BIOLOGY

Laboratory Manual

Eleventh Edition

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McGraw Hill Education

Biology

Laboratory Manual

eleventh edition

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BIOLOGY LABORATORY MANUAL, ELEVENTH EDITION

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Some of the laboratory experiments included in this text may be hazardous if materials are handled improperly or if procedures are conducted incorrectly. Safety precautions are necessary when you are working with chemicals, glass test tubes, hot water baths, sharp instruments, and the like, or for any procedures that generally require caution. Your school may have set regulations regarding safety procedures that your instructor will explain to you. Should you have any problems with materials or procedures, please ask your instructor for help.

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Contents

Indicates a *LearnSmart Lab*® activity is available for all or part of this exercise. For more information, visit www.learnsmartadvantage.com.

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, traditional topics, and experiments that help students 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 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 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 Thought and Study" in each exercise. We hope they will help you expand students' perceptions that each exercise has broad application to their world.

KEY UPDATES TO THE 11TH EDITION

DIGITAL INTEGRATION

As educators, we recognize that today's students are digital learners. Therefore, a significant feature of this edition is the integration of various digital resources into the content of the exercises. Virtually every exercise of this manual is now accompanied by tailor-made digital resources. Rather than generic images from Internet sources, we have produced 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. For this edition, we have included numerous new videos.

All digital resources can be found at **connect.mheducation.com.** Students will enjoy viewing these presentations, and 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.

EXERCISE UPDATES

Updates and changes include:

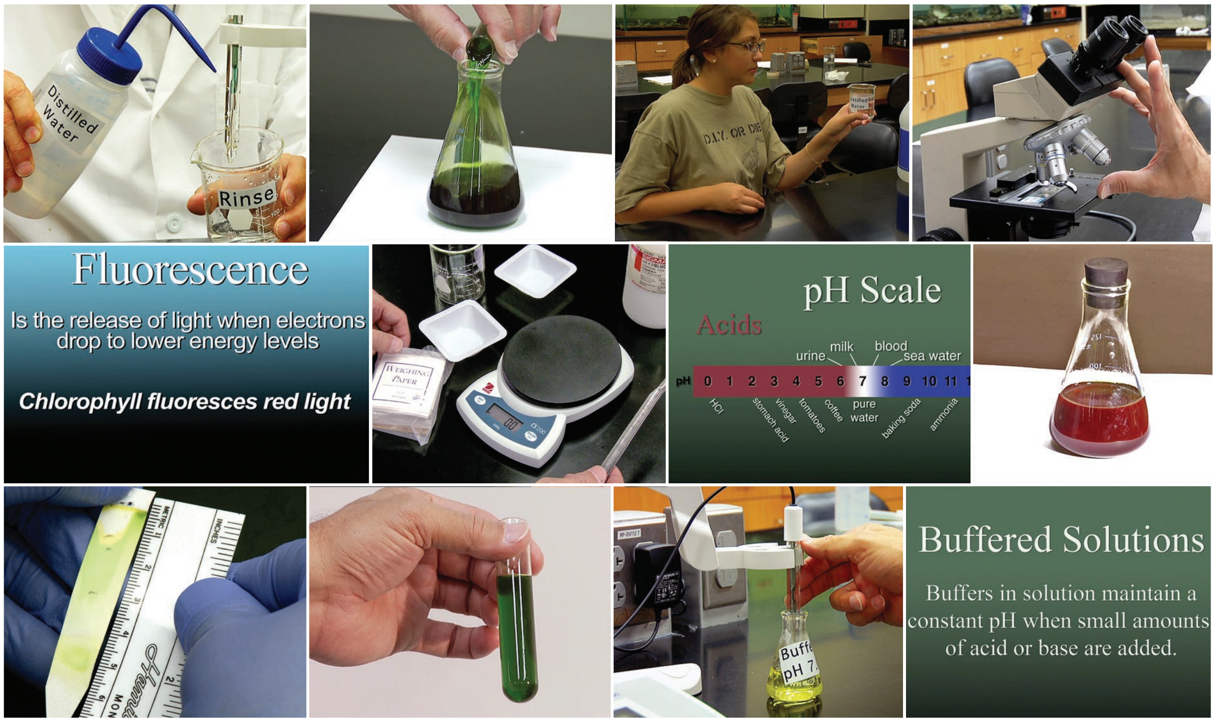
- Yellow highlighting is placed throughout the manual to indicate, at a glance, all laboratory actions expected of the students.
- Many procedures are revised to help clarify steps and outline what needs to be done.
- An extensive number of photographs are added or changed to improve your understanding and provide a visual of what you will see.
- Additional art is added to help illustrate concepts, procedures, and results.
- New boxed inserts highlight the relationships of biological processes with health care.

As you examine this manual, you'll see that we've improved several of the most popular and effective features of previous editions:

- **Safety First** and **Caution** icons remind you to read the manual to ensure that you are aware of safety issues associated with the exercises.

