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THIRTEENTH EDITION

BIOLOGY

LABORATORY MANUAL

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Mc Graw Hill

Biology

Laboratory Manual

Thirteenth Edition

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Preface

We have designed this laboratory manual for an introductory biology course with a broad survey of basic laboratory techniques. The experiments and procedures are simple, safe, easy to perform, and especially appropriate for large classes. Few experiments require more than one class meeting to complete the procedure. Each exercise includes many photographs and illustrations, traditional topics, and experiments that help students *do* biology as they learn about life. Procedures within each exercise are numerous and discrete so that an exercise can be tailored to the needs of the students, the style of the instructor, and the facilities available.

TO THE STUDENT

We hope this manual is an interesting guide to many areas of biology. As you read about these areas, you'll probably spend equal amounts of time observing and experimenting. Don't hesitate to go beyond the observations that we've outlined—your future success as a scientist and an informed citizen depends on your ability to seek and notice things that others may overlook. Now is the time to develop this ability with a mixture of hard work and relaxed observation. Have fun, and learning will come easily. Also, remember that this manual is designed with your instructors in mind as well. Go to them often with questions—their experience is a valuable tool that you should use as you work.

TO THE INSTRUCTOR

This manual's simple, straightforward approach emphasizes experiments and activities that optimize students' investment of time and your investment of supplies, equipment, and preparation. Simple, safe, and straightforward experiments are most effective if you interpret the work in depth. Most experiments can be done easily by a student in 2 to 3 hours. Terminology, structures, photographs, and concepts are limited to those that the student can readily observe and understand. In each exercise we have included a few activities requiring a greater investment of effort if resources are available, but omitting them will not detract from the objectives.

This manual functions best with an instructor's guidance and is not an autotutorial system. We've provided background information for context and understanding, but the focus of each exercise remains on students doing interesting and meaningful activities to learn basic information about biology. We've tried to guide students from observations to conclusions, to help students make their own discoveries, and to make the transition from observation to understanding biological principles. But discussions and interactions between student and instructor are major components of a successful laboratory experience. Be sure to examine the "Questions for Further Study and Inquiry" in each exercise. We hope they will help you expand students' perceptions that each exercise has broad application to their world.

DIGITAL INTEGRATION

Today's students are digital learners, and this lab manual integrates that learning with interesting activities that help students learn about biology. Virtually every exercise of this manual is accompanied by tailor-made digital resources, including assignable questions and a variety of high-definition videos, PowerPoint images, and other resources that demonstrate basic techniques, emphasize biological principles, test for understanding, and engage students as they learn biology in the laboratory.

Digital resources are available to instructors at **connect.mheducation.com.** Instructors will want to assign these resources to help students know what they'll be doing, what principles they'll be investigating, and what concepts they'll need to understand before coming to lab.

WHAT'S NEW IN THIS EDITION

Throughout the manual, we have expanded and improved several of the most popular and effective features of previous editions, including

- **Learning Objectives** have been updated to provide an overview of what students will do and learn in the exercise.
- **Procedures** and **Doing Biology Yourself** require students to *do* biology as they apply skills they've learned to develop and study hypotheses they formulate about biology.
- **Questions** throughout each exercise encourage students to pause and think about their data and what they've learned.
- **Questions for Further Study and Inquiry** at the end of each exercise help students apply what they've learned to broader topics and issues in biology.

- **Writing to Learn Biology** encourages students to use writing to develop their ideas about what they learned in lab.
- **Caution** and **Safety First** icons make students aware of safety issues associated with the procedures they'll use in lab.
- **Boxed readings** titled **Inquiry-Based Learning** encourage students to apply what they've learned to independently answer questions about intriguing biological topics.
- Updated health-related exercises help students better understand how topics such as genetics, cell biology, blood pressure, atherosclerosis, and their risk of cardiovascular disease relate to our health.
- Several illustrations have been replaced with photographs to provide more realistic images to support the Exercise content.
- Approximately 90 illustrations and photos have been revised.
- Questions within procedures now include lines on which students can write their answers.
- An assignable, updated library of videos and Connect questions helps students prepare for lab and understand the instruments and techniques that will be important for their investigations. **Instructors may assign these videos before class time to help ensure that students arrive prepared for lab.**

Exercise-Specific Changes

- Exercise 1—Edited text for improved readability and relevance (e.g., climate change, COVID-19); Improved questions to help students better understand what science is and how science is done
- Exercise 2—Improved the readability of the text and the presentation of metric units; Specified the differences in using a triple-beam balance and an electronic scale; Emphasized the importance of significant figures in measurements; Emphasized that in biology, the mean is usually preferred to the median when reporting descriptive statistics; Added a question about measurements of COVID-19
- Exercise 3—Improved the instructions for how to use a compound light microscope
- Exercise 4—Added an objective for understanding the relative sizes of cells and organelles; Added a boxed insert about surface-area-to-volume ratios in cells; Added a boxed insert about cellular structure and human disease
- Exercise 5—Reorganized and edited the text for increased understanding and readability
- Exercise 6—Replaced figure 6.9 with a better, more informative image; Added a table for students to summarize the biochemical tests they performed in the lab; Added a question to emphasize the significance of acid precipitation; Added a boxed insert about using the iodine test to detect counterfeit money; Added a boxed insert about dietary fats
- Exercise 7—Reorganized the procedures for better use of time in the lab
- Exercise 9—Revised the Introduction and Diffusion sections to emphasize the relevance of osmosis and diffusion to general physiology; Enhanced the safety notice to use appropriate PPE; Added question for problem-solving based on experimental data; Revised captions for figures 9.7 and 9.9 to emphasize the flow of water into and out of cells
- Exercise 10—Revised the Introduction to reinforce understanding of how membranes regulate the movement of materials into and out of cells
- Exercise 12—Replaced figure 12.1 (i.e., rising bread dough) to show the production of carbon dioxide; Edited questions for improved understanding; Updated the terminology for the citric acid cycle
- Exercise 13—Replaced figure 13.1 to emphasize the production of oxygen by photosynthesis; Edited the text for improved readability and understanding; Corrected figure 13.10 for improved entry of data by students
- Exercise 14—Enhanced the readability of the Introduction; Expanded the description of chromatids versus chromosomes; Added new figure 14.6 showing the metaphase plate and chromosomal alignment
- Exercise 15—Revised the Introduction to emphasize the value of genetic recombination for adaptation to changing environments; Revised labels of figure 15.1 to better distinguish maternal homologues from paternal homologues; Revised figure 15.2 to emphasize (1) the replication of chromosomes and (2) the formation of chromatids; Added new figure 15.6 of spermatogenesis to emphasize the steps of maturation from spermatogonium to spermatozoa
- Exercise 16—Updated the information about the use and yield of genetically modified crops; Edited questions to emphasize critical thinking about genetically modified crops
- Exercise 17—Edited the text for improved readability and understanding; Added updates about phenylketonuria, Huntington's disease, and familial hypercholesteremia; Added information and a new image to improve students' understanding of transposons

