LAB TOPIC 21

Plant Growth

This lab topic gives you another opportunity to practice the scientific process introduced in Lab Topic 1. Before going to lab, review scientific investigation in Lab Topic 1 and carefully read Lab Topic 21. Be prepared to use this information to design an experiment for plant growth.

Laboratory Objectives

After completing this lab topic, you should be able to:

1. Describe external and internal factors that influence the germination of angiosperm seeds.
2. Explain the effect of auxin on plant growth.
3. Explain the effect of gibberellins on the growth of dwarf corn seedlings.
4. Define and give examples of phototropism and gravitropism.
5. Design and execute an experiment testing factors that influence seed germination and plant growth.
6. Present the results of the experiment in oral or written form.

Introduction

Plant growth and development are determined by the interactions of external environmental conditions and internal cellular processes, beginning with the formation of the seed. As you studied the life cycle of angiosperms (Lab Topic 15 Plant Diversity II), you observed that fertilization of the egg in the female gametophyte results in an embryo protected in a **seed** consisting of the young embryonic sporophyte, food, and a protective seed coat. Seeds begin their development in the parent plant, but once mature, they are dispersed by a variety of mechanisms. Most seeds go through a period of dormancy, but when the environmental conditions (internal and external) are favorable, a dormant seed will begin to **germinate;** that is, it resumes its development and embryonic growth. Most plants continue to grow as long as they live, a condition known as **indeterminate growth.** Indeterminate growth is possible because of plant tissues called **meristems,** which actively divide as long as the plant lives. Seed germination and plant growth are regulated by external factors such as light, temperature, nutrients, and water availability. The seed coat may constrain dormancy because of impermeability to water and oxygen, its rigidity, and inhibitors. Plants respond to these conditions and stimuli by internal processes that are triggered by plant **hormones.** Hormones (in plants and animals) are chemical messengers that are produced in small quantities in one part of the organism and transported to another site, where they induce some special effect. However, there are a few plant hormones that are produced and act locally. In addition to seed germination, plant hormones regulate plant growth and responses to the environment, including gravity and light. Some hormones stimulate growth, whereas others inhibit, and hormones can have different effects depending on the tissue, concentration of the hormone, and the ratios of multiple hormones. Recent research with mutant strains of the model plant *Arabidopsis* has allowed plant scientists to detect new groups of hormones. Auxin was the first hormone discovered, and the current list also includes gibberellins, cytokinins, abscisic acid, and ethylene, in addition to three newly recognized hormones, brassinosteroids, strigolactones, and jasmonates.

In this lab topic, you will work in teams to investigate external stimuli and internal mechanisms that influence the germination of seeds and the growth of plants. You will complete several brief introductory experiments (Experiment A of Exercises 21.1, 21.2, and 21.3); then your team will propose one or more testable hypotheses based on questions generated during these first experiments. You will then design and carry out an independent investigation based on your hypotheses (Exercise 21.4). You may design an experiment that can be completed in the laboratory period. However, you should plan to make observations of your plants over several days or at the beginning of the next laboratory. Your instructor will tell you if you will be able to return to the lab to make observations or if you should carry your experiment elsewhere for observations. You may be given time to finalize your results and presentation at the beginning of the next laboratory period. Your team should discuss the results and prepare an oral presentation. One member of your team will present your team's results to the class for discussion. You should be prepared to persuade the class that your experimental design is sound and that your results support your conclusions. If assigned by the lab instructor, each of you will submit an independent laboratory report describing your experiment and results in the format of a scientific paper (see Appendix A).

The following summarizes the components of each activity in this lab topic.

- Complete Experiment A in Exercises 21.1, 21.2, and 21.3.
- Discuss possible questions that your research team might investigate.
- Choose one interesting question from your list; be certain you can develop a *testable hypothesis.*
- Design and initiate your open-inquiry investigation (Exercise 21.4).
- Complete the experiment and report your results during the following laboratory period.

General Procedures for Independent Investigations: Germinating Seeds and Growing Plants

The following sections provide general procedures you will use in designing your open-inquiry investigation (Exercise 21.4). Return to these procedures when planning your investigation.

Experimental Plants

You may choose plants used in the lab studies for your independent investigation. These include *Zea mays* (corn), *Phaseolus vulgaris* (pinto bean), *Phaseolus limensis* (lima bean), *Coleus blumei* (a common ornamental annual with colorful variegated leaves), and *Brassica rapa* (related to *Arabidopsis*, mustard, and cabbage). If you decide to use different plant species, check with your laboratory instructor about the availability of additional plants.

Germinating Bean and Pea Seeds

Bean and pea seeds can be germinated by first submerging them in a 10% sodium hypochlorite solution for 5 minutes to kill bacteria and fungus spores on their surfaces. Follow this with a distilled water rinse and plant the seeds 1 cm deep in flats of vermiculite, a clay mineral that looks like mica and is frequently used as a starting medium for seeds. Add water or a test solution to the flats daily or as needed.

