda lime	

13. Give your reasons for the measurements in Table 4. ______________________________

____

14. One hundred dormant seeds are placed into a tube with soda lime. A second tube containing soda lime only is prepared. Both tubes are inverted in a beaker of water. Complete Table 5 by providing what you might expect in measurements for the rise in water 10 days later.

TABLE 5.	
	HEIGHT OF WATER 10 DAYS LATER
Dormant seeds with soda lime	
Soda lime only	

15. Give your reasons for the measurements in Table 5. ______________________________

____

APPENDIX G

APPENDIX G

PLANT RESPONSES TO LIGHT AND GRAVITY

STUDENTS' WORKSHEET

Background

Have you ever wondered how seedlings "know" which way to grow to emerge above the soil, or why plants on a windowsill seem to lean toward the light? Downward growth of roots (toward water) and upward growth of the shoot (toward light) are essential for a plant's survival.

The response to gravity is known as **gravitropism** (or geotropism), and the response to light is called **phototropism**. Both of these responses are thought to be mediated by plant hormones called **auxins**, which affect cell elongation. These experiments investigate these responses and their causes.

New Terms

auxin A growth hormone which influences cell elongation and is involved with geotropic and phototropic responses. In unequal amounts, auxin causes a curvature of the tissue in stems and roots by causing cells to elongate differentially.

gravitropism The response of a shoot or root to the pull of the earth's gravity.

phototropism Growth in which the direction of light is the determining factor; turning or bending in response to light.

Objectives

To understand the response of seedlings to light of different wavelengths, and how plants respond to gravity.

Investigation I

Materials

- lightproof, plastic film canisters from 35-mm film
- plastic film sheets—red, green, blue
- hand-held hole punch or electric drill and $^{13}/_{64}$" drill bit
- clear plastic tape and black plastic electrical tape
- 2-cm square pieces of blotting paper
- waterproof pen
- RCBr seeds and 3- to 5-day-old seedlings

Pre-Lab Questions

1. What is your hypothesis about why seedlings grow upward?

2. An ideal control in a geotropism experiment would be a plant grown without gravity. How could this be done?

From Wisconsin Fast Plants Program (1989), Wisconsin Fast Plants Manual (Madison, Wisconsin: Wisconsin Alumni Research Foundation; Burlington, North Carolina: Carolina Biological Supply Company).

Procedures and Observations

Phototropism

1. Make a phototropism chamber as follows (Figure 1):
   a. Punch or drill three windows in the sides of the film container 20 to 22 mm from the bottom.
   b. Tape squares of colored plastic over the windows with clear tape. Cover one window with green film, one with red, and one with blue.
   c. Mark the lid with the waterproof pen to line up the lid with the windows at the same locations each day.
   d. Place a square of wet blotting paper in the lid of the film container. The lid becomes the base of the tropism chamber.
2. Place three seeds on the blotting paper. Close the chamber and put it, with the lid at the bottom, under the light bank where all three windows receive uniform light.
3. After 48 to 72 hours, open the chamber and observe which way your plants have grown. Which color did your plants grow toward? ____________

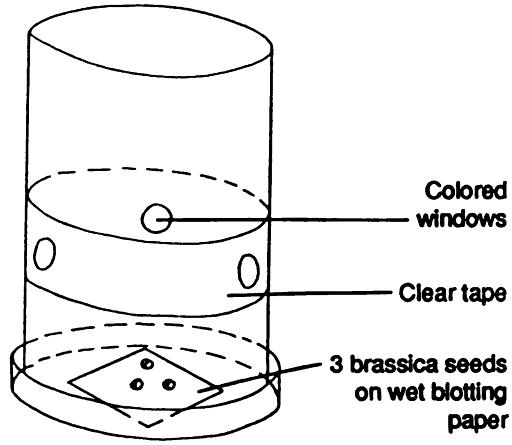


Figure 1. Phototropism chamber.

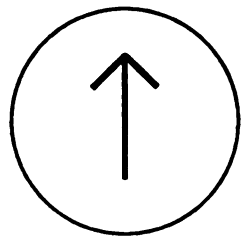


Figure 2. Mark top of lid with an arrow.

Gravitropism—Experiment A

1. Set up a windowless chamber. Mark the top of the lid with an arrow (Figure 2). Place a 2-mm square of blotting paper in the lid and moisten.
2. Place three seeds on the blotting paper. Close the chamber and place vertically with the lid at the bottom.
3. After 2 days, observe your seedlings and record your observations in (Figure 3). Close the chamber tightly and place the chamber horizontally (Figure 4) with the arrow pointing upward.