- Exercise 18—Added an example of calculating Hardy-Weinberg frequencies
- Exercise 19—Revised figure 19.2 to reflect recent discoveries about human evolution; Revised Procedure 19.2 to compare the sizes of brain cases in apes versus humans; Added new figure 19.10 comparing skeletons of humans and chimpanzees
- Exercise 20—Clarified the definitions of soil types; Revised Procedure 20.3 to clarify calculations
- Exercise 21—Edited the objectives for improved understanding
- Exercise 22—Plagues; Added a boxed insert about Population Growth and Our Carbon Footprint; Updated information in the text about population and population growth; Expanded table 22.1 to include 10 generations of bacterial growth; Emphasized and added a question about how population growth affects public health, economic stability, social structure, and the well-being of our environment
- Exercise 23—Edited text to improve readability and accuracy
- Exercise 24—Relabeled figure 24.6 to help students better understand the structure of bacterial cell walls; Replaced figure 24.7 to better show steps of the Gram stain procedure; Revised the description and interpretation of antibiotic effectiveness apparent on bacterial sensitivity plates
- Exercise 25—Enhanced explanations of autotrophic versus heterotrophic protistans; Added new figure 25.1 to distinguish between algae and protozoans; Replaced figure 25.5 to better explain *Chlamydomonas* life cycle; Expanded the explanation of asexual versus sexual reproduction in unicellular algae; Rearranged the descriptions of brown algae and red algae to adhere to current phylogeny based on molecular taxonomic techniques
- Exercise 26—Moved the coverage and procedures about slime molds forward to better reflect current phylogeny; Added new figure 26.8 showing a scanning electron micrograph that emphasizes the cell surface of a ciliate
- Exercise 27—Multiple clarifications of the structures and processes of asexual versus sexual reproduction in fungi; Revised figure 27.1 to highlight aseptate hyphae; Revised figure 27.2 to distinguish between sporangia and sporangiophores; Expanded the coverage of the major phyla of fungi to include phylum Glomeromycota; Added new figure 27.3b to show infection by chytrid fungi; Revised table 27.1 to include description and artwork of key reproductive features of Glomeromycota; Updated figure 27.4 to better illustrate stolons, spores, and sporangiophores of Zygomycota; Expanded explanation of asexual versus sexual reproduction in Zygomycota; Revised figure 27.6b to emphasize distinctions between sexual reproduction and asexual reproduction in bread molds; Expanded descriptions in Procedure 27.3 to help students better interpret conjugation plates of Rhizopus; Revised figure 27.9 to better distinguish between a sporangium and conidiophore; Revised figure 27.13 to better distinguish asexual from sexual reproductive structures and processes; Revised figure 27.15 to emphasize sexual reproduction in mushrooms; Included coverage and new procedures for examining Glomeromycota and other mycorrhizae; Added descriptions and illustrations of mycorrhizae, including arbuscular and ectomycorrhizae forms; Added new figure 27.18e illustrating the structure of a lichen cross section
- Exercise 28—Updated classification information; Replaced figures 28.6 and 28.11 to help students better understand the information
- Exercise 29—Enhanced figures 29.1 and 29.11 for better understanding
- Exercise 30—Edited text for better readability and understanding; Added a question about the distinguishing features of the groups of plants that students examined in this lab
- Exercise 31—Improved table 31.1 and figure 31.5 for better understanding; Improved "Dichotomous Key to Major Types of Fruit"; Replaced figure 31.18 with better, more informative images and information; Added a question to emphasize the differences between monocots and eudicots
- Exercise 32—Edited text for improved readability and understanding; Improved the description of the endodermis and its function; Replaced figure 32.1 to better show the differences in tap versus fibrous root systems; Added scale-markers to figures; Edited the text to better emphasize the differences between gymnosperms and angiosperms; Enhanced figure 32.16 for better understanding; Added a question to emphasize the differences between stomata and lenticels
- Exercise 33—Edited the Introduction for improved understanding; Removed the redundant instruction in Procedure 33.2; Added an alternate procedure for making a leaf-impression for counting and visualizing stomata
- Exercise 34—Emphasized and added a question about how plants, unlike animals, have a small number of growth regulators that influence many traits; Added scale-markers to figures; Added information about the use of 2,4-D; Added information about how gibberellic acid is important for increasing yields and profits for grape growers

- Exercise 35—Added text to improve understanding about bioassays and standard curves; Added a more specific question to the "Inquiry-Based Learning" assignment; Added graph paper for reporting students' results
- Exercise 36—Clarified functional relationships among spicules, spongin fibers, porocytes, and amoebocytes; Expanded the description of water flow through a wall of a sponge as depicted in figure 36.4; Revised figure 36.12 to show the relative size of cnidarian medusae; Revised figure 36.16 to show the relative size of ephyrae; Expanded the description of corals to include information about coral bleaching and coral symbioses with algae
- Exercise 37—Significantly revised the sequence of coverage of invertebrate phyla to adhere to current phylogeny based on molecular taxonomic techniques; Included taxonomic classifications of lophophorazoa and ecdysozoa; Positioned coverage of nematodes to immediately precede coverage of arthropods, as both are now considered ecdysozoans; Mollusk coverage now immediately follows that of flatworms, as they are both considered lophophorazoans; Added new figure 37.3 to illustrate a trochophore larva; Revised table 37.1 to replace nematode descriptions with mollusk descriptions; Replaced figure 37.3 with new art illustrating flatworm anatomy; Replaced figure 38.5 with new art illustrating molluscan radula
- Exercise 38—Coverage of nematodes now follows that of annelids
- Exercise 39—Revised figure 39.16 to clarify position of retinula cells
- Exercise 40—Revised legend of figure 40.18 to better describe the evolution of jaws among fish ancestors; Changed common name of chordate class Actinopterygii from boney fish to ray-finned fish; Added new table 40.3 to provide space for students to organize classes of vertebrates and their major characteristics
- Exercise 41—Revised Procedure 41.1 to emphasize safety when using stains; Revised figure 41.5 to clearly label nuclei of simple columnar epithelial cells; Clarified the varied functions of connective tissues; Expanded Procedure 41.3 to describe the appearance of red blood cells and leukocytes on prepared slides; Included new terminology of central canals in place of Haversian systems of bones
- Exercise 42—Clarified the differences between tendons and ligaments; Added new figure 42.1 to illustrate the parts of the human skeleton; Revised figure 42.2 to include labels of the ileum, ischium, and pubis; Expanded the Questions for Further Study and Inquiry
- Exercise 43—Modified labels of figure 43.2 to show the origin and insertion of triceps brachii
- Exercise 44—Revised figure 44.4 to emphasize how changes of internal air pressure affect the mechanics of breathing; Emphasized the value of measuring lung capacity to understanding respiratory disease; Clarified Procedure 44.2 to better describe the use of a spirometer
- Exercise 45—Expanded the procedure for examining a cow heart to include the use of a heart model; Added a new question to describe heartbeat sounds heard with a stethoscope; Revised figure 45.2 to better show differences in the walls of arteries versus veins; Revised Procedure 45.2 to better describe the steps to measure blood pressure; Added new figure 45.7 to illustrate the anatomy of venous valves; Updated the table for scoring risk factors of cardiovascular disease; Questions for Further Thought and Inquiry now include library research to understand diseases of the heart and circulatory system
- Exercise 46—Quantified differences in retinal resolutions among humans and other animals; Described and distinguished sensorineural versus nerve deafness; Clarified the steps of Procedure 46.8 to better determine nerve deafness; Updated figure 46.6 to show the size of the ear drum; Modified Procedure 46.1 to include safety procedures
- Exercise 47—Expanded Questions for Further Study and Inquiry include an analysis of bipedalism
- Exercise 48—Added new figure 48.7 to include art and a photograph showing the structure of microvilli; Relabeled figure 48.6 to show the common bile duct
- Exercise 49—Added new figure 49.4 to illustrate kidney anatomy with sagittal section
- Exercise 50—Clarified the distinction between an embryo and a zygote; Expanded the description of gray crescent formation; Added new figure 50.5 to illustrate the formation of a gray crescent; Added new figure 50.8 to illustrate differences between the vegetal pole and animal pole; Relabeled figure 50.9 to clearly distinguish the endoderm and mesoderm; Quantified the egg sizes among birds to emphasize variety in egg anatomy; Relabeled figure 50.12 to show albumin
- Exercise 51—Added questions to encourage students to think about agonistic behaviors in humans and why it is important to try to integrate all aspects of an organism's behavior
- Appendix II Updated information about the metric system