- **Learning Objectives** will give you an overview of what you will do and learn in the exercise.
- **Writing to Learn Biology** will encourage you to expand on what you have done and learned.
- **Investigations, Procedures,** and **Doing Biology Yourself** will require you to *do* biology and apply skills you've learned to develop and answer your own questions about biology.
- **Questions** throughout each exercise will encourage you to integrate and reflect on what you've done and learned.
- **Questions for Further Thought and Study** at the end of each exercise will help you apply what you've learned to other topics.

As noted previously, we have also tailored a variety of videos and other visual materials to help you succeed in the laboratory. You'll learn from a growing library of high-quality videos that demonstrate basic laboratory techniques. You'll observe these techniques in action before you polish your own skills in the laboratory.



Teaching and Learning Tools

McGraw-Hill Connect® Biology

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With Connect Biology, you can deliver assignments, quizzes, and tests online. A robust set of questions and activities are presented and aligned with the textbook'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 problems. Track students' performance—by question, 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.

LearnSmart Labs®

Based on the same adaptive technology as LearnSmart, LearnSmart Labs is an outcomes-based lab simulation that assesses a student's knowledge and adaptively corrects deficiencies, allowing the student to learn faster and retain more knowledge with greater success.

First, a student's knowledge is focused on core learning outcomes: Questioning reveals knowledge deficiencies that are corrected by the delivery of content that is conditional on a student's response. Then, a simulated lab experience requires the student to think and act like a scientist: Recording, interpreting, and analyzing data using simulated equipment found in labs and clinics. The student is allowed to make mistakes—a powerful part of the learning experience! A virtual coach provides subtle hints when needed, asks questions about the student's choices, and allows the student to reflect upon and correct those mistakes. Whether your need is to overcome the logistical challenges of a traditional lab, provide better lab prep, improve student performance, or make your online experience one that rivals the real world, LearnSmart Labs accomplishes it all. To learn more, visit **www.learnsmartadvantage.com**.

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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.

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 organisms, do experiments, test ideas, collect data, and make conclusions about what you've learned. You'll do biology.

You'll enjoy the exercises in this manual—they're interesting, 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 answer questions that you've posed. To make these exercises most useful and enjoyable, follow these guidelines:

THE IMPORTANCE OF COMING TO CLASS

Biology labs are designed to help you experience biology first-hand. To do that, you must attend class. If you want to do well in your biology course, you'll need to attend class and pay attention. To appreciate the importance of class attendance for making a good grade in your biology course, examine figure 1, which is a graph showing how students'

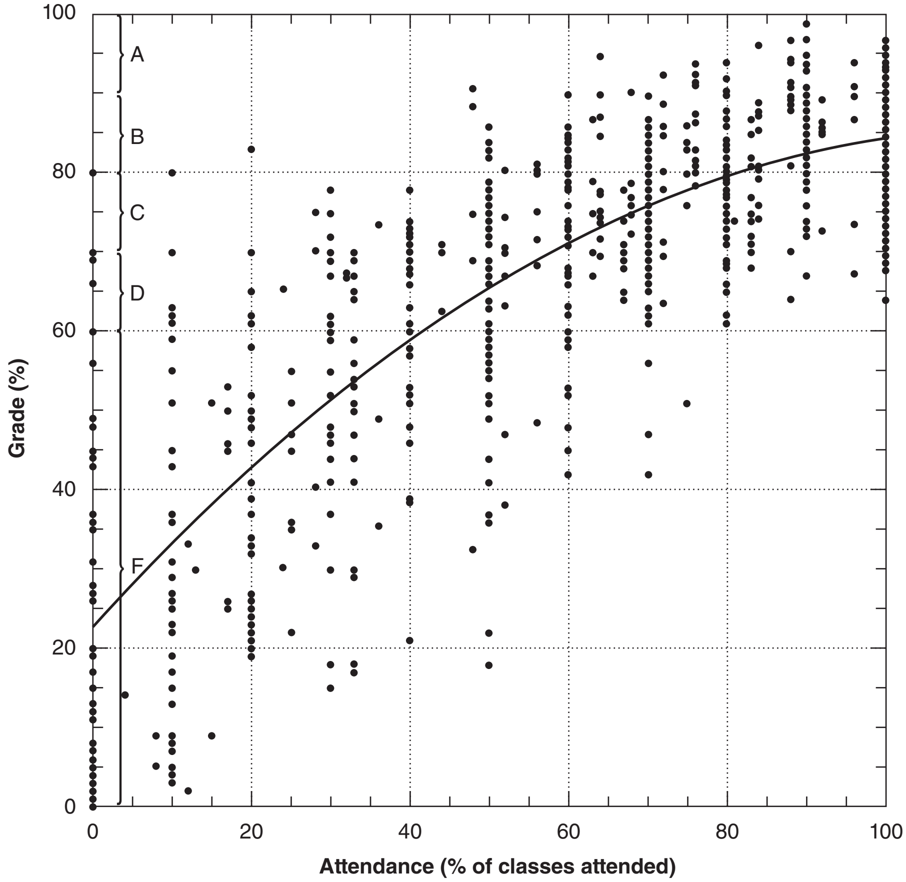

Figure 1 How students' grades in an introductory biology course relate to their rates of class attendance.

grades in an introductory biology course relate to their rates of class attendance. Data are from a general biology class at the University of Minnesota. On page xii, 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 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, color-blind, 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 well prepared and stay busy. You'll not be able to finish the exercise if you spend your time talking about this weekend's party or last week's big game.
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 follow safety guidelines presented by your instructor.
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 that is at the bottom of page xii.