Growing Wisconsin Fast Plants

The *Brassica rapa* seeds used in this exercise were developed by Dr. Paul Williams of the University of Wisconsin, Madison. Dr. Williams used traditional breeding techniques to produce plants, called Wisconsin Fast Plants™, that can complete an entire breeding cycle from seed to seed in 35 days (Figure 21.1). Because of the rapid growth and shortened breeding cycle of these plants, they are excellent investigative tools for use in plant growth experiments. *Brassica rapa* and *Arabidopsis* (a model plant used in molecular biology and genetics research) are in the same plant family, Brassicaceae or Mustard family.

A. Seed Germination Exercises

Brassica rapa seeds can be germinated by placing them on wet filter paper in the lid of a petri dish. Stand the dish, tilted on its end, in a water reservoir such as the bottom of a 2-L soft-drink bottle (Figure 21.2a, b). The dish and

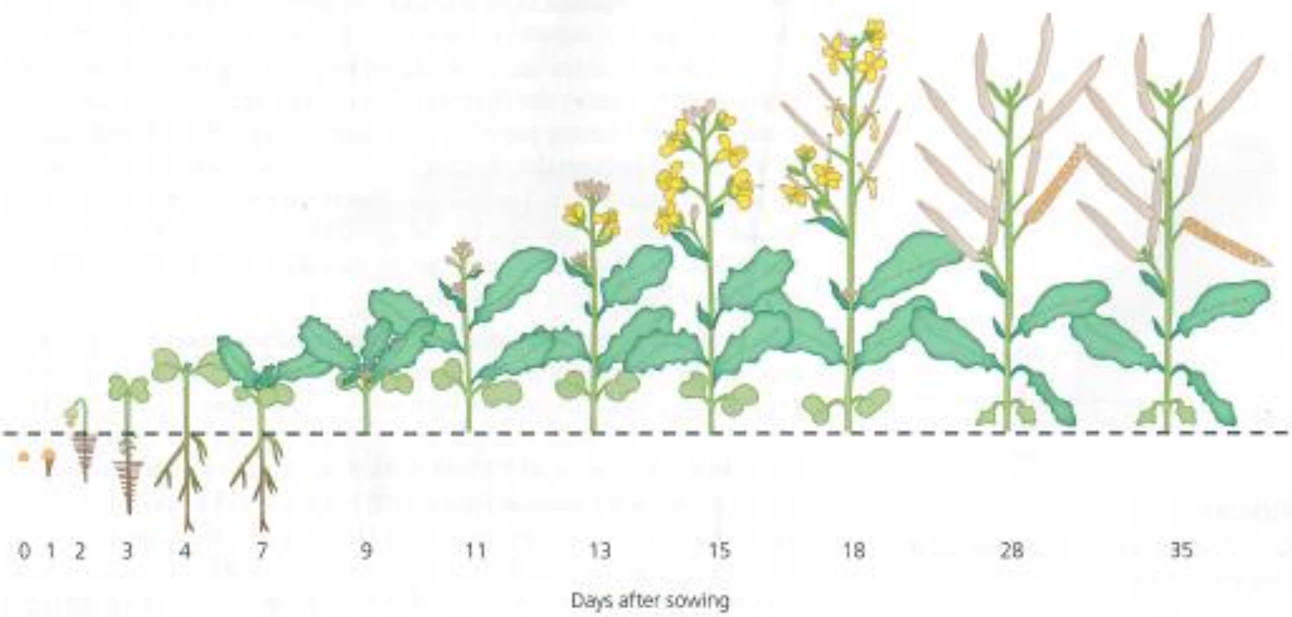

FIGURE 21.1
Life cycle of Fast Plant *Brassica rapa*. These plants can complete their entire life cycle from seed to seed in 35 days.

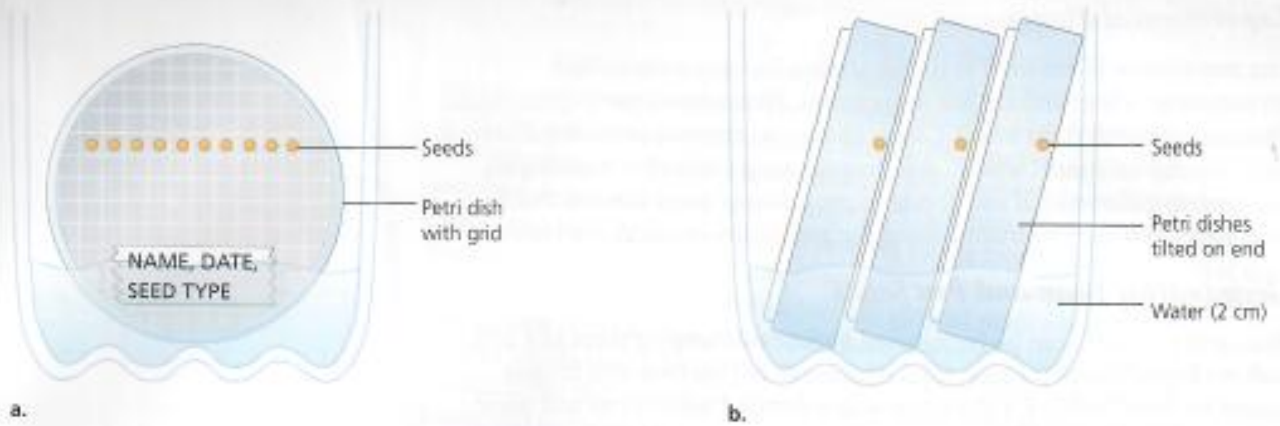

FIGURE 21.2

Germinating *Brassica rapa* seeds in a petri dish. (a) Place the seeds on wet filter paper in the lid of a petri dish. Attach a grid to the outside of the lid for easy seedling measurement. (b) Stand the dishes on end in a water reservoir.

reservoir should be placed under fluorescent lights. Germination begins within 24 hours, and observations can be made for several days. It is important to keep the filter paper moist by carefully adding water. If you wish to make quantitative measurements of seed germination, tape a transparent grid sheet marked in measured increments to the outside of the petri dish lid. Place the wet filter paper in the lid, as before, and plant the seeds at a particular position in relation to the grid. As the seeds germinate and grow, you can easily use the grid to measure their size (Figure 21.2a).