Teaching and Learning Tools

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McGraw Hill Connect provides online presentation, assignment, and assessment solutions. It connects your students with the tools and resources they'll need to succeed at **connect.mheducation.com**.

With Connect Biology, you can deliver assignments and quizzes online. A robust set of questions and activities is presented and aligned with this lab manual's learning outcomes. Pre-lab worksheets and Investigation worksheets are also included within Connect. As an instructor, you can edit existing questions and write entirely new questions. Track students' performance—by question, by assignment, or in relation to the class overall—with detailed grade reports. Integrate grade reports easily with Learning Management Systems (LMS), such as Blackboard—and much more.

Virtual Labs and Lab Simulations

While the biological sciences are hands-on disciplines, instructors are now often being asked to deliver some of their lab content online, as full online replacements, supplements to prepare for in-person labs, or make-up labs.

These simulations help each student learn the practical and conceptual skills needed, then check for understanding and provide feedback. With adaptive pre-lab and post-lab assessment available, instructors can customize each assignment.

From the instructor's perspective, these simulations may be used in the lecture environment to help students visualize complex scientific processes, such as DNA technology or Gram staining, while at the same time providing a valuable connection between the lecture and lab environments.

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Laboratory Resource Guide

The *Laboratory Resource Guide* is essential for instructors and laboratory assistants and is available free to adopters of the Laboratory Manual within Connect under the Instructor Resources tab.

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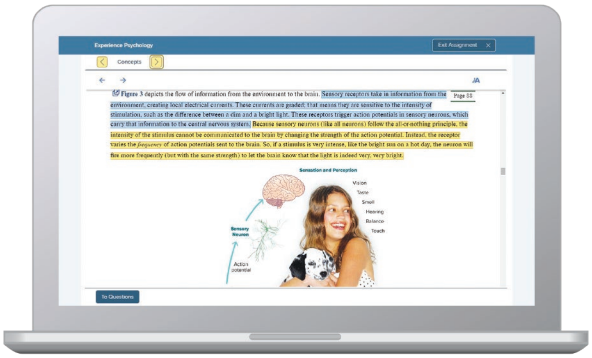

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Welcome to the Biology Laboratory

Welcome to the biology laboratory! Although reading your textbook and attending lectures are important ways of learning about biology, nothing can replace the importance of the laboratory. In lab you'll get hands-on experience with what you've heard and read about biology—for example, you'll observe and manipulate organisms, do experiments, test ideas, collect and organize data, and make conclusions about what you've learned. You'll *do* biology.

You'll enjoy the exercises in this manual—they're interesting and informative and can be completed within the time limits of your laboratory period. We've provided questions to test your understanding of what you've done; in some of the exercises, we've also asked you to devise your own experiments to test hypotheses and answer questions that you've posed. To make these exercises most useful and enjoyable, follow these guidelines noted in the next sections.

THE IMPORTANCE OF COMING TO CLASS

Biology labs are designed to help you experience biology firsthand. To do well in your biology course, you'll need to attend class and pay attention. **Remember this: Attending and being prepared for class are critical for learning about biology and earning a good grade in this course.** To appreciate this, examine figure 1, which is a graph

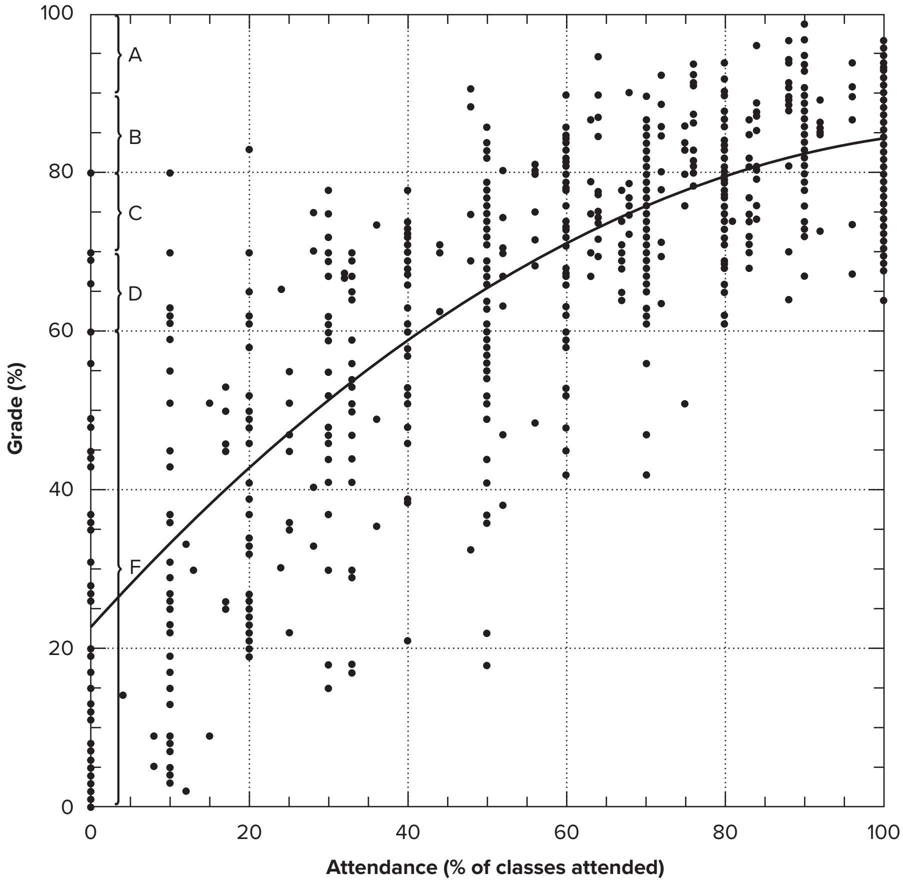

Figure 1 Relationship of students' grades in an introductory biology course to their rates of class attendance.

showing how students' grades in an introductory biology course correlate to their rates of class attendance. Data are from a general biology class at the University of Minnesota. On page xv, write an analysis of the data shown in figure 1. What do these data mean?