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.	

Table 1

Laboratory Safety Rules (continued)

Rule	Why is this rule important? What could happen if this rule is not followed?
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

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 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 way of learning and knowing about the natural world (fig. 1.1).

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.

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.

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 re-test
- 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 the strongest and most 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 introduction 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 the most 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 most 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.

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×).

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.

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 the most 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 ____________________________

____

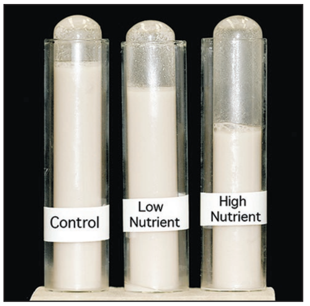

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Figure 1.3 These tubes of yeast are fermenting nutrients provided in solution. The CO_2 produced by the yeast accumulates at the top of the test tubes and indicates that yeast's rate of metabolism. From left to right, the tubes include a control with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

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 leads 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.

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 the most 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.

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 indicating 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.

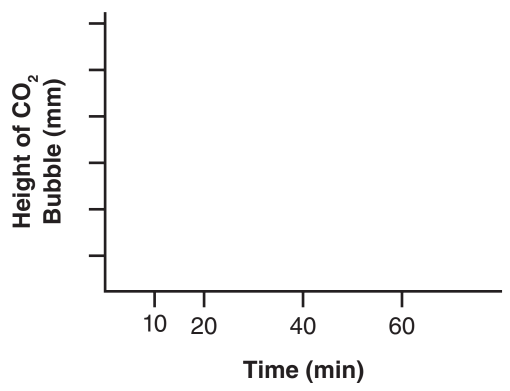
An experiment that compensates for natural variation must be well designed. It should (1) include replications, (2) test only one treatment variable, and (3) include controls.

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** $(\bar{x})$ of the response variable for replicates of each treatment, and for the control replicates. 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.

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

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

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.

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*.

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 the 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.

INVESTIGATION

How Temperature Affects 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 Investigation 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 Thought and Study

1. 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 applying the scientific method? How so?

4. Suppose that you hear that two means are *significantly* different. What does this mean?

5. Can means be different but not significantly different? Explain your answer.

6. How can science be used to address “big” issues such as climate change?

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?

Worksheet 1 The Process of Science: Nutrient Use in Yeast

OBSERVATION ______________________________

QUESTIONS

General Question: ______________________________

Specific Question 1: ______________________________

Specific Question 2: ______________________________

HYPOTHESIS H_0: ______________________________

EXPERIMENTAL DATA: Nutrient Use in 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 ______________________________

Worksheet 2 The Process of Science: Food Preference by Pillbugs

OBSERVATION ____________________

QUESTIONS

General Question: ____________________

Specific Question 1: ____________________

Specific Question 2: ____________________

HYPOTHESIS H_0: ____________________

EXPERIMENTAL DATA: Food Preference by Pillbugs

Treatments						Treatments Minus Control $\bar{x}$	
Replicate	**Control**	**Replicate**	**Treatment 1**	**Replicate**	**Treatment 2**	**Treatment 1 Adjusted for the Control $\bar{x}$**	**Treatment 2 Adjusted for the Control $\bar{x}$**
1	______	1	______	1	______	______	______
2	______	2	______	2	______	______	______
3	______	3	______	3	______	______	______
4	______	4	______	4	______	______	______

Control $\bar{x}$ = ______

Treatment 1 $\bar{x}$ = ______

Treatment 1 range = ______ – ______

Treatment 1 SD = ______

Treatment 2 $\bar{x}$ = ______

Treatment 2 range = ______ – ______

Treatment 2 SD = ______

TEST HYPOTHESIS

Treatment 1 $\bar{x}$ – (½)SD = ______

Treatment 1 $\bar{x}$ + (½)SD = ______

Treatment 2 $\bar{x}$ – (½)SD = ______

Treatment 2 $\bar{x}$ + (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 ____________________

BIOLOGY

Exercise 2

Measurements in Biology

The Metric System and Data Analysis

Learning Objectives

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

1. Understand the difference between accuracy and precision in measurements.
2. Identify the metric units used to measure length, volume, mass, and temperature.
3. Measure length, volume, mass, and temperature in metric units.
4. Convert one metric unit to another (e.g., grams to kilograms).
5. Use measures of volume and mass to calculate density.
6. Practice the use of simple statistical calculations such as mean, median, range, and standard deviation.
7. Analyze sample data using statistical tools.