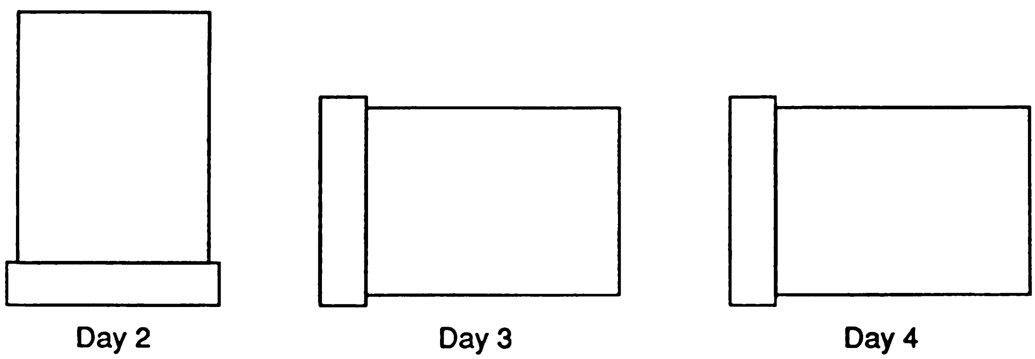


Figure 3. Draw your seedlings after 2, 3, and 4 days in the chambers.

4. Examine the seedlings on the third day and record your observations in Figure 3. Replace the chamber horizontally with the arrow pointing upward. Examine the seedlings on the fourth day and record your observations in Figure 3. (The seedlings may now be transplanted to potting mix.)

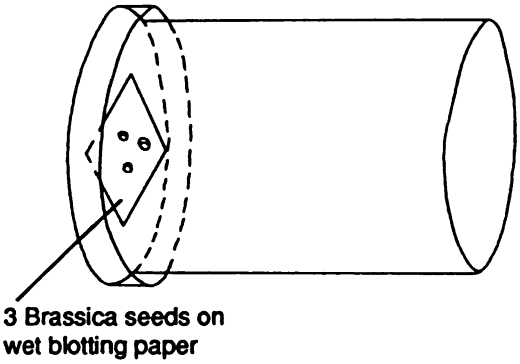


Figure 4. Gravitropism chamber.

Gravitropism—Experiment B

1. Set up another windowless chamber. Mark the top of the lid with an arrow (Figure 2). Place a 2-mm square of blotting paper in the lid and moisten.
2. With a sharp instrument, cut off a 3- to 5-day-old seedling at the soil level. Stick the cotyledons to the moistened blotting paper (water will hold them in place; Figure 5). Close the chamber and place horizontally with the arrow pointing upward.
3. Examine the orientation of the hypocotyl after 24 and 48 hours, and after 5 to 7 days. Record your observations in Figure 6. After each examination, close the chamber and place it horizontally with the arrow pointing upward. What is happening at the very tip of the hypocotyl?

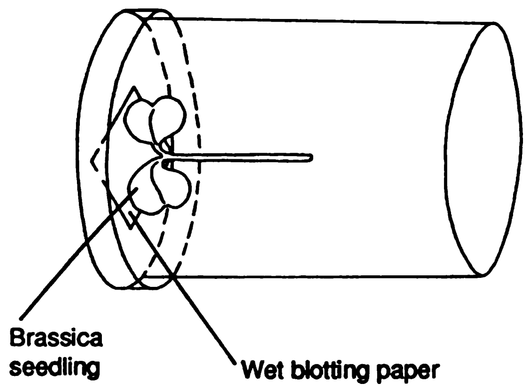


Figure 5. Gravitropism chamber.

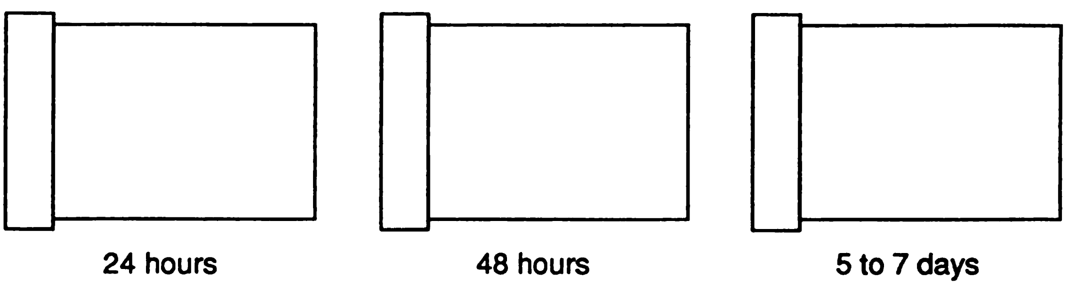


Figure 6. Draw your seedlings after 24 and 48 hours and 5 to 7 days in the chamber.