BEFORE COMING TO LAB

Watch the lab video. Videos are provided for several of the labs in this manual. Be sure to watch any assigned video associated with the lab you will be completing. These videos will help you know more about what you will be doing, what principles you will be investigating, and what concepts you need to understand before coming to lab.

Read the exercise before coming to lab. This will give you a general idea about what you're going to do, as well as why you're going to do it. Knowing this will not only save time, it will also help you finish the experiments and make you aware of any safety-related issues associated with the lab.

Review any of the lab safety concerns. Before doing any procedures, you'll encounter a section of each exercise titled "SAFETY FIRST" that is marked with its icon:

This icon will warn you of safety concerns (e.g., solvents, acids, bases, hotplates) associated with the work. If you have questions about these safety issues, contact your lab instructor before starting the lab work.

Notify your instructor if you are pregnant, are color-blind, are taking immunosuppressive drugs, have allergies, or have any other conditions that may require precautionary measures. Also, before coming to lab, cover any cuts or scrapes with a sterile, waterproof bandage.

WHEN IN LAB

1. Know what you are going to do. Read and understand the lab before coming to lab.
2. Don't start the exercise until you've discussed the exercise with your laboratory instructor. She or he will give you specific instructions about the lab and tell you how the exercise may have been modified.
3. Work carefully and thoughtfully, and stay focused as you work. You'll be able to finish each exercise within the allotted time if you are prepared and stay on task.
4. Discuss your observations, results, and conclusions with your instructor and lab partners. Perhaps their comments and ideas will help you better understand what you've observed.
5. Always follow instructions and safety guidelines presented by your instructor. Speak up!
6. If you have questions, ask your instructor.

SAFETY IN THE LABORATORY

Laboratory accidents can affect individuals, classes, or the entire campus. To avoid such accidents, the exercises in this manual were designed with safety as a top priority. You'll be warned about any potentially hazardous situations or chemicals with this image:

When you see this image, pay special attention to the instructions.

The laboratory safety rules listed in table 1 will help make lab a safe place for everyone to learn biology. Remember, it is much easier to prevent an accident than to deal with its consequences.

Read the laboratory safety rules listed in table 1. If you do not understand them, or if you have questions, ask your instructor for an explanation. Then complete table 1 and sign the statement at the bottom of page xv.

BEFORE YOU LEAVE LAB

Put away all equipment and glassware, and wipe clean your work area.

AFTER EACH LABORATORY

Soon after each lab, review what you did. What questions did you answer? What data did you gather? What conclusions did you make?

Also note any questions that remain. Try to answer these questions by using your textbook or visiting the library. If you can't answer the questions, discuss them with your instructor.

Welcome to the biology laboratory!

Table 1

Laboratory Safety Rules

Rule	Why is this rule important? What could happen if this rule is not followed?
Behave responsibly. No horseplay or fooling around while in lab.	
Do not bring any food or beverages into lab, and do not eat, drink, smoke, chew gum, chew tobacco, or apply cosmetics when in lab. Never taste anything in lab. Do not put anything in lab into your mouth. Avoid touching your face, chewing on pens, and other similar behaviors while in lab. Always wear shoes in lab.	
Unless you are told otherwise by your instructor, assume that all chemicals and solutions in lab are poisonous, and act accordingly. Never pipette by mouth. Always use a mechanical pipetting device (e.g., a suction bulb) to pipette solutions. Clean up all spills immediately, and report all spills to your instructor.	
Wear safety goggles when working with chemicals. Carefully read the labels on bottles and know the chemical you are dealing with. Do not use chemicals from an unlabeled container, and do not return excess chemicals back to their container. Report all spills to your instructor immediately.	
Unless your instructor tells you to do otherwise, do not pour any solutions down the drain. Dispose of all materials as per instructions from your instructor.	
If you have long hair, tie it back. Don't wear dangling jewelry. If you are using open flames, roll up loose sleeves. Wear contact lenses at your own risk; contacts hold substances against the eye and make it difficult to wash your eyes thoroughly.	
Treat living organisms with care and respect.	
Your instructor will tell you the locations of lab safety equipment, including fire extinguishers, fire blanket, eyewash stations, and emergency showers. Familiarize yourself with the location and operation of this equipment.	
If anything is splashed into your eyes, wash your eyes thoroughly and immediately. Tell your lab instructor what happened.	
Notify your instructor of any allergies to latex, chemicals, stings, or other substances.	
If you break any glassware, do not pick up the pieces of broken glass with your hands. Instead, use a broom and dustpan to gather the broken glass. Ask your instructor how to dispose of the glass.	
Unless told by your instructor to do otherwise, work only during regular, assigned hours when the instructor is present. Do not conduct any unauthorized experiments; for example, do not mix any chemicals without your instructor's approval.	
Do not leave any experiments unattended unless you are authorized by your instructor to do so. If you leave your work area, slide your chair under the lab table. Keep walkways and desktops clean and clear by putting books, backpacks, and so on along the edge of the room, in the hall, in a locker, or in an adjacent room. Keep your work area as clean and uncluttered as possible.	
Don't touch or put anything on the surface of hotplates unless told to do so. Many types of hotplates have no visible sign that they are hot. Assume they are hot.	
Know how to use the equipment in lab. Most of the equipment is expensive; you may be required to pay all or part of its replacement cost. Keep water and solutions away from equipment and electrical outlets. Report malfunctioning equipment to your instructor. Leave equipment in the same place and condition that you found it. If you have any questions about or problems with equipment, contact your instructor.	
Know what to do and whom to contact if there is an emergency. Know the fastest way to get out of the lab. Immediately report all injuries—no matter how minor—to your instructor. Seek medical attention immediately if needed. If any injury appears to be life-threatening, call 911 immediately.	
At the end of each lab, clean your work area, wash your hands thoroughly with soap, slide your chair under the lab table, and return all equipment and supplies to their original locations. Do not remove any chemicals or equipment from the lab.	

Name ____________________________

Lab Section ____________________________

Your lab instructor may require that you submit this page at the end of today's lab.