B. Tropism Studies

1. *Phototropism. Brassica rapa* seeds can be germinated in empty 35-mm clear or black film canisters (Figure 21.3). The canisters can be used as is or black canisters can be modified by punching holes in the sides to allow light to enter the chamber. Place small, appropriately sized squares of wet blotting paper or floral foam disks in the lid, and place two or three seeds on the blotting paper or foam disks. (Do not use filter paper; it dries out too quickly.) Invert the canister and snap it into the lid. Holes in the canister can be covered with different-colored filters, and the size of the holes can be varied to alter the quality or quantity of light hitting the plants.
2. *Gravitropism.* Seeds and seedlings may be used to demonstrate gravitropism. For investigating *gravitropism* and *seed germination*, prepare a windowless black film canister with wet blotting paper as described for phototropism. Place three seeds on the blotting paper. Place the chamber horizontally and use a permanent marker to indicate which side is up. The chamber will resemble Figure 21.3, but there will be no holes and the chamber will be placed on its side. (*Hint: Tape a film canister lid to the outside of the canister to keep it from rolling.*) Within 1 or 2 days you will be able to observe the effects of gravitropism.

   To observe gravitropism in 3-day-old seedlings, attach a wick and grid germination strip to the inside wall of a windowless black film canister,

FIGURE 21.3

Growing *Brassica rapa* seeds in film canisters. Place seeds on moist blotting paper in the lid. Holes can be punched in the canister to allow light to enter the chamber.

FIGURE 21.4
Growing *Brassica rapa* seedlings in film canisters. Attach the seedling to the center of the wick strip with the cotyledons against the wick as shown.

with the grid strip between the wick and the side of the canister. Add just enough water to cover the bottom of the canister, and have the wick in contact with the water. Attach a young seedling with cotyledons present to the center of the wick strip with the cotyledons against the wick and the hypocotyl pointing out, into the canister. (See Figure 21.4.)

C. Growing *Brassica rapa* Seedlings in Quads

Scientists working with Wisconsin Fast Plants suggest germinating seeds in small, commercially available Styrofoam™ containers called *quads,* which contain four cells, or chambers. To germinate seeds in quads (Figure 21.5):

1. Add a wick to each cell to draw water from the source into the soil.
2. Add potting mix until each cell is about half full.

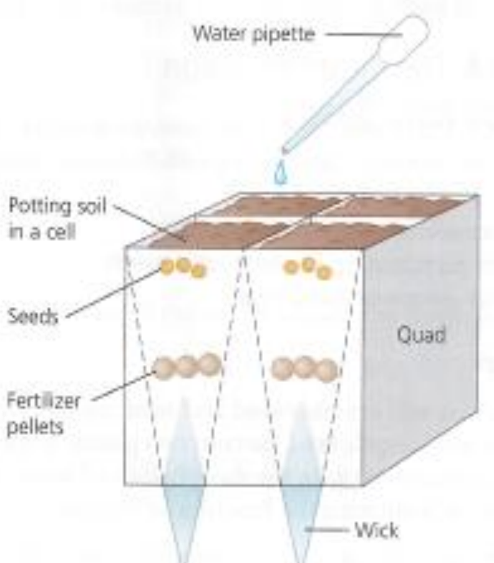

FIGURE 21.5
Growing *Brassica rapa* plants in quads. Pull a wick through the hole in each cell. Add potting soil, fertilizer, and seeds. Initially, water using a pipette.

3. Add three fertilizer pellets.
4. Add more soil and press to make a depression.
5. Add two or three seeds to each cell and cover them with potting mix.
6. Carefully water each section using a pipette until water soaks through the potting mix and drips from the wick.
7. Place the quad on the watering tray under fluorescent lights.

After the seeds begin to germinate, you can manipulate the plants in many different ways to investigate plant growth.

EXERCISE 21.1
Factors Influencing Seed Germination

Seeds are the means of reproduction, dispersal, and, frequently, survival for a plant. Plants are immobile and can colonize new habitats and escape inhospitable weather only through the dispersal and dormancy of seeds. *Dormancy* is a special condition of arrested growth in which the seed cannot germinate without special environmental cues. The environmental conditions for germination (breaking dormancy) are very different for plants in the desert or swamp, for tiny or large seeds, and for seeds that begin to grow in early spring or late fall. Some seeds require that the seed coat be broken, whereas others can only germinate after passing through the digestive system of a bird or mammal. Consider the range of environmental cues and the role of chemical signals (hormones) to initiate germination. In this exercise, you will observe germinating bean and *Brassica rapa* seeds. The beans have been germinating in a moist environment for several days. The *Brassica rapa* seeds are germinating on wet filter paper in the lid of a petri dish.