Discussion

1. What caused the plants to grow as they did in the phototropism experiment?

2. What do the following prefixes mean?

   photo–

   gravi–

   tropism–

3. Did the stems and roots grow the way you expected them to in Gravitropism—Experiment A? Explain what you observed.

4. Did the modified seedling grow the way you expected it to in Gravitropism—Experiment B? Explain what you observed.

5. What direction would a seedling grow if a darkened horizontal chamber was slowly, constantly rotated?

6. Which do you think is the more important factor affecting the direction of plant growth, light or gravity? Design an experiment to test your hypothesis.

APPENDIX H

APPENDIX H

Pollen Germination

Introduction
Sexual reproduction involves the joining of two different sex cells to produce the first cell of the offspring. This process is called **fertilization**. In flowering plants, the male sex cells are contained within pollen grains produced by a flower. The female sex cells are contained inside the ovules which are inside the flower ovary. Sexual reproduction in flowering plants involves two important and separate steps--first, **pollination**, which involves the transfer of pollen to the stigma on top of the pistil, and second, fertilization. Because both of these events must occur for sexual reproduction to take place, a plant must have a way of transferring the sperm inside the pollen grains to the eggs inside the ovules within the ovary after pollination has occurred. This investigation will illustrate what must happen in order for the sperm to reach the eggs in flowering plants.

Material

40% sucrose solution
mineral salt solution
pipettes
pollen grains
microscope slide and cover slip
petri dish with wet paper towels inside
light microscope

Procedure
1. Place one drop of the sucrose solution on a microscope slide.
2. Add one drop of the salt solution to the sucrose solution drop and mix the solutions using the pipette.
3. Touch a flower anther with freshly shedding pollen to the drop on the slide.
4. Add a coverslip and place the slide into a petri dish with a moist paper towel inside of it.
5. Keep the slide in the "moisture chamber" for 15-20 minutes. Then observe the slide on low power with a light microscope. Observe and sketch what is occurring with some of the pollen grains.

Teacher's notes

This lab was adapted from "Pollen Germination with Fast Plants", from Wisconsin Fast Plants Project, University of Wisconsin, 1630 Linden Dr., Madison WI 53706

1. If successful, some of the pollen grains will begin to grow tubes after 15 minutes.
2. To make a 40% sucrose solution, dissolve 40 grams of sucrose (table sugar) in enough distilled water to make a final volume of 100 ml. Keep this solution refrigerated to avoid bacterial and/or fungal growth.
3. To make the mineral salt solution, add the following amounts of substances to distilled water and bring the final volume to 1 liter.

   0.417 g $Ca(NO_3)_2$
   0.100 g H_3BO_3
   0.101 g KNO_3
   0.217 g $MgSO_4$ $7H_2O$
   3.5 ml of 1.0 M NH_4OH

4. This investigation can be done as a teacher demonstration (recommended if a microscope-camera for T.V. viewing is available) or student lab investigation.
5. Results in this investigation can be very variable. Sometimes you will be successful, other times you will not. Different pollen grains germinate better with different concentrations of sugar solutions. It is best to try several concentrations of sugar solutions (like 40%, 20%, 10%, 5%, etc.). Also, some pollen grains will germinate while others won't. I had the best success with impatient pollen. You may want to experiment with several different pollen types. Also, some pollen grains will germinate without the mineral salt solution. However, I did have success when I used the mineral salt solution.
6. The petri dish serves as a moisture chamber to enhance the germination process.
7. Another option besides using a microscope slide and coverslip would be to use a "hanging drop" method. This is the method described in the Fast Plant literature. However, I did have success using the method described in the procedure of this investigation.

APPENDIX I

APPENDIX I

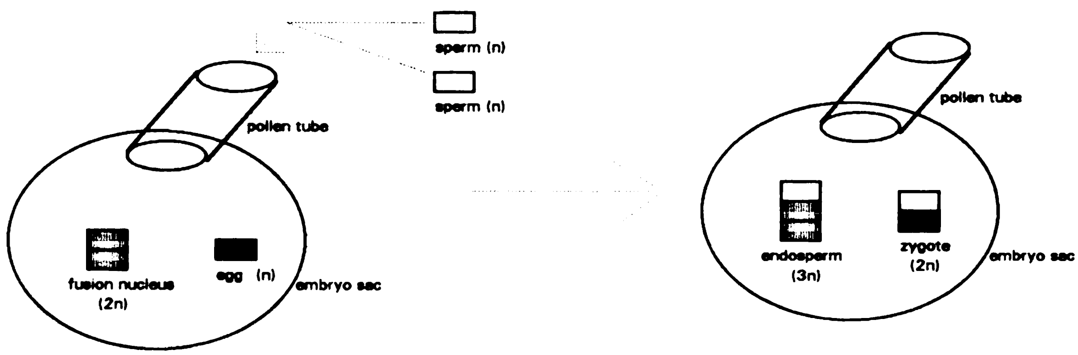
Model of Plant Fertilization

This is simple model of plant fertilization using common items. Use it to help students visualize the process of double fertilization in flowering plants.