1. In the space below, write an analysis of the data shown in figure 1.

After completing table 1, read and sign this statement:

2. I have read and I understand and agree to abide by the laboratory safety rules described in this exercise and discussed by my instructor. I know the locations of the safety equipment and materials. If I violate any of the laboratory safety rules, my instructor will lower my grade and/or remove me from the lab.

____

Signature

____

Name (printed)

____

Date

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EXERCISE 1

Scientific Method

The Process of Science

Learning Objectives

By the end of this exercise you should be able to:

1. Define science and understand the logic and sequence of the scientific method.
2. Develop productive observations, questions, and hypotheses about the natural world.
3. Calculate the range, mean, and standard deviation for a set of replicate measurements.
4. Design and conduct a controlled experiment to test a null hypothesis.
5. Understand the difference and connection between a hypothesis and a scientific theory.

Please visit connect.mheducation.com to review online resources tailored to this lab.

The word *science* brings to mind different things to different students. To some students, science is a textbook. To others, it's a microscope, a dissected frog, or a course that you take. In fact, science is none of those things. Some definitions are more useful than others, but for biological research a good definition of **science** is *the orderly process of posing and answering questions about the natural world through repeated and unbiased experiments and observations*. This definition emphasizes that science is a process rather than a book, course, or list of facts. Science is not a "thing." It's a way of thinking about and doing things—a powerful way of learning and knowing about the natural world (fig. 1.1). Science has helped us understand phenomena such as climate change and the coronavirus 2019 (COVID-19) pandemic, produce antibiotics and other drugs, and improve our lives in many, many ways.

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Figure 1.1 Science is a process of learning about the natural world. Doing experiments that involve gathering repeated and unbiased measurements (data) is at the heart of testing hypotheses and answering questions.

Our definition also emphasizes that people do science by *asking questions* and then *doing experiments* to answer those questions. Questions and curiosity are part of human nature, and science is a human activity. Like any human task, it takes practice to do science effectively.

Finally, our definition emphasizes that science is a tool for learning about the *natural world*. It is ineffective for moral choices, ethical dilemmas, and untestable ideas. For example, the scientific method cannot tell us if pollution is good or bad. It can tell us the environmental *consequences* of pollution, but whether these consequences are "good" or "bad" is a judgment that we make based on our values or goals, not on science. Although this is an important limitation of the scientific method, science remains one of the most powerful ways of understanding our world.

Question 1

What practices besides science are used among world cultures to learn about the natural world?

The questioning and testing inherent in science systematically sift through natural variation to find underlying patterns. The natural world includes much variation, and learning biology would be relatively easy if simple observations accurately revealed patterns of the natural world. But they usually don't—nature is too complicated to rely solely on simple observation. We can certainly learn much about our environment just by looking around us, but casual observations are often biased and misleading because nature varies from time to time and from organism to organism. Biologists need a structured and repeatable process for testing their ideas about the variation in nature. Science is that process.

Question 2

What factors might be responsible for variation in measurements of traits such as the heights of 10-year-old pine trees or the kidney filtration rates of 10 replicate lab-mice?

The process of science deals with variation primarily through an organized sequence of steps that maintains as much objectivity and repeatability as possible. Although these loosely organized steps, sometimes called the **scientific method,** vary from situation to situation, they are remarkably effective for research and problem solving. The typical steps in the process of science are:

- Make insightful observations
- Pose and clarify testable questions
- Formulate hypotheses
- Do experiments to gather data
- Quantify the data
- Test the hypotheses
- Refine hypotheses and retest
- Answer the questions and make conclusions

DEVELOPMENT OF OBSERVATIONS, QUESTIONS, AND HYPOTHESES

Make Insightful Observations

Good scientists make insightful observations. But that's not as easy as it seems. Consider these two observations:

Observation 1: There are fewer elk in Yellowstone National Park than there used to be.

Observation 2: The density of elk in Yellowstone National Park has declined during the consecutive dry years since the reintroduction of the native wolf population.

Which of these two observations is stronger and more useful? Both of them may be true, but the second one is much more insightful because it provides a context to the observation that the elk population is declining. It also suggests a relevant factor—that is, the reintroduction of the wolf population—as a productive topic for investigation. It also suggests a relationship between density of the elk population and the variation in the local environment.

Procedure 1.1 **Make insightful observations**

1. Consider the following two observations.

Observation 1: Fungi often grow on leftover food.

Observation 2: Fungi such as mold and yeast grow more on leftover bread than on leftover meat.

Which of the above observations is more useful for further investigation? Why? ____________________

____

____

SAFETY FIRST Before coming to lab, you were asked to read this exercise so you would know what to do and be aware of safety issues. Briefly list the safety issues associated with today's procedures. If you have questions about these issues, contact your laboratory assistant before starting work.

Record the more insightful of the two observations on Worksheet 1 on page 9.

2. Consider this observation: Pillbugs (sometimes called roly-poly bugs) often find food and shelter where fungi are decomposing leaf litter (fig. 1.2).

For this example we are interested in whether pillbugs are attracted to leaves or to fungi (including yeasts) growing on the leaves' surfaces.

Observation 1: Pillbugs often hide under things.

Propose a more productive observation.

Observation 2: ______________________________

____

Record Observation 2 on Worksheet 2 on page 10. You may revise this later.

Pose and Clarify Testable Questions

Productive observations inspire questions. Humans think in terms of questions rather than abstract hypotheses or numbers. But phrasing a good question takes practice and experience, and the first questions that capture our attention are usually general. For example, "Which nutrients can yeast most readily metabolize?" is a general question that expands the observation posed in procedure 1.1. This question is broadly applicable and is the type of question that we ultimately want to understand. Enter this as the General Question in Worksheet 1.

Broad questions are important, but their generality often makes them somewhat vague. The best questions for the process of science are specific enough to answer clearly. Therefore, scientists usually refine and subdivide broad questions into more specific ones. For example, a more specific question is "What classes of biological molecules are most readily absorbed and metabolized by yeast?" Enter this as Specific Question 1 in Worksheet 1.

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Figure 1.2 Pillbugs are excellent experimental organisms to test hypotheses about microenvironments, such as those under logs and within leaf litter. Pillbugs are readily available and easily cultured in the lab (10×).

A further clarification might be "Does yeast absorb and metabolize carbohydrates better than it absorbs and metabolizes proteins?" This is a good, specific question because it clearly refers to organisms, processes, and variables that are likely involved. It also suggests a path for investigation—that is, it suggests an experiment. Enter this as Specific Question 2 in Worksheet 1.

Question 3

Consider the questions "What color is your roommate's car?" and "How many legs do cats have?" To answer these questions, would you use the scientific method, or would you rely on observation? Why?

Procedure 1.2 **Posing and refining questions**

1. Examine the following two questions.

Question 1: Do songbird populations respond to the weather?

Question 2: Do songbirds sing more often in warm weather than in cold weather?

Which of those questions is more useful for further investigation? Why? ___________________________

____

____

____

2. Examine the following general question, and record it in Worksheet 2.

General Question: What influences the distribution of pillbugs?