Experiment A. Germinating Bean and *Brassica rapa* Seeds

Materials

germinating bean seeds
petri dishes with germinating *Brassica rapa* seeds
stereoscopic microscope or hand lens

Introduction

In this lab study, you will examine seed and seedling morphology. Working individually, you will identify seed parts in two plants, a species of bean and *Brassica rapa*. As you investigate the morphology of seeds, consider the role of each structure in facilitating the function of the seed.

Procedure

1. Examine a germinating bean seed and identify the **seed coat, cotyledons** (seed leaves), and **embryo** consisting of the **radicle** (embryonic root), **hypocotyl** (plant axis below the cotyledons), and **epicotyl** with young leaves (plant axis above the cotyledons).

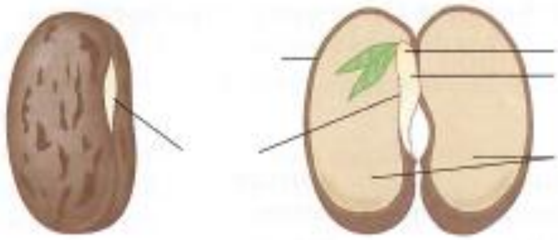

FIGURE 21.6

The structure of a bean seed. Add the labels: *seed coat, cotyledons, radicle, hypocotyl,* and *epicotyl.*

2. Secure a petri dish with germinating *Brassica rapa* seeds. Carefully examine the seeds using a hand lens or the stereoscopic microscope and identify the **seed coat** (which may have been shed), **cotyledons** (how many?), **hypocotyl** (the portion of the plant below the cotyledons), **primary root, root hairs,** and **young shoot,** consisting of the epicotyl and young leaves.

Results

1. Label the parts of the bean seed in Figure 21.6.
2. Draw and label several germinating *B. rapa* seeds in the margin of your lab manual.

Discussion

1. What is the function of the seed coat? From what does it develop?

2. What has happened to the endosperm that formed in the embryo sac of the developing ovule observed in Lab Topic 15 Plant Diversity II?

3. How have the cotyledons developed, and from what? (Check your text; see, for example *Campbell Biology* 10th ed., Chapter 38.)

4. How does the structure of the seed facilitate the dispersal and survival of the plant?

5. What environmental conditions or cues might be required for seed germination? Consider the variety of seed types (Lab Topic 15 Plant Diversity II) and the range of plant habitats, seasonal growth patterns, and climatic conditions.

Experiment B. Student-Designed Investigation of Seed Germination

Materials

seeds of *Brassica rapa*
various other seeds—beans, corn, radish, okra, lettuce
35-mm film canisters—clear plastic, black, or black with holes punched in the sides
small squares of blotting paper soaking in water
floral foam disks 28 mm diameter, 2–4 mm thick, soaking in water
red, green, and blue light filter sheets
tape
water baths, incubator, refrigerator
grid sheets that fit the lids of petri dishes
wick and grid germination strips
reservoir
forceps
scissors
waterproof pen
agar plates
empty petri dishes
sandpaper
various pH solutions
10% sodium hyperchlorite solution
solutions of gibberellin or other hormones
fertilizer solutions in various concentrations and/or dry fertilizer pellets
hole punch

Introduction

Consider the results of your seed germination experiment and background information provided in this lab and your text as you review the following questions and suggestions for an open-inquiry investigation. If your team chooses to study seed germination for your independent research and report, use the available materials. Design a simple experiment to investigate factors involved in the germination of seeds.

Procedure

1. Collaborating with your research team, read the following potential questions and choose a question to investigate using this list or an original question proposed by your team. You may want to check your text and other sources for supporting information. You should be able to explain the rationale behind your choice of question.
   a. Do seeds need light to germinate? What effect will germination in total darkness have on the process? Is germination better in alternating light and dark, as in nature? Do different species have different light or dark requirements for germination?
   b. Is germination different in different wavelengths (colors) of light?
   c. What effect does scarification (scratching the seed coat) have on germination of various seeds? How does scarification occur in nature?
   d. What temperature regimens are optimum for seed germination? Is germination affected by alternating temperatures (as in nature)? Is a constant temperature favorable?
   e. Does gibberellin (Exercise 21.3) promote or inhibit seed germination? What about other hormones—for example, cytokinins or abscisic acid? Check your text for other test substances.
   f. What effect does fertilizer have on seed germination and seedling growth? Is more always better?

g. What effect will salt solutions or acid solutions have on seed germination? Why would questions such as these be of interest?

h. Does seed size have an effect on germination rates? On seedling size?

i. Some crops are limited in their distribution by cold soils that affect seed germination. Will changes in regional climate affect seed germination in okra (a summer plant), broccoli (a fall plant), or varieties of wheat?

2. Design your experiment, proposing hypotheses, making predictions, determining procedures, and recording results as instructed in Exercise 21.4.