Key:

embryo sac = clear plastic bag
pollen tube = rolled up and taped overhead projector film
(tape the opening of the bag around one end)
egg = blue square lego piece
fusion nucleus = 2 red square lego pieces attached together
sperm = 2 yellow square lego pieces
endosperm = 1 yellow lego piece attached to the 2 red lego pieces
zygote = 1 yellow lego piece attached to the blue lego piece

Steps:
1. Describe the location and contents of the embryo sac in a flower.
2. Explain why the fusion nucleus has 2 lego pieces (it is 2n and contains 2 sets of chromosomes) and why the egg has 1 lego piece (it is has only 1 set of chromosomes).
3. Explain how the pollen tube is formed and how it reaches the embryo sac.
4. Identify why there are 2 sperm. Drop them through the pollen tube into the embryo sac.
5. Illustrate double fertilization by attaching a sperm (yellow lego pieces) to the fusion nucleus (2 red lego pieces) and the other sperm to the egg (blue lego piece).
6. Explain that the fertilized fusion nucleus cell will divide to form endosperm, stored food for the embryo, and the fertilized egg (zygote) will become the young plant (embryo).

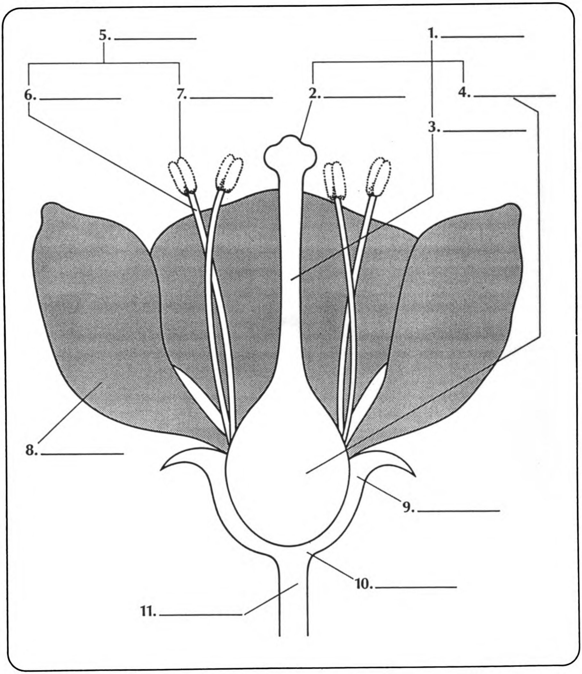


APPENDIX J

APPENDIX J

CHAPTER
24
OVERHEAD TRANSPARENCY MASTER

Structure of a Flower



From Schraer, William D., and Herbert J. Stoltze (1990), <u>Biology: The Study of Life Teacher's Resource Book</u> 3rd ed. (Needham, Massachusetts: Allyn and Bacon) 24-3.