Propose a specific question that refers to the food of pillbugs as a variable, and record it here and in Worksheet 2. Know that you may revise this later.

Specific Question 1 ___________________________

____

Propose a more specific question that refers to pillbugs eating leaves, as opposed to pillbugs eating fungi growing on leaves. Record this question here and in Worksheet 2. Know that you may revise this later.

Specific Question 2 ___________________________

____

Formulate Hypotheses

Well-organized experiments to answer questions require that questions be restated as testable hypotheses. A **hypothesis** is a statement that clearly states the relationship between biological variables. A good hypothesis identifies the organism or process being investigated, identifies the variables being recorded, and implies how the variables will be compared. A hypothesis is a statement rather than a question, and an analysis of your experimental data will ultimately determine whether you accept or reject your hypothesis. Remember that even though a hypothesis can be falsified, it can never be proved true.

Accepting or rejecting a hypothesis, with no middle ground, may seem like a rather coarse way to deal with questions about subtle and varying natural processes. But using controlled experiments to either accept or reject a hypothesis is effective. The heart of science is gathering and analyzing experimental data that lead to rejecting or accepting hypotheses relevant to the questions we want to answer.

In this exercise, you are going to do science as you investigate yeast nutrition and then experiment with food choice by pillbugs. As yeast ferments its food, CO_2 is produced as a by-product. Therefore, we can measure the growth of yeast by measuring the production of CO_2 (fig. 1.3).

A hypothesis related to our question about the growth of yeast might be:

H_0: CO_2 production by yeast fed sugar is not significantly different from the CO_2 production by yeast fed protein.

A related alternative hypothesis can be similarly stated:

H_a: Yeast produces more CO_2 when fed sugar than when fed protein.

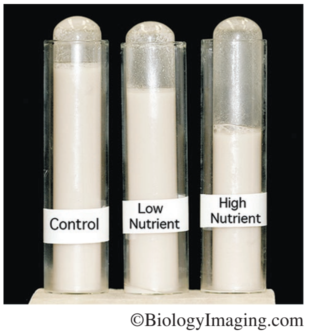

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Figure 1.3 These tubes of yeast are fermenting nutrients provided in solution. The CO_2 produced by the yeast accumulates at the top of the test tubes and indicates that yeast's rate of metabolism. From left to right, the tubes include a control with no added nutrients, a tube with low nutrients, and a tube with high nutrients.

The first hypothesis (H_0) is a **null hypothesis** because it states that there is *no difference*. This is the most common way to state a clear and testable hypothesis. (Your instructor may elaborate on why researchers state and test null hypotheses more effectively than alternative hypotheses.) Researchers usually find it more useful to associate statistical probabilities with null hypotheses rather than with alternative hypotheses. Enter the null hypothesis into Worksheet 1.

A well-written null hypothesis is useful because it is testable. In our experiment, the null hypothesis (1) specifies yeast as the organism, population, or group that we want to learn about; (2) identifies CO_2 production as the variable being measured; and (3) leads directly to an experiment to evaluate variables and compare means of replicated measurements.

Procedure 1.3 Formulating hypotheses

1. Examine the following two hypotheses:

   Hypothesis 1: Songbirds sing more when the weather is warm.

   Hypothesis 2: The number of bird songs heard per hour during daylight temperatures above 80°F (27°C) is not significantly different from the number heard per hour at temperatures below 80°F (27°C).

   Which of these hypotheses is more useful for further investigation? Why? ______________________

   ____

   Which of these hypotheses is a null hypothesis? Why?

   ____

2. Examine the following hypothesis.

   Hypothesis 1: Pillbugs prefer leaves coated with a thin layer of yeast.

   Propose a more effective null hypothesis. Be sure that it is a null hypothesis, that it is testable, and that it includes the parameter you will control in an experiment.

   Hypothesis 2 (H_0): ______________________

   ____

   Enter your null hypothesis in Worksheet 2.

EXPERIMENTATION AND DATA ANALYSIS: YEAST NUTRITION

Gather Experimental Data

To test our hypothesis about yeast growth, we must design a controlled and repeatable experiment. The experiment suggested by our specific question and hypothesis involves offering sugar such as glucose to one population of yeast, offering protein to another population of yeast, and then measuring their respective growth rates. Fortunately, yeast grows readily in test tubes. As yeast grows in a closed, anaerobic container, it produces CO_2 in proportion to how readily it uses the available food. CO_2 production is easily measured by determining the volume of CO_2 that accumulates at the top of an inverted test tube (fig. 1.3).

Experiments provide data that determine if a hypothesis should be accepted or rejected. A well-designed experiment links a biological response to different levels of the variable being investigated. In this case, the biological response is CO_2 production, which indicates growth. The levels of the variable are sugar and protein. These levels are called **treatments,** and in our experiment they include glucose, protein, and a control. For this experiment the **treatment** (i.e., independent) **variable** being tested is the type of food molecule (i.e., protein, sugar), and the **response** (i.e., dependent) **variable** is the CO_2 production that indicates yeast growth.

An experiment that compensates for natural variation must be well designed. It should (1) include replications, (2) test only one treatment variable, and (3) include controls. **Replications** are repeated measures of each treatment under the same conditions. Replications effectively deal with naturally occurring variation. Usually the more replications, the better. Your first experiment today will include replicate test tubes of yeast, each being treated the same. Good design tests only one treatment variable at a time.

Good experimental design also requires **controls** to verify that the biological response we measure is a function of the variable being investigated and nothing else. Controls are standards for comparison. They are replicates with all of the conditions of an experimental treatment *except the treatment variable*. For example, if the treatment is glucose dissolved in water, then a control has only water (i.e., it lacks only glucose, the treatment variable). This verifies that the response is to glucose and not to the solvent. Controls validate that our results are due only to the treatment variable.

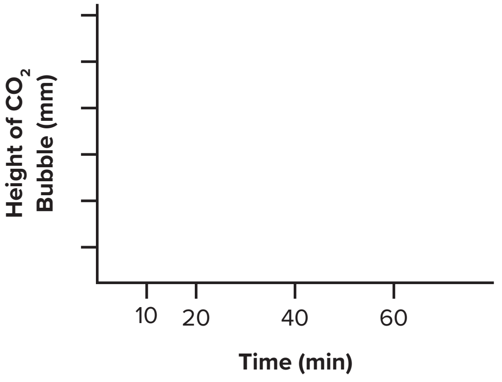
Procedure 1.4 An experiment to determine the effects of food type on yeast growth

1. Label 12 test tubes as C1–C4, G1–G4, and P1–P4. See Worksheet 1.
2. To test tubes C1–C4 add 5 mL of water. These are control replicates.
3. To test tubes G1–G4 add 5 mL of 5% glucose solution. These are replicates of the glucose treatment.
4. To test tubes P1–P4 add 5 mL of 5% protein solution. These are replicates of the protein treatment.
5. Swirl the suspension of yeast until the yeast is distributed uniformly in the liquid. Then completely fill the remaining volume in each tube with the yeast suspension that is provided.
6. For each tube, slide an inverted, flat-bottomed test tube down over the yeast-filled tube. Hold the yeast-filled tube

firmly against the inside bottom of the cover tube and invert the assembly. Your instructor will demonstrate how to slip this slightly larger empty tube over the top of each yeast tube and invert the assembly. If done properly, no bubble of air will be trapped at the top of the tube of yeast after inversion.