EXERCISE 21.2
Plant Growth Regulators: Auxin

Both plants and animals respond to environmental cues. Animals generally respond rapidly via the nervous system or more slowly via hormones secreted from endocrine glands. Plants lack a nervous system, are sedentary, and respond to environmental stimuli via chemical messengers or hormones. Changes in these hormones lead to altered patterns of growth and development. **Auxin** is the name given to a complex of substances that promotes stem growth. The natural auxin indoleacetic acid (IAA) is a hormone produced in apical meristems. It migrates down the stem from the zone of production to tissues in the stem, leaves, and roots. If the growing tip is removed, the stem will not elongate, but if the tip is replaced with a paste containing IAA, elongation will continue. At low concentrations, IAA facilitates cell elongation and promotes growth by breaking linkages among cellulose fibers and loosening the cell wall. In this exercise, you will investigate the role of auxin in stem and root curvature in response to light and gravity.

Experiment A. Gravitropic and Phototropic Curvature in *Coleus blumei*

Materials

(on demonstration)
Coleus plant placed on its side
Coleus plant in unilateral light
Coleus plant in upright position

Introduction

In this exercise, you will investigate the growth of the stem and root in response to two environmental stimuli, gravity and light. **Gravitropism** is the response of plant organs to gravity. Different plant organs may show positive or negative gravitropism. **Phototropism** is the response of a plant to light. A plant organ may grow toward a light stimulus (positive phototropism) or away from a light stimulus (negative phototropism). Three *Coleus blumei* plants are on demonstration in the lab room. One was placed on its side several days ago. Another has been growing in unilateral light for several days. The third, the control, was left undisturbed in the greenhouse until lab time.

Procedure

1. Study gravitropic curvature in *Coleus blumei.*
   a. Carry your lab notebook to the demonstration area and observe the *Coleus* plant placed on its side.
   b. Examine the plant, noting the appearance of different regions of the stems and roots (if visible). What part of each stem has curved? To what degree? How could you measure the amount of curvature in the stem?
   c. Compare this plant with the control plant left in an upright position.
   d. Make a simple sketch of the plant, showing the curvature of stem and roots (if any).
   e. Describe your observations and answer the questions in the Results section.
2. Study phototropic curvature in *Coleus blumei.*
   a. Examine the plant growing in unilateral light, noting the appearance of different regions of the stems.
   b. Compare the plant to the control plant, which has received light from all directions in the greenhouse. What measurements can you make to quantify the differences in the two plants?
   c. Make a simple sketch of the plant, showing the curvature of stem and roots (if any).
   d. Record your observations and answer the questions in the Results section.

Results

1. Describe the appearance of the plant lying on its side. How does this compare with the appearance of the control plant?

2. What is the extent of the response to gravity? How could you measure or quantify the response?

3. Describe the appearance of the plant in unilateral light. Compare the plant with the control plant.

4. What is the extent of the response to the light? How could you measure or quantify the response?

5. What part of the plant specifically is being affected? (If you need to, review the anatomy of the apical meristem in Lab Topic 20 Plant Anatomy.) Can you explain why?

Discussion

1. What type of response would you expect to see if you reoriented the plant lying on its side? Explain.

2. Current research has confirmed that plants detect gravity by the location of **statoliths** (specialized amyloplasts or starch grains). Can you suggest how these might signal a change in orientation of the plant from vertical to horizontal? Consult your text for additional information. (This is not the only mechanism, as plants that lack statoliths still have a weak response to gravity.)

3. Review with your team members the physiological basis for the growth response. How is auxin involved in gravitropism? Where is it produced? How is the action of auxin different in root and stem tissues? Consult your text, if necessary.

4. Is curvature of the stem in response to gravity and light the result of additional cell division or cell elongation? How do you know, or how could you investigate this?

5. What is the role of auxin in phototropism? How is directional light detected in the plant? Do you think that any or all wavelengths of light can trigger phototropism? Use your text and other resources to answer these questions.

MB Student Media Videos—Ch. 39: Phototropism; Gravitropism

Experiment B. Student-Designed Investigation of Auxins

Materials

auxin solutions in various concentrations
auxin in lanolin paste
lanolin with no auxin
scissors
Coleus plants
glass containers for planting
Brassica rapa seedlings in quads
corn and bean seedlings in pots or flats
lamps
toothpicks
protractor
spray bottles
cotton-tipped applicators
aluminum foil
35-mm black film canisters
floral foam disks, 28 mm diameter, 2–4 mm thick, soaking in water
wick and grid germination strips
forceps
red, green, and blue light filter sheets
Brassica rapa seeds
3-day-old *Brassica rapa* seedlings germinated in petri dishes on wet filter paper

Introduction

Consider the results of your phototropism and gravitropism experiments and the background information provided in this lab and your text as you review the following questions and suggestions for an open-inquiry investigation. Discuss with your team members ways to use *Coleus, Brassica,* or corn or bean seedlings to further investigate these processes. Using the materials available, design a simple experiment to investigate the role of auxin in plant growth or factors involved specifically in phototropism and gravitropism.

Procedure

If spraying solutions with plant hormones or herbicides, isolate plants so that the spray only affects your experimental plants.