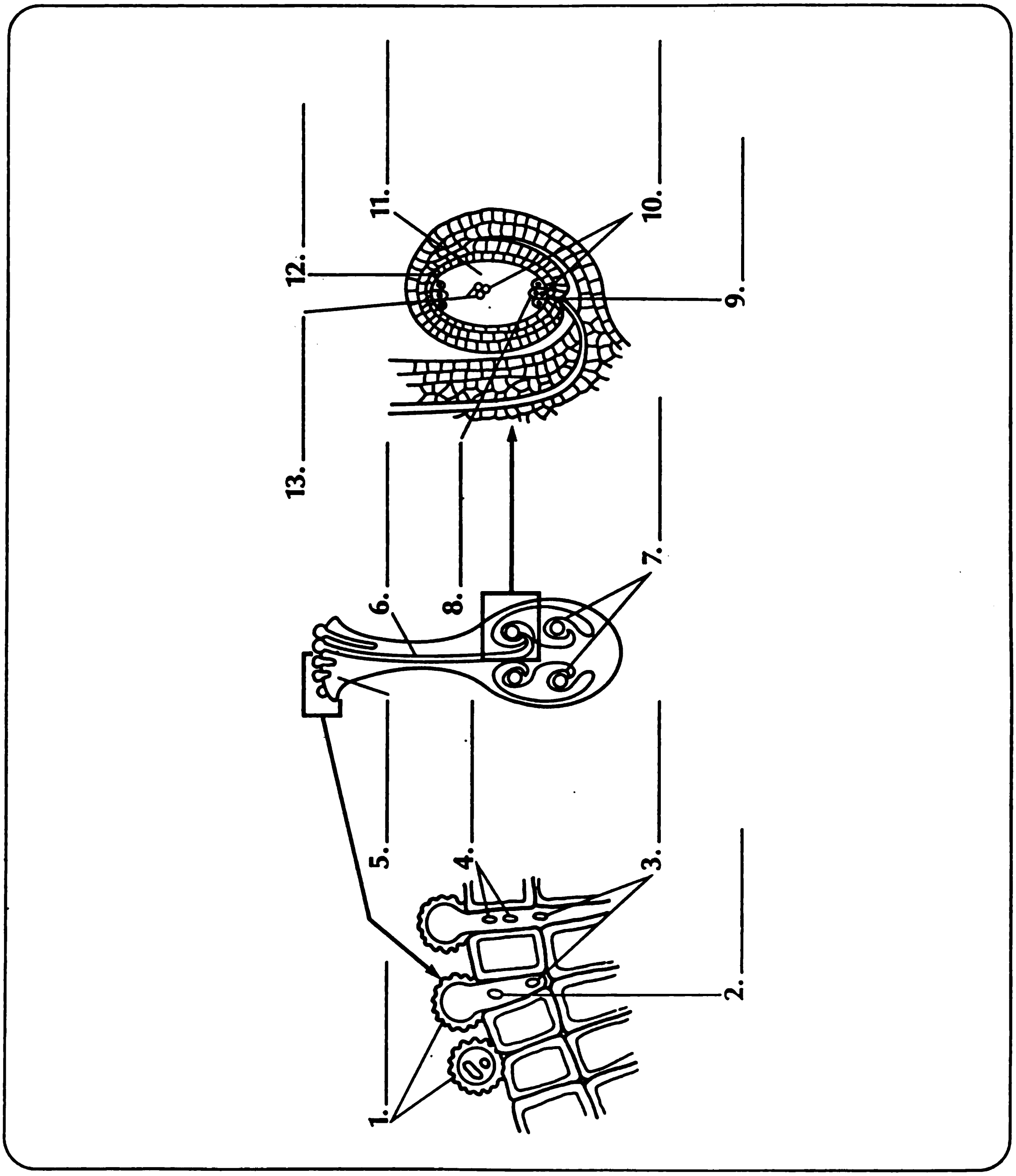
APPENDIX K

CHAPTER

24

OVERHEAD TRANSPARENCY MASTER

Fertilization in a Flower



From Schraer, William D., and Herbert J. Stoltze (1990), Biology: The Study of Life Teacher's Resource Book 3rd ed. (Needham, Massachusetts: Allyn and Bacon) 24-3.

APPENDIX L

BRASSICAS AND BEES

A Partnership in Survival

Symbiosis is the close association of two or more dissimilar organisms. Such associations can be beneficial to both organisms (**mutualistic**) or detrimental to one (**parasitic**). Symbiotic relationships among species occur frequently in nature. When the two or more species in a symbiosis evolve reciprocally, in response to each other, they are said to **coevolve**. Under close examination each symbiosis stands out as an example of the miraculous complexity which has evolved in our everyday world. The coevolution of brassicas and bees, each dependent upon the other for survival, is such a relationship.

What is a flower? In our eyes it is something to enjoy. For bees and other nectar-gathering insects, it is a source of food. For the plant, flowers are vital organs of reproduction containing both male and female gametes. Within each Brassica flower the male and female parts are just millimeters apart so that when pollen from the anthers falls onto the stigma, pollination may occur.

For many brassicas, however, the act of pollination does not insure fertilization and seed formation. Some brassica species contain special recognition compounds, **glycoproteins**, which are found within both the stigma and the pollen and are unique to each plant. These compounds enable the plant to recognize "self", causing the abortion of the plant's own pollen. The prevention of fertilization by "self" pollen is called **self-incompatibility**. In order for fertilization to occur pollen must travel from one brassica plant to the stigma of an entirely different brassica (**cross-pollination**). In this way brassicas ensure that their genes will be well mixed throughout the population.