7. Place the tubes in a rack and incubate them at 50°C.

8. Measure the height (mm) of the bubble of accumulated CO_2 after 10, 20, 40, and 60 minutes. Record your results in Worksheet 1 and graph them here:



9. When you are finished, clean your work area and dispose of the contents of each tube as instructed by your lab instructor.

Test Your Predictions by Analyzing the Experimental Data

Analysis begins with summarizing the raw data for biological responses to each treatment. The first calculation is the **mean** ($\bar{x}$), which is the average of a set of numbers (e.g., measurements) for replicates of each treatment and the control. That is, the mean is a single number that represents the central tendency of the response variable. Later the mean of each treatment will be compared to determine if the treatments had different effects.

The second step in data analysis is to calculate variation within each set of replicates. The simplest measure of variation is the **range,** which is the highest and lowest values in a set of replicates. A wide range indicates much variation in the data. The **standard deviation (SD),** another informative measure of variation, summarizes variation just as the range does, but the standard deviation is less affected by extreme values. Refer to the box "Variation in Replicate Measures" to learn how to calculate the standard deviation.

Question 4

Even the seemingly simple question "How tall are mature males of the human species?" can be difficult to answer. How would you best express the answer?

Procedure 1.5 **Quantify and summarize the data**

1. Examine your raw data in Worksheet 1.

2. Calculate the mean of the response variable (CO_2 production) for the four control replicates. To calculate the means for the four replicates, sum the four values and divide by four. Record the mean for the control replicates in Worksheet 1.

3. The CO_2 production for each glucose and protein replicate must be adjusted with the control mean. This ensures that the final data reflect the effects of only the treatment variable and not the solvent. Subtract the control mean from the CO_2 production of each glucose replicate and each protein replicate, and record the results in Worksheet 1.

4. Record in Worksheet 1 the range of adjusted CO_2 production for the four replicates of the glucose treatment and of the protein treatment.

5. Calculate the mean CO_2 production for the four adjusted glucose treatment replicates. Record the mean in Worksheet 1.

6. Calculate the mean CO_2 production for the four adjusted protein treatment replicates. Record the mean in Worksheet 1.

7. Refer to "Variation in Replicate Measures," and calculate the standard deviation for the four adjusted glucose treatment values and for the four adjusted protein treatment values. Record the two standard deviations in Worksheet 1.

Test the Hypotheses

Our hypothesis about yeast growth is tested by comparing the mean CO_2 production by yeast fed glucose to the mean CO_2 production by yeast fed protein. However, only determining if one mean is higher than the other is not an adequate test because natural variation will always make the two means at least slightly different, even if the two treatments have the same effect on yeast growth. Therefore, the means and the variation about the means must be compared to determine if the means are not just different but **significantly different.** To be significantly different, the differences between means must be due to the treatment and not just due to natural variation. If the difference is significant, then the null hypothesis is rejected. If the difference is not significant, then the null hypothesis is accepted. Testing for significant differences is usually done with statistical methods.

Statistical methods calculate the probability that the means are significantly different. But these complex calculations are beyond the scope of this exercise. We will use a simpler method to test for a significant difference between the means of our two treatments. We will declare that two means are significantly different *if the means plus or minus 1/2 of the standard deviation do not overlap.*

Variation in Replicate Measures

Natural variation occurs in all processes of biology. This variation will inevitably produce different results in replicated treatments. One of the most useful measures of variation of values about the mean is **standard deviation.** It's easy to calculate: calculate the mean, calculate the deviation of each sample from the mean, square each deviation, and then sum the deviations. This summation is the sum of squared deviations. For example, data for CO_2 production by yeast in four replicate test tubes might be 22, 19, 18, and 21 mm. The mean is 20 mm.

CO_2 Production (mm)	Mean	Deviation	Deviation^2
22	20	2	4
19	20	−1	1
18	20	−2	4
21	20	1	1
			Sum of squared deviations = 10

The summary equation for the sum of squared deviations is

$$\textbf{Sum of squared deviations} = \sum_{i=1}^{N}(x_i - \bar{x})^2$$

where

N = **total number of samples**

$\bar{x}$ = **the sample mean**

x_i = **measurement of an individual sample**

The summation sign ($\sum_{i=1}^{N}$) means to add up all the squared deviations from the first one ($i = 1$) to the last one ($i = N$).

The sum of squared deviations (10) divided by the number of samples minus one (4 − 1 = 3) produces a value of 10/3 = 3.3 mm^2 (the units are millimeters squared). This is the variance:

$$\textbf{Variance} = \frac{\textbf{sum of squared deviations}}{N - 1}$$

The square root of the variance, 1.8 cm, equals the standard deviation

$$\textbf{SD} = \sqrt{\textbf{Variance}} = \sqrt{3.3} = 1.8$$

The standard deviation is often reported with the mean in statements such as, "The mean CO_2 production was 20 ± 1.8 mm." The standard deviation helps us understand the spread or variation among replicated treatments. For example, if the standard deviation is zero, all of the numbers in the set are the same. A larger standard deviation implies that individual numbers are farther from the mean.

For example, consider these two means and their standard deviations (SD):

$Mean_a = 10$ SD = 5 $Mean_b = 20$ SD = 10

$Mean_a - (½)SD = 7.5$ $Mean_b - (½)SD = 15$

$Mean_a + (½)SD = 12.5$ $Mean_b + (½)SD = 25$

Are $Mean_a$ and $Mean_b$ significantly different according to our test for significance? Yes they are, because 7.5 ↔ 12.5 does not overlap 15 ↔ 25.

Procedure 1.6 Testing hypotheses

1. Consider your null hypothesis and the data presented in Worksheet 1.
2. Calculate the glucose mean − (½)SD and the glucose mean + (½)SD. Record them in Worksheet 1.
3. Calculate the protein mean − (½)SD and the protein mean + (½)SD. Record them in Worksheet 1.
4. Do the half standard deviations surrounding the means of the two treatments overlap? Record your answer in Worksheet 1.
5. Are the means for the two treatments significantly different? Record your answer in Worksheet 1.
6. Is your null hypothesis accepted? Or rejected? Record your answer in Worksheet 1.

Answer the Questions

The results of testing the hypotheses are informative, but it still takes a biologist with good logic to translate these results into the answers of our specific and general questions. If your specific questions were well stated, then answering them based on the results of your experiment and hypothesis testing should be straightforward.