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

Every day we're bombarded with numbers and measurements. They come at us from all directions, including while we're at the supermarket, gas station, golf course, and pharmacy, as well as while we're in our classrooms and kitchens. Virtually every package that we touch is described by a measurement.

Scientists use a standard method to collect data as well as use mathematics to analyze measurements. We must measure things before we can objectively describe what we are observing, before we can experiment with biological processes, and before we can predict how organisms respond, adjust to, and modify their world. Once we have made our measurements, we can analyze our data and look for variation and the sources of that variation. Then we can infer the causes and effects of the biological processes that interest us.

ACCURACY AND PRECISION

Scientists strive to make accurate, precise measurements. The **accuracy** of a group of measurements refers to how closely the measured values agree with the true or correct value. In contrast, the **precision** of a group of measurements refers to how closely the measurements agree with each other. That is, precision is the degree to which the measurements produce the same results, regardless of their accuracy. Measurements that are both accurate and precise are **valid** measurements. Scientists strive to make valid measurements.

Question 1

a. Can measurements be accurate but not precise? Explain.

b. Can measurements be precise but not accurate? Explain.

To help you check your answers, consider an analogy involving shooting arrows at a bull's-eye target (fig. 2.1). In this

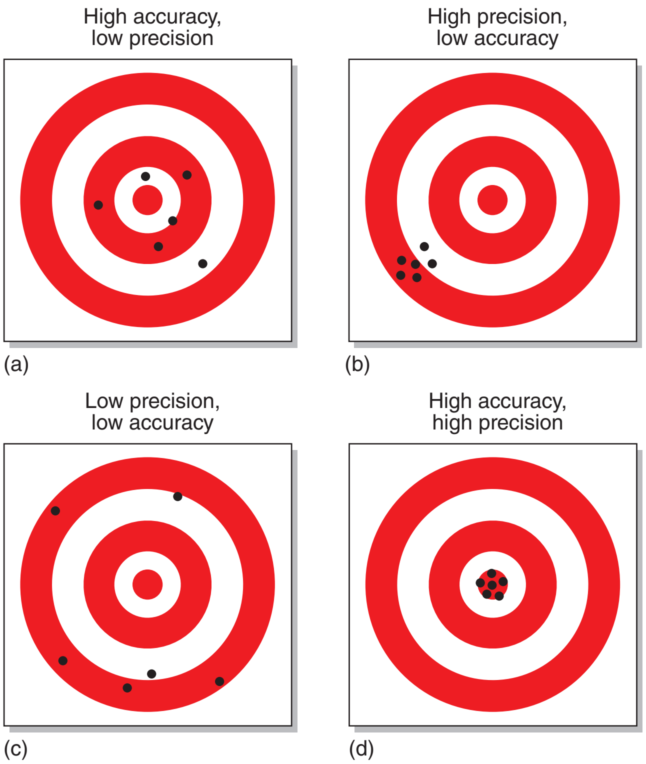


Figure 2.1 Precision and accuracy. Measurements can be (*a*) accurate but not precise, (*b*) precise but not accurate, (*c*) neither precise nor accurate, or (*d*) both precise and accurate. Measurements that are precise and accurate are termed *valid*.

analogy, each arrow would represent a measurement. Accuracy would be the closeness of the arrows to the center of the target; arrows closest to the bull's-eye would be most accurate. Precision would be the size of the cluster of arrows, regardless of how close they are to the center of the target.

THE METRIC SYSTEM

Scientists throughout the world use the **metric system** to make measurements. The metric system is also used in everyday life virtually everywhere except the United States. With few exceptions (e.g., liter bottles of soda), most measurements in the United States use the antiquated English system of pounds, inches, feet, and so on. Check with your instructor about bringing to class common grocery store items with volumes and weights in metric units, or examining those items on display.

Metric measurement is used worldwide in science to improve communication in the scientific community. Scientists make all of their measurements in the metric system; they do not routinely convert from one system to another. When scientists have mixed metric units with English units, the results have often been confusing, and have sometimes been disastrous. For example, in 1999, the $125-million Mars Climate Orbiter was approaching Mars to study the planet's climate. Lockheed Martin Astronautics, which built the spacecraft, gave NASA critical flight information in English units, but software aboard the orbiter expected the data in metric units. As a result, the orbiter was sent into, rather than safely above, the Mars atmosphere, where it disintegrated.

The following conversions will help give you a sense of how some common English units are related to their metric equivalents:

1 inch = 2.5 centimeters
1 foot = 30 centimeters
1 yard = 0.9 meter
1 mile = 1.6 kilometers
1 ounce = 28 grams
1 pound = 0.45 kilogram
1 fluid ounce = 30 milliliters
1 pint = 0.47 liter
1 quart = 0.95 liter
1 gallon = 3.8 liters
1 cup = 0.24 liter

If you want to know more about these conversions, see Appendix II.