The pollen itself is heavy and sticky -- unable to be easily windborne. For brassica plants, bees are marvelously coevolved pollen transferring devices. Bees are members of the insect family Apidae, which are unique in that their bodies are covered with feather-like hairs. The bright yellow flower petals act as both beacon and landing pad for the bees, attracting them to the flower and guiding them to the nectaries. The bee drives its head deep into the flower to reach the sweet liquid (nectar) secreted by the nectaries and brushes against the anthers and stigma. Quantities of pollen are entrapped in its body hairs. As the bees work the brassica fields, moving from plant to plant, cross-pollination occurs and genetic information is widely transferred.

Bees depend on the flower for their survival. Sugars in the nectar provide carbohydrates to power flight and life activities. Pollen is the primary source of proteins, fats, vitamins, and minerals to build muscular, glandular, and skeletal tissues. The average colony of bees will collect 44 to 110 pounds of pollen in a season. It is fed in a partially digested state to the larvae and young emerging bees. **Royal Jelly**, a glandular secretion of the workers, rich in pollen protein is fed to the young larvae and to the queen.

A worker bee foraging for pollen will hover momentarily over the flower as she uses her highly adapted legs for pollen collection. The foreleg is equipped with the **antenna cleaner**, a deep semicircular notch with a row of small spines. This is quickly passed over the antenna. Using the large flat **pollen brushes** on the midlegs, the bee quickly brushes the sticky pollen from her head, thorax and forelegs. The pollen is transferred to **pollen baskets** by special adaptive features of the hind legs. First the pollen captured on the midleg brushes is raked off by the **pollen combs** onto the **pollen press**. This press is a deep notch located in the joint just below the pollen basket. Flexing the leg, the bee packs the pollen into the baskets which are enclosed spaces on the upper hindleg formed by a concave outer surface fringed with long curved hairs. When the baskets are filled, the worker bee returns to the hive with her supplies to feed the colony -- nectar in her honey stomach, pollen in her baskets. In the process the continuation of a new generation of brassicas is ensured through her pollination activities.

Department of Plant Pathology, University of Wisconsin, 1630 Linden Dr., Madison , WI 53706.
Wisconsin Fast Plants is an NSF funded instructional materials development project in the biological sciences.
Reprinted from Wisconsin Fast Plants Notes, Vol. 1, No. 1.

APPENDIX M

APPENDIX M

Worksheet for "Brassicas and Bees: A Partnership in Survival"

Name____________________________________

1. What is a mutualistic association of organisms? Give one example in nature that is NOT given in this article.

2. In the first paragraph, the author states that the relationship between brassicas and bees "stands out as an example of the miraculous complexity which has evolved in our everyday world." How do you think this design comes about in nature?

3. What is pollination?

4. What is cross-pollination? Why must some brassicas cross-pollinate?

5. How is pollen transferred in brassica cross-pollination?

6. What is the funtion of Fast Plant flower petals?

7. Why do bees associate with flowers? (Identify 2 items collected from flowers by bees and what each is used for)

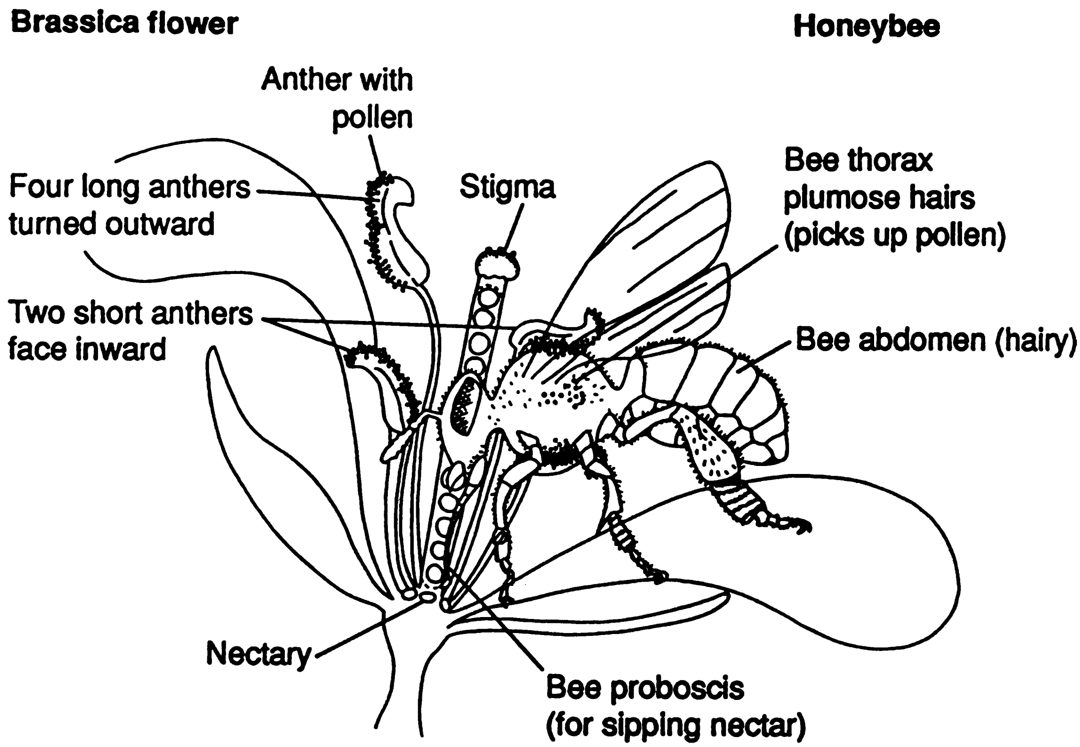
8. Fill in the chart below concerning the adaptive features on a honeybee's legs:

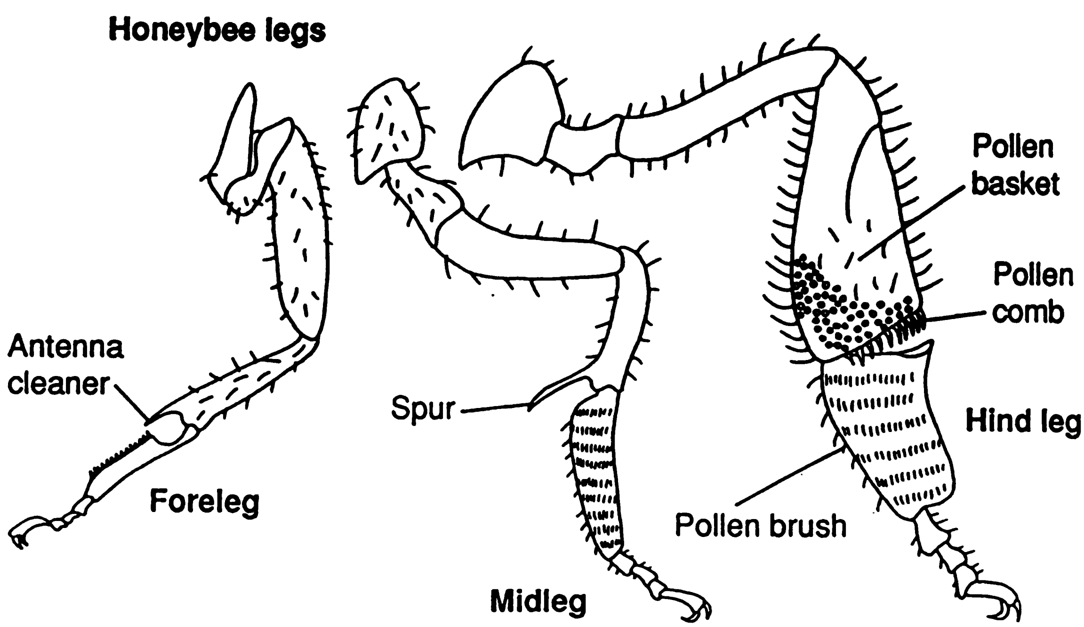
	leg adaptation	function
foreleg	1. antenna cleaner -----	
midleg	2.	
hindleg	3.	
	4.	
	5.	