Procedure 1.7 Answering the questions: yeast nutrition

1. Examine the results of hypothesis testing presented in Worksheet 1.
2. Specific Question 2 was "Does yeast absorb and metabolize carbohydrates better than it absorbs and metabolizes proteins?" Enter your answer in Worksheet 1.
3. Does your experiment adequately answer this question? Why or why not? ______________________

   ____

   ____
4. Specific Question 1 was "What classes of biological molecules are most readily absorbed and metabolized by yeast?" Enter your best response in Worksheet 1.

5. Does your experiment adequately answer Specific Question 1? Why or why not? ____________________

____

____

6. The General Question was "Which nutrients can yeast most readily metabolize?" After testing the hypotheses, are you now prepared to answer this general question? Why or why not? ____________________

____

____

EXPERIMENTATION AND DATA ANALYSIS: FOOD PREFERENCE BY PILLBUGS

In the previous procedures you developed and recorded observations, questions, and hypotheses concerning food preference by pillbugs. Pillbugs may be attracted to dead leaves as food, or they may be attracted to fungi growing on the leaves as food. Leaves dipped in a yeast suspension can simulate fungi growing on leaves. Use the following procedures as a guide to the science of experimentation and data analysis to test the hypothesis you recorded in Worksheet 2.

Procedure 1.8 Design an experiment to test food preference by pillbugs

1. Design an experiment to test your hypothesis in Worksheet 2 about food preference by pillbugs. To do this, specify:

   Experimental setup ____________________

   ____

   Treatment 1 to be tested ____________________

   ____

   Treatment 2 to be tested ____________________

   ____

   Control treatment ____________________

   ____

   Response variable ____________________

   ____

   Treatment variable ____________________

   ____

   Number of replicates ____________________

   ____

   Means to be compared ____________________

   ____

2. Conduct your experiment and record the data in Worksheet 2.
3. Analyze your data. Record the control means and adjusted treatment-means in Worksheet 2.
4. Calculate the range and standard deviation for your treatments, and record them in Worksheet 2.
5. Test your hypothesis. Determine if the null hypothesis should be accepted or rejected. Record the results in Worksheet 2.
6. Answer the Specific Question 2, Specific Question 1, and General Question posed in Worksheet 2.

Procedure 1.9 Answering the questions: food preference by pillbugs

1. Examine the results of your hypothesis testing presented in Worksheet 2.
2. Enter your answer to Specific Question 2 in Worksheet 2. Does your experiment adequately answer this question? Why or why not? ____________

   ____

   ____

3. Enter your best response to Specific Question 1 in Worksheet 2. Does your experiment adequately answer this question? Why or why not? ____________

   ____

   ____

4. After testing the hypotheses, are you now prepared to answer your General Question "What influences the distribution of pillbugs?" Why or why not? ________

   ____

   ____

Question 5
What are some examples of biological theories?

Scientific Theories

Throughout this course you will make many predictions and observations about biology. When you account for a group of these observations with a generalized explanation, you have proposed a scientific theory.

In science, as opposed to common usage, a theory is a well-substantiated explanation of some aspect of the natural world that usually incorporates many confirmed observational and experimental facts. A scientific theory makes predictions consistent with what we see. It is not a guess; on the contrary, a scientific theory is widely accepted within the scientific community—for example, the germ theory claims that certain infectious diseases are caused by microorganisms. Scientific theories do not become facts; scientific theories *explain* facts.

INQUIRY-BASED LEARNING

How do changes in temperature affect the production of CO_2 by yeast?

Observation: Fermentation of nutrients by yeast produces CO_2, and the production rate of this CO_2 can be used to measure growth of the yeast. In this lab you've already investigated how the production of CO_2 is affected by different nutrients (i.e., sugar, protein). Here you'll investigate another variable: temperature.

Question: How is the production of CO_2 by yeast affected by temperature?

a. Establish a working lab group and obtain Inquiry-Based Learning Worksheet 1 from your instructor.

b. Discuss with your group well-defined questions relevant to the preceding observation and question. Choose and record your group's best question for investigation.

c. Translate your question into a testable hypothesis. Record this hypothesis.

d. Outline on Worksheet 1 your experimental design and supplies needed to test your hypothesis. Ask your instructor to review your proposed investigation.

e. Conduct your procedures, record your data, answer your question, and make relevant comments.

f. Discuss with your instructor any revisions to your questions, hypothesis, or procedures. Repeat your work as needed.

Questions for Further Study and Inquiry

1. Consider the traits of science. Newspaper articles often refer to a discovery as "scientific" or claim that something has been proved "scientifically." What is meant by this description?

2. Experimental results in science are usually reviewed by other scientists before they are published. Why is this done?

3. Have all of our discoveries and understandings about the natural world been the result of testing hypotheses and applying the scientific method? How so?

4. Suppose that you hear that two means are *significantly* different. What does this mean? Can means be different but not significantly different? Explain your answer.

5. Why do scientists refrain from saying, "These results prove that . . ."?

6. How can science be used to address "big" issues such as climate change and COVID-19?

7. Some people dismiss evolution by natural selection as being "only a theory." Biologists often respond that yes, evolution *is* a scientific theory. What does this mean?

8. A hallmark of a scientific theory is that it is falsifiable. What does this mean, and why is it important?

9. Why is there no role for superstition in science?

Worksheet 1 The Process of Science: Nutrient Use by Yeast

OBSERVATION ______________________________

QUESTIONS

General Question: ______________________________

Specific Question 1: ______________________________

Specific Question 2: ______________________________

HYPOTHESIS H_0: ______________________________

EXPERIMENTAL DATA: Nutrient Use by Yeast

Treatments						Treatments Minus Control $\bar{x}$	
Replicate	**Control CO_2 Production (mm)**	**Replicate**	**Glucose CO_2 Production (mm)**	**Replicate**	**Protein CO_2 Production (mm)**	**Glucose CO_2 Production Adjusted for the Control $\bar{x}$**	**Protein CO_2 Production Adjusted for the Control $\bar{x}$**
C1	______	G1	______	P1	______	______	______
C2	______	G2	______	P2	______	______	______
C3	______	G3	______	P3	______	______	______
C4	______	G4	______	P4	______	______	______

Control $\bar{x}$ = ______

Glucose $\bar{x}$ = ______

Glucose range = ______ – ______

Glucose SD = ______

Protein $\bar{x}$ = ______

Protein range = ______ – ______

Protein SD = ______

TEST HYPOTHESIS

Glucose $\bar{x}$ − (½)SD = ______

Glucose $\bar{x}$ + (½)SD = ______

Protein $\bar{x}$ − (½)SD = ______

Protein $\bar{x}$ + (½)SD = ______

Do the half standard deviations surrounding the means of the two treatments overlap? Yes ______ No ______

Are the means for the two treatments significantly different? Yes ______ No ______

Is the null hypothesis accepted? ______ or rejected? ______

ANSWER QUESTIONS

Answer to Specific Question 2 ______________________________

Answer to Specific Question 1 ______________________________

Answer to General Question ______________________________