This exercise will introduce you to making metric measurements of length, mass, volume, and temperature. During this lab, you should spend your time making measurements, not reading background information. Therefore, *before lab*, *read this exercise carefully to familiarize yourself with the basic units of the metric system*.

Metric units commonly used in biology include:

meter (m)—the basic unit of length
liter (L)—the basic unit of volume
kilogram (kg)—the basic unit of mass
degrees Celsius (°C)—the basic unit of temperature

Unlike the English system with which you are already familiar, the metric system is based on units of ten. This simplifies conversions from one metric unit to another (e.g., from kilometers to meters). This base-ten system is similar to our monetary system, in which 10 cents equals a dime, 10 dimes equals a dollar, and so forth. Units of ten in the metric system are indicated by Latin and Greek prefixes placed before the base units:

Prefix (Latin)		***Division of Metric Unit***	
deci	(d)	0.1	10^{-1}
centi	(c)	0.01	10^{-2}
milli	(m)	0.001	10^{-3}
micro	(μ)	0.000001	10^{-6}
nano	(n)	0.000000001	10^{-9}
pico	(p)	0.000000000001	10^{-12}

Prefix (Greek)		***Multiple of Metric Unit***	
deka	(da)	10	10^{1}
hecto	(h)	100	10^{2}
kilo	(k)	1000	10^{3}
mega	(M)	1000000	10^{6}
giga	(G)	1000000000	10^{9}

Thus, multiply by

0.01 to convert centimeters to meters
0.001 to convert millimeters to meters
1000 to convert kilometers to meters
0.1 to convert millimeters to centimeters

For example, there are 10 millimeters per centimeter. Therefore, to convert 62 centimeters to millimeters,

$$\mathbf{62\ cm \times \frac{10\ mm}{cm} = 620\ mm}$$

In these conversion equations, the units being converted *from* (in this case, centimeters) cancel out, leaving you with the desired units (in this case, millimeters). Also note that when units are converted to *smaller* units, the number associated with the new units will *increase*, and vice versa. For example, 620 meters = 0.620 kilometers = 620,000 millimeters = 62,000 centimeters.

Question 2

Make the following metric conversions:

1 meter =______centimeters =______millimeters

92.4 millimeters =______meters =______centimeters

10 kilometers =______meters =______decimeters

82 centimeters =______meters =______millimeters

3.1 kilograms =______grams =______milligrams

281 milliliters =______liters =_______deciliters

35 millimeters =_____centimeters =_______meters

Length and Area

The **meter** (m) is the basic unit of length. Units of area are squared units (i.e., two-dimensional) of length.

$$1 \text{ m} = 100 \text{ cm} = 1000 \text{ mm} = 0.001 \text{ km} = 1 \times 10^{-3} \text{ km}$$
$$1 \text{ km} = 1000 \text{ m} = 10^3 \text{ m}$$
$$1 \text{ cm} = 0.01 \text{ m} = 10^{-2} \text{ m} = 10 \text{ mm}$$
$$470 \text{ m} = 0.470 \text{ km}$$
$$1 \text{ cm}^2 = 100 \text{ mm}^2 \text{ (i.e., } 10 \text{ mm} \times 10 \text{ mm} = 100 \text{ mm}^2\text{)}$$

To help you appreciate the magnitudes of these units, here are the lengths and areas of some familiar objects:

Length	
Housefly	0.5 cm
Diameter of penny	1.9 cm
Diameter of baseball	7.4 cm
Soda can	12.2 cm
Toyota Camry	4.7 m
Mt. Everest	8848 m

Area	
Credit card	46 cm^2
Total skin area of adult human male	1.8 m^2
Ping-pong table	4.18 m^2
Surface area of human lungs	80 m^2
Football field (goal line to goal line)	4459 m^2
Central Park (New York City)	3.4 km^2

Procedure 2.1 **Make metric measurements of length and area**

Most biologists measure lengths with metric rulers or metersticks.

1. Examine intervals marked on the metric rulers and metersticks available in the lab.

2. Make the following measurements. Be sure to include units for each measurement.

Length of this page	__________
Width of this page	__________
Area of this page (Area = Length × Width)	__________
Your height	__________
Thickness of this manual	__________
Height of a 200-mL beaker	__________
Height of ceiling	__________
Height of your chair	__________
Length of your cell phone	__________

Question 3
What are some potential sources of error in your measurements?

Volume

Volume is the space occupied by an object. Units of volume are cubed (i.e., three-dimensional) units of length. The liter (L) is the basic unit of volume.

$$1 \text{ L} = 1000 \text{ cm}^3 = 1000 \text{ mL}$$
$$1 \text{ L} = 0.1 \text{ m} \times 0.1 \text{ m} \times 0.1 \text{ m}$$
$$1 \text{ cm}^3 = 0.000001 \text{ m}^3$$

To help you appreciate the magnitudes of these units, here are the volumes of some familiar objects:

Chicken egg	60 mL
Coke can	355 mL
One breath of air	500 cm^3

Scientists often measure volumes with pipets and graduated cylinders. Pipets are used to measure small volumes, typically 25 mL or less. Liquid is drawn into a pipet using a bulb or pipet pump (fig. 2.2). Never pipet by mouth.