APPENDIX N

APPENDIX N

Brassica Pollination – The Honeybee



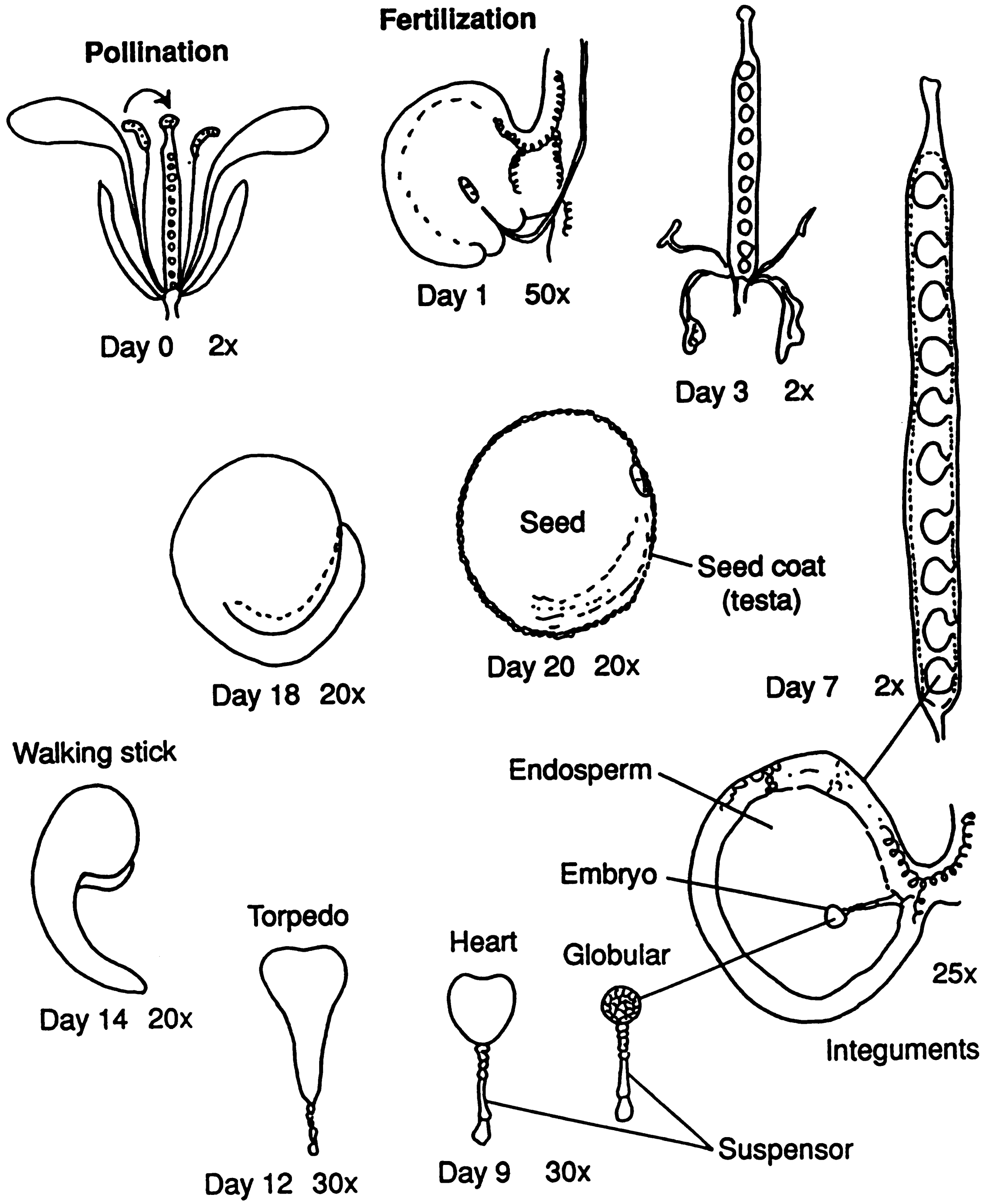


From Wisconsin Fast Plants Program (1989), Wisconsin Fast Plants Manual (Madison, Wisconsin: Wisconsin Alumni Research Foundation, North Carolina: Carolina Biological Supply Company).

APPENDIX O

APPENDIX O

Embryogenesis



From Wisconsin Fast Plants Program (1989), Wisconsin Fast Plants Manual (Madison, Wisconsin: Wisconsin Alumni Research Foundation, North Carolina: Carolina Biological Supply Company).

APPENDIX P

APPENDIX P

Wisconsin Fast Plants Report Grade Sheet Name________________

Neatness (25 pts.)

-- Text and Data	15	_____
-- Sketches	10	_____

Completeness (75 pts.)

-- Introduction	5	_____
-- Hypotheses (# green vs. yellow in F1)	2	_____
-- Day 1 - planting, seed information	5	_____
-- Days 2 - 4 - watering, seedling emergence	5	_____
-- Day 5 - F1 color, sketch seedling /roots	5	_____
-- Hypotheses (effect of rubbing)	2	_____
-- Day 8 - plant data, sketch	7	_____
-- Days 9 - 11 - height, rubbing	5	_____
-- Day 12 - data, sketch, buds, bee-sticks	7	_____
-- Days 15 - 16 - rubbing, height, pollinate	5	_____
-- Days 17 - 19 - flower study/sketches	5	_____
- bee study/sketches	5	_____
-- Day 22 -- # flowers, clip buds	2	_____
-- Days 25 - 37 - pod data, embryo sketch	5	_____
-- Day 43 - harvest day, seed/pod data	5	_____
-- Summary	5	_____

- - - - - - - - - - - - - -

Total points (100) __________

Comments

Grade = ________

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