1. Collaborating with your research team, read the following potential questions and choose a question to investigate using this list or an original question proposed by your team. You may want to check your text and other sources for supporting information. You should be able to explain the rationale behind your choice of question.
   a. If only some wavelengths stimulate phototropic response, which ones do and which do not?
   b. If the apical meristem is removed, will plants respond to unilateral light?
   c. How does the root respond to gravity (if the cotyledons are kept stationary)?
   d. If the tip of the root is removed, will roots respond to gravity? (Seedlings can be planted close to the wall in glass containers so that root growth can be viewed, or you may use *Brassica rapa* seeds germinating in dark film canisters.)
   e. Can these tropisms be altered by applying auxin paste to the plant?
   f. What will happen if the tips of the plants (root or stem) are covered with aluminum foil?
   g. How else does auxin affect plants? How does auxin affect apical dominance? Can auxin be used as an herbicide? (In what concentrations? What is the effect on plants?) What concentration of auxin produces the largest roots on stem cuttings? (What horticultural applications would this have?)
   h. Will seedlings growing in the dark respond to auxin applied to the side of the stem? At all locations on the stem?
   i. The herbicide 2,4-dichlorophenoxyacetic acid (2,4-D), used to control weeds, is described as a synthetic auxin. How does 2,4-D affect plant growth? What plants are affected or unaffected by 2,4-D and at what concentrations?
2. Design your experiment, proposing hypotheses, making predictions, and determining procedures as instructed in Exercise 21.4.

EXERCISE 21.3
Plant Growth Regulators: Gibberellins

Gibberellins are another group of important plant growth hormones found in high concentrations in seeds and present in varying amounts in all plant parts. In some plants, gibberellins produce rapid elongation of stems; in others they produce **bolting,** the rapid elongation of the flower stalk. Produced near the stem apex, gibberellins work by increasing both the number of cell divisions and the elongation of cells produced by those divisions. The effects of gibberellins can be induced by artificially applying solutions to plant parts. Not all plants respond to the application of gibberellins, however, and in this exercise, you will investigate the effect of applying gibberellin solutions to normal and to dwarf (mutant) corn seedlings.

Experiment A. Effects of Gibberellins on Normal and Dwarf Corn Seedlings

Materials

2 pots each with 4 tall (normal) corn seedlings
2 pots each with 4 dwarf (mutant) corn seedlings
calculator

Introduction

The seedlings used in this exercise are approximately the same age, but they exist in two phenotypes, tall and dwarf (Figure 21.7). The tall seedlings are wild type, or normal. A genetic mutation produces dwarf plants that lack gibberellins. Each team of students has *four pots, each with four corn seedlings*. Your instructor has previously treated the plants with either water or a gibberellin solution. In this experiment, you will investigate the effects of these treatments on the corn plants.

Procedure

1. Several days ago, your instructor sprayed the plants with either distilled water or a gibberellin solution, as follows:

Control	***Treated***
Pot 1: normal corn, water treatment	Pot 2: normal corn, gibberellin treatment
Pot 3: dwarf corn, water treatment	Pot 4: dwarf corn, gibberellin treatment

2. Observe the results of the treatments.
3. Measure the height of each of your plants and record these data in Table 21.1.

FIGURE 21.7
Normal corn plants and recessive dwarf mutants.

Results

1. Determine and record the mean height of plants in each category in Table 21.1.
2. Using the mean height for each category of plants, calculate the percentage difference in the mean height of treated normal plants and control normal plants. Then calculate the percentage difference in the mean height of treated dwarf plants and control dwarf plants. Use the given formula for your calculations:

$$\text{Normal\% difference} = \frac{\text{treated} - \text{control}}{\text{control}} \times 100 = \_\_\_\_\_\_ \%$$

$$\text{Dwarf\% difference} = \frac{\text{treated} - \text{control}}{\text{control}} \times 100 = \_\_\_\_\_\_ \%$$

3. Record your data for the average percentage difference in the mean values for both normal and dwarf plants from Table 21.1 on the class master sheet. Then calculate the average percentage differences for the entire class.

TABLE 21.1 Height of Normal and Dwarf Corn Seedlings with and Without Gibberellin Treatment

Download an Excel version of this table from www.masteringbiology.com in the Study Area under Lab Media.

	Normal Control (Pot 1)	Normal Treated (Pot 2)	Dwarf Control (Pot 3)	Dwarf Treated (Pot 4)
Plant 1 Height				
Plant 2 Height				
Plant 3 Height				
Plant 4 Height				
Mean Height				

	Your Data	***Class Data***
Average % difference: normal	____________	____________
dwarf	____________	____________

Discussion

1. How do values for percentage difference compare for dwarf versus normal treated and untreated plants?

2. What is the action of gibberellins? What can you conclude about the mutation that produces dwarfism in corn? Discuss your results with your group, and consult your text or other references.

Experiment B. Student-Designed Investigation of Gibberellins

Materials

normal and dwarf *Brassica rapa* seedlings (*petite* and *rosette* dwarf strains)
normal and dwarf corn seedlings
normal and dwarf pea seedlings (Little Marvel peas, *Pisum sativum*)
solutions of gibberellin
dropper bottles
sprayers
cotton-tipped applicators
supplies to grow *Brassica rapa* seedlings in quads

Introduction

Having seen the effect of gibberellins on the growth of normal and dwarf corn seedlings in the preceding experiment, discuss with your team members possible questions for further study of this group of hormones. If you choose to carry out your independent investigation with this system, the questions provided in the following Procedure section will be appropriate for your study. Using the materials available, design a simple experiment to investigate the actions of gibberellins in *plant growth or seed germination.*

Procedure

If spraying solutions with plant hormones, isolate plants so that the spray only affects your experimental plants.