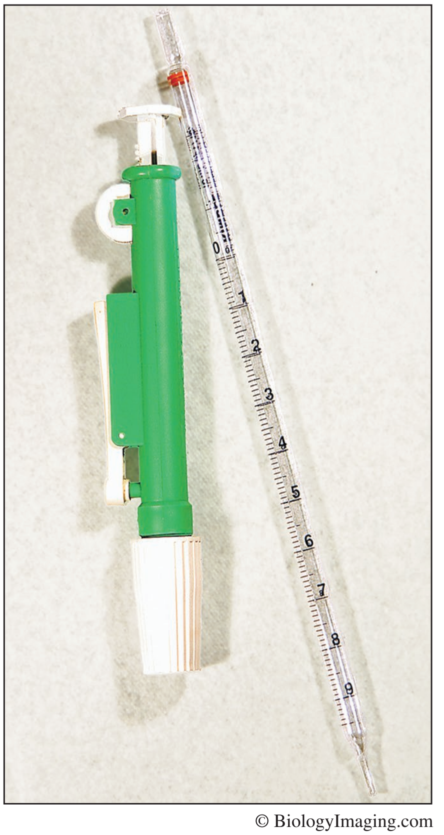


Figure 2.2 A pipet is used to extract and dispense volumes of liquid. A suction device (shown in green on the left) draws fluid into the pipet, and graduated markings on the pipet allow precise measurement of a fluid's volume. Never use your mouth to suck fluid into a pipet.

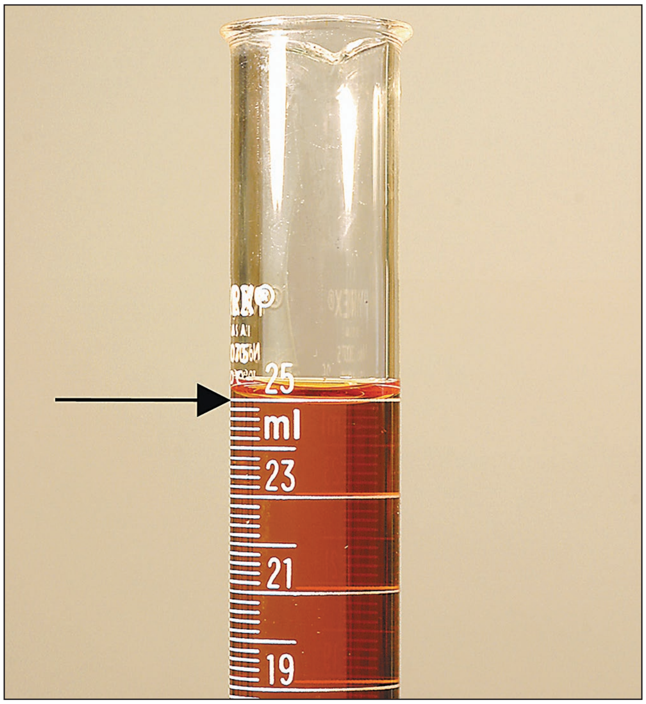


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Figure 2.3 When measuring the volume of liquid in a graduated cylinder, always measure at the bottom of the meniscus. The bottom of the meniscus in this photograph is indicated by the arrow. The correct volume is 25 mL.

Graduated cylinders are used to measure larger volumes. To appreciate how to make a measurement accurately, pour 40–50 mL of water into a 100-mL graduated cylinder, and observe the interface between the water and air. This interface, called the **meniscus,** is curved because of surface tension and the adhesion of water to the sides of the cylinder. When measuring the liquid in a cylinder such as a graduated cylinder, always position your eyes level with the meniscus and read the volume at the lowest level (fig. 2.3).

Procedure 2.2 Make metric measurements of volume

1. Biologists often use graduated cylinders to measure volumes. Locate the graduated cylinders available in the lab to make the following measurements. Determine what measurements the markings on the graduated cylinder represent. Be sure to include units for each measurement.
2. Measure the milliliters needed to fill a cup (provided in the lab). ________________
3. Measure the liters in a gallon. _______________

Procedure 2.3 Measure the volume of a solid object by water displacement

1. Obtain a 100-mL graduated cylinder, a thumb-sized rock, and a glass marble.
2. Fill the graduated cylinder with 70 mL of water.
3. Gently submerge the rock in the graduated cylinder. Notice that the volume of the contents rises.
4. Carefully observe the meniscus of the fluid and record its volume.
5. Calculate and record the volume of the rock by subtracting the original volume (70 mL) from the new volume.

   Rock volume ____________
6. Repeat steps 2–5 to measure and record the volume of the marble.