1. Collaborating with your research team, read the following potential questions and choose a question to investigate using this list or an original question proposed by your team. You may want to check your text and other sources for supporting information. You should be able to explain the rationale behind your choice of question.
   a. Plant scientists have discovered a mutant strain of *Brassica rapa* in which plants are dwarf. In these plants, the internodes do not elongate, and plants consist of a cluster of leaves spreading close to the soil. Flowers cluster close to the leaves. How can you determine if these are GA-deficient dwarf plants?
   b. Would other plant hormones produce the same response in dwarf corn seedlings as do gibberellins?
   c. In the demonstration experiment, the gibberellin solution was sprayed on all parts of the plant. If the gibberellin solution were added only to specific regions, such as the roots or apical meristem, would the effect be the same?
   d. Would the results in the corn experiment differ with different concentrations of gibberellin solution?
   e. What effect do gibberellins have on seed germination?
   f. What effect do gibberellins have on root growth on cut stems?
   g. Is the dwarf condition seen in certain strains of peas (Little Marvel peas) due to the lack of gibberellins?

h. There are two dwarf forms of *Brassica rapa—rosette* and *petite*. Is dwarfism in these mutant strains due to insufficient gibberellin or to some other factor?

i. *Brassica rapa* mutant, *tall* (ein/ein genotype) produces an excess of gibberellins. Can the elongated growth in this mutant be inhibited by the growth regulator Cyocel™? Can growth be further stimulated by applying gibberellins? Research the mode of action for Cyocel™.

2. Design your experiment, proposing hypotheses, making predictions, and determining procedures as instructed in Exercise 21.4.

EXERCISE 21.4
Designing and Performing an Open-Inquiry Investigation

Materials

See each Experiment B materials list in Exercises 21.1, 21.2, and 21.3.

Introduction

Now that you have completed Experiment A in each of the exercises, your research team should select one factor that affects plant growth to investigate. Return to the investigation of your choice and review the suggestions in Experiment B. Use Lab Topic 1 Scientific Investigation as a reference for designing and performing this independent investigation. You will need to think critically and creatively as you ask questions and formulate your hypothesis. As a team, review and modify the procedures, determine any additional required materials, review the techniques and procedures for growing plants and germinating seeds, and assign tasks to all members of your research team. Your experiments will be successful if you plan carefully, think critically, perform techniques accurately and systematically, and record and report data accurately. The following outline will assist you in designing and performing your original investigation.

You and your lab partner are responsible for the care and maintenance of your plants. Remember to check the water. The success of your investigation depends on the plants' survival.

Procedure

1. **Develop a research question to investigate.** Consider one or two potential questions, then as a team select one question. Suggested questions are included in Experiment B of Exercises 21.1, 21.2, and 21.3 or select an original question of your choice. (Refer to Lab Topic 1, Exercise 1.1, Lab Study A. Asking Questions.)

   Question:

2. **Formulate a testable hypothesis.** (Refer to Lab Topic 1, Exercise 1.1, Lab Study B. Developing Hypotheses.)

   Hypothesis:

3. **Summarize the essential elements of the experiment.** (Use separate paper.)

4. **Predict the results of your experiment based on your hypothesis.** (Refer to Lab Topic 1, Exercise 1.2, Lab Study C. Making Predictions.)

   Prediction: (If/then)

5. **Outline the procedures used in the experiment.** (Refer to Lab Topic 1, Exercise 1.2, Lab Study B. Choosing or Designing the Procedure.)
   a. Review and modify the procedures used in Experiment A of one of the exercises: 21.1 Seed Germination, 21.2 Auxin, or 21.3 Gibberellins. Review the General Procedures for Independent Investigations: Germinating Seeds and Growing Plants section in the Introduction to this lab topic. List each step in your procedure in numerical order.
   b. Critique your procedure: check for replicates, level of treatment, controls, duration of experiment, growing conditions, glassware, and age and size of plants. Review measurements and intervals between measurements. Assign team members to check plants periodically and water if needed.
   c. If your experiment requires materials other than those provided, ask your instructor about their availability. If possible, submit requests in advance.
   d. Create a table for data collection. Using examples in this lab topic as a model or design your own. If computers are available, create your table in Excel. Remember to include space for general observations of plant growth.
6. **Perform the experiment,** making observations and collecting data for analysis.
7. **Record results, including observations and data,** in your data table. Make notes about experimental conditions and observations. Do not rely on your memory for information that you will need when reporting your results.
8. **Prepare your discussion.** Discuss your results in light of your hypothesis.
   a. Review your prediction. Did your results correspond to the prediction you made? If not, explain how your results are different from your predictions, and why this might have occurred.
   b. Review your hypothesis. Review your results (tables and graphs). Do your results support or falsify your hypothesis? Explain your answer, using your data for support.
   c. If you had problems with the procedure or questionable results, explain how they might have influenced your conclusion.

d. If you had an opportunity to repeat and expand this experiment to make your results more convincing, what would you do?

e. Summarize the conclusion you have drawn from your results.