   Marble volume ____________

Biologists use pipets to measure and transfer small volumes of liquid from one container to another. The following procedure will help you appreciate the usefulness of pipets.

Procedure 2.4 Learn to use a pipet

1. Add approximately 100 mL of water to a 100-mL beaker.
2. Use a 5-mL pipet with a bulb or another filling device provided by your instructor to remove some water from the beaker.
3. Fill the pipet to the zero mark.
4. To read the liquid level correctly, your eye must be directly in line with the bottom of the meniscus.
5. Release the liquid into another container.

Question 4
What volume of liquid did you measure?

Mass

The **kilogram** (kg) is the basic unit of mass.[1] A kilogram equals the mass of 1000 cubic centimeters (cm^3) of water at 4°C. Similarly,

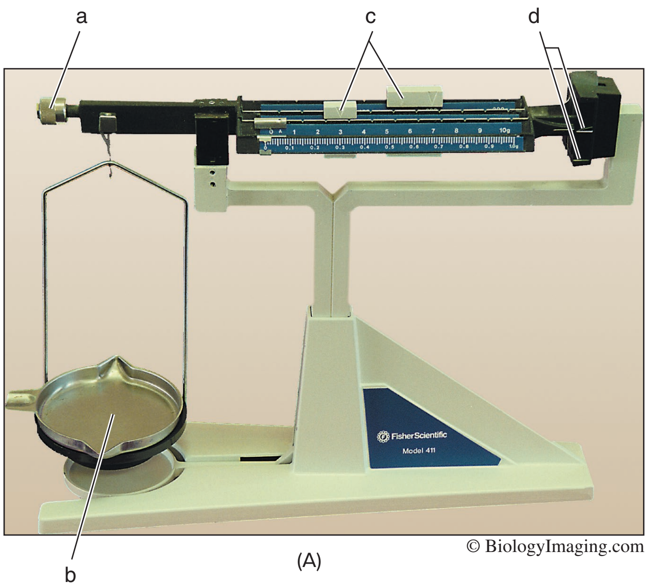
$$\mathbf{1\ kg = 1000\ g = 10^3\ g \qquad 1\ mg = 0.001\ g = 10^{-3}\ g}$$

Here are the masses of some familiar objects:

Housefly	12 mg	9V battery	40 g
Hummingbird	1.6 g	Human heart	300 g
Ping-pong ball	2.45 g	Basketball	0.62 kg
Quarter	6.25 g		

Biologists usually measure mass with a top-loading balance or a triple-beam balance (fig. 2.4). Locate the triple-beam balances or top-loading electronic balances in the lab. Triple-beam balances get their names from their three

1 *Remember that mass is not necessarily synonymous with weight. Mass measures an object's* **potential** *to interact with gravity, whereas weight is the force exerted by gravity on an object. Thus, a weightless object in outer space has the same mass as it has on earth.*



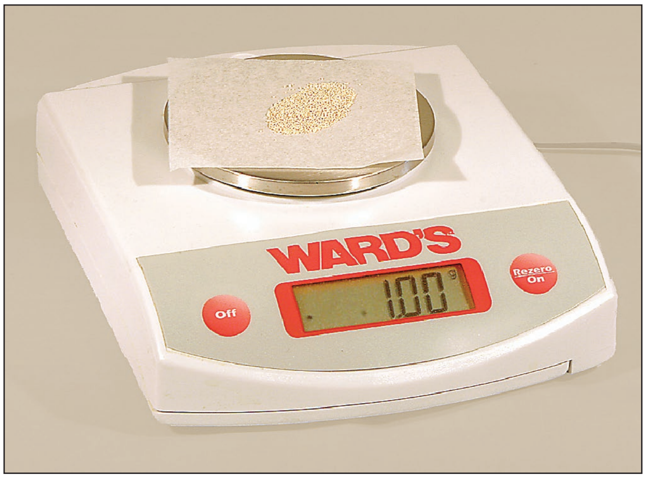


Figure 2.4 Biologists use balances to measure mass. (A) The parts of a triple-beam balance include the (*a*) zero-adjustment knob, (*b*) measuring pan, (*c*) movable masses on horizontal beams, and (*d*) balance marks. (B) A top-loading balance has a measuring pan, a power switch, and a zero calibration ("Tare") button.

horizontal beams. Suspended from each of the three beams are movable masses. Each of the three beams of the balance is marked with graduations: the closest beam has 0.1-g graduations, the middle beam has 100-g graduations, and the farthest beam has 10-g graduations.