9. **Be prepared to report your results to the class.** Prepare to persuade your fellow scientists that your experimental design is sound and that your results support your conclusions.

10. If your instructor requires it, **submit a written laboratory report** in the form of a scientific paper (see Appendix A). Keep in mind that although you have performed the experiments as a team, you must turn in a lab report of *your original writing*. Your tables and figures may be similar to those of your team members, but your paper must be the product of your own literature search and creative thinking.

Reviewing Your Knowledge

1. Having completed this lab topic, you should be able to define and use the following terms, providing examples when appropriate: *hormones, seed, seedling, seed coat, cotyledon, endosperm, radicle, hypocotyl, epicotyl, germination, dormancy, statoliths, phototropism, gravitropism, apical dominance, auxin, gibberellins, bolting.*
2. Students investigating plant growth and the effects of hormones removed the seeds from developing strawberries and compared the size and time of fruit development. The strawberries failed to enlarge and become red and fleshy in plants where the seeds were removed. Research the roles of auxin and gibberellin and determine which hormone is responsible for fruit development.

Applying Your Knowledge

1. Auxin is directly or indirectly responsible for apical dominance in plants. In this phenomenon, the growth of lateral or axillary buds (described in Lab Topic 20 Plant Anatomy) is inhibited by the auxin that moves down the stem from the apical meristem. It has long been the practice of horticulturists to clip off the apical meristems of certain young houseplants. What impact should this practice have on subsequent plant growth and appearance?

2. What adaptive role would positive phototropism play in a natural ecosystem where plants are crowded?

3. Plant hormones are used in agriculture to enhance crops and regulate the timing of crop development. For each of the following scenarios, suggest the growth hormone (auxin, gibberellin, cytokinin, ethylene, or abscisic acid) involved and the mode of action. Use your textbook or other references to assist with the functions of hormones not investigated in this lab topic.

   Thompson seedless grapes are treated with a hormone to increase the size of the grapes and also extend the stem so that the clusters are less compact (more loose and full).

   Seed companies treat a field of mature plants of mustard, cabbage, and canola with a growth hormone to stimulate flower growth and seed production in all plants at the same time.

   Hormones are used in tissue culture to increase cell division and to promote the differentiation of meristems into mature cells. (More than one hormone is involved.)

   Tomatoes are shipped green to the distributor. They are then treated with a hormone that promotes fruit development, changing the tomatoes to the bright red color customers expect.

   When seedlings are transplanted, they suffer severe drought stress. Horticulturists spray the plants with a low concentration of a hormone that causes stomata closure and reduces water loss.

4. During the 1960s, a world food shortage was solved by the breeding and cultivation of a race of wheat with higher grain production and short stems that resisted the damage of wind and rain. Norman Borlaug won the Nobel Prize in 1970 for his contributions to this "Green Revolution" that reportedly saved the lives of more than 1 billion people. Based on your knowledge of plant hormones, suggest the hormone that would be deficient in this race of wheat. Explain using the evidence observed in the laboratory.

5. Brassinosteroids are a recently discovered class of plant hormones that are similar in structure to animal steroids. Initially isolated in *Brassica napus* (thus their name), they now have been identified in a wide range of plants. Brassinosteroids are more potent than auxins and gibberellins, requiring much smaller concentrations to effect changes in plant

growth. These plant hormones can cause cell elongation, among other effects on plant growth. Scientists have long known that the stems of normal seedlings grown in the dark elongate rapidly and become light colored, a condition called *etiolation*. Recently, scientists have cultured a mutant race of *Arabidopsis*, a model plant for physiology studies, that does not become etiolated in the dark. Utilizing *Arabidopsis* mutant and normal plants, devise an experiment to test the role of brassinosteriods in etiolation. Consider controlled variables, control treatments, replicates, how you will measure plant growth, and the time period for making measurements and observations. State your prediction based on the experiment you design.

Student Media: BioFlix, Activities, Investigations, Videos, and Data Table

www.masteringbiology.com (select Study Area)

Activities—Ch. 35: Primary and Secondary Growth; Ch. 39: Flowering Lab

Investigations—Ch. 39: What Plant Hormones Affect Organ Formation?

Videos—Ch. 35: Root Growth in a Radish Seed (time-lapse); Ch. 39: Phototropism; Gravitropism

Data Table—Table 21.1 can be downloaded in Excel format. Look in the Study Area under Lab Media.

References

Chamovitz, D. *What a Plant Knows: A Field Guide to the Senses.* New York: Scientific American/Farrar, Straus and Giroux, 2012.

Evert, R. F. and S. E. Eichhorn. *Raven Biology of Plants*, 8th ed. New York: W.H. Freeman, 2013.

Mauseth, J. D. *Botany. An Introduction to Plant Biology*, 5th ed. Sudbury, MA: Jones and Bartlett Publishers, 2012.

Reece, J., et al. *Campbell Biology*, 10th ed. San Francisco, CA: Pearson Education, 2014.

Srivastava, L. M. *Plant Growth and Development: Hormones and Environment*. San Diego, CA: Academic Press, 2002.

Taiz, L. and E. Zeiger. *Plant Physiology*, 5th ed. Sunderland, MA: Sinauer, 2010.