Procedure 2.5 Make metric measurements of mass

1. Before making any measurements, clean the weighing pan and move all of the suspended weights to the far left. The balance marks should line up to indicate zero grams; if they do not, turn the adjustment knob until they do. Measure the mass of an object by placing it in the center of the weighing pan and moving the suspended masses until the beams balance. The mass of the object is the sum of the masses indicated by the weights on the three beams.
2. If you're using an electronic balance, turn on the balance and let it warm up for 5 minutes. Wait until the display reads 0.0 g; if the display does not read 0.0 g, press the "Tare" button to reset the display to 0.0 g. If you are weighing an object such as a coin or pencil, place the object on the measuring pan. After the display has stabilized, read and record the object's mass.
3. If you are weighing a liquid, powder, or similar specimen, place an empty beaker (in which you will place the liquid) or a piece of weighing paper (on which you will place the powder) on the balance's measuring pan. After the display has stabilized, press the "Tare" button to reset the display to 0.0 g. Place the liquid in the beaker (or the powder on the weighing paper). After the display has stabilized, read and record the mass.
4. Measure the masses of the following items. Be sure to include units for each measurement.

   Penny ______________

   Paper clip ______________

   Pencil ______________

   Rock (used in procedure 2.3) ____________

   100-mL beaker (empty) ____________

   100-mL beaker containing 50 mL of water _________

Question 5

a. **Density** is mass per unit volume. Use data that you've gathered to determine the density of water at room temperature.

Density of water = (mass/volume) = __________

b. What is the density of the wooden pencil? Does it float? Why?

c. What is the density of the rock? Does it sink? Why?

Temperature

Temperature is the measure of the kinetic energy of molecules—that is, the amount of heat in a system. Biologists measure temperature with a thermometer calibrated in degrees Celsius (°C). The Celsius scale is based on water freezing at 0°C and boiling at 100°C. You can interconvert °C and degrees Fahrenheit (°F) by using the formula 5(°F) = 9(°C) + 160. Here are some typical temperatures:

−20°C	temperature in a freezer
−18°C	mixture of ice and salt
0°C	water freezes
4°C	temperature in a refrigerator
22°C	room temperature
30.6°C	butter melts
37°C	human body temperature
40°C	a hot summer day
50°C	hottest day on record in Phoenix, AZ
71°C	flash pasteurization of milk
75°C	hot coffee
100°C	water boils
260°C	broiler temperature

Procedure 2.6 **Make metric measurements of temperature**

1. Obtain a thermometer in the lab. Handle the thermometer with care. If it breaks, notify your instructor immediately.
2. Determine the range of the temperatures that can be measured with your thermometer by examining the scale imprinted along the barrel of the thermometer.
3. Measure the following temperatures:

Room temperature	_____________	°C
Cold tap water	_____________	°C
Hot tap water	_____________	°C
Inside refrigerator	_____________	°C

UNDERSTANDING NUMERICAL DATA

Statistics offer a way to organize, summarize, and describe data—the data are usually samples of information from a much larger population of values. Statistics and statistical tests allow us to analyze the sample and draw inferences about the entire population. Consequently, the use of statistics enables us to make decisions even though we have incomplete data about a population. Although this may seem unscientific, we do it all the time; for example, we diagnose diseases with a drop of blood. Decisions are based on statistics when it is impossible or unrealistic to analyze an entire population.

Let's say that you want to know the mass of a typical apple in your orchard. To obtain this information, you could analyze one apple, but how would you know that you'd picked a "typical" sample? After all, the batch from

Significant Figures

Let's suppose that you're measuring the length of a bone, as shown in figure 2.5. How would you record this length—as 8 cm? 8.3 cm? 8.33 cm? 8.33333 cm? To answer this question, you need to know something about significant figures.

Significant figures are the number of figures required to record a measurement so that only the last digit in the number is in doubt. For example, if the ruler you're using is calibrated only in centimeters and you find that the object you're measuring is between 8 and 9 cm long (fig. 2.5), then you should estimate your measurement only to a tenth of a centimeter. That is, a measurement of 8.3 cm is acceptable, but 8.33 is not because it implies a precision that did not exist in the equipment you used to make the measurement. If, however, your ruler was calibrated in millimeters, then 8.33 cm would be acceptable. Remember this: When recording measurements, include all of the digits you are sure of plus an estimate to the nearest one-tenth of the next smaller digit.

Here are some other guidelines for using the correct number of significant figures in your measurements:

When adding or subtracting measurements, the answer should have no more precision than the measurement having the least number of significant figures. For example, suppose the air temperature in an incubator drops from 8.663°C to 8.2°C. This is a difference of 8.663°C – 8.2°C = 0.5°C, not 0.463°C. If the second temperature reading had been 8.200°C, then the correct answer would have been 0.463°C.

When converting measurements from one set of units to another, do not introduce precision that is not present in the first number. For example, 8.3 cm = 83 mm, not 83.0 mm.

When manipulating two measurements simultaneously, the precision of the final measurement should not exceed that of the least number of significant figures. For example, the calculation for the mass of 17.2 mL of water is 17.2 mL × 0.997821 g mL^{-1} = 17.2 g, not 17.162521 g.

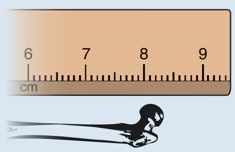


Figure 2.5 How long is this bone? 8 cm? 8.3 cm? 8.33 cm?