

■ THE AP[®] BIOLOGY CURRICULUM FRAMEWORK

The revised Advanced Placement[®] Biology course shifts from a traditional teacher-directed “content coverage” model of instruction to one that focuses on helping students gain enduring understandings of biological concepts and the scientific evidence that supports them. This approach enables students to spend more time understanding biological concepts while developing reasoning skills essential to the science practices used throughout their study of biology. A *practice* is a way to coordinate knowledge and skills in order to accomplish a goal or task. The science practices, as noted in the AP Biology Curriculum Framework, enable students to establish lines of evidence, and use them to develop and refine testable explanations and predictions of natural phenomena. Because content, inquiry, and reasoning are equally important in AP Biology, each learning objective combines content with inquiry and reasoning skills described in the science practices.

The key concepts and related content that define the revised AP Biology course and exam are organized around four underlying principles called the *big ideas*, which are as follows:

Big Idea 1: The process of evolution drives the diversity and unity of life.

Big Idea 2: Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis.


Big Idea 3: Living systems store, retrieve, transmit, and respond to information essential to life processes.

Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.

These four big ideas will be referred to as evolution, cellular processes: energy and communication, genetics and information transfer, and interactions, respectively, for the sake of brevity. The big ideas encompass the core scientific principles, theories, and processes governing organisms and biological systems. For each big idea, *enduring understandings* incorporate the core concepts that students should retain from the learning experience.

A more student-directed, inquiry-based lab experience supports the AP Biology course revision and curricular requirements by providing opportunities for students to design plans for experiments, data collection, application of mathematical routines, and refinement of testable explanations and predictions. Such a lab experience reinforces the revised curriculum’s focus on quantitative skills.

The suite of laboratory investigations within the new lab manual supports the recommendation by the National Science Foundation (NSF) that science teachers build into their curriculum opportunities for students to develop skills in communication, teamwork, critical thinking, and commitment to lifelong learning (Waterman 2008, NSF 1996). These labs will allow teachers to develop and use investigations they design based on their own experiences as an investigator and teacher. The manual’s engaging, inquiry-



based approach will inspire students to investigate meaningful questions about the real world. The investigations are organized under the four big ideas, and are integrated into the curriculum. They align with best practices and the goals of laboratory learning reported in *America's Lab Report*¹. The goals are as follows:

- Mastery of subject matter
- Development of scientific reasoning
- Understanding of the complexity and ambiguity of empirical work
- Development of practical skills
- Understanding of the nature of science
- Interest in science and science learning
- Development of teamwork abilities

■ Development of the Lab Investigations

To create a model of excellence for the lab component in AP science courses, the College Board worked in conjunction with the AP Lab Manual Vision Team and AP Biology Lab Development Team to create an innovative vision and approach to lab investigations. Both teams of subject matter experts consisted of AP Biology teachers and higher education faculty members, as well as experts in the fields of inquiry instruction, quantitative skill application, and lab investigations. Collectively, they created *AP Biology Investigative Labs: An Inquiry-Based Approach*. The labs in this manual support the concepts, content, and science practices within the revised AP Biology course.

1 *America's Lab Report* looks at a range of questions about how laboratory experiences fit into U.S. high schools, and investigates factors that influence a high school laboratory experience, looking closely at what currently takes place and what the goals of those experiences are and should be.

Introduction

■ GOALS OF THE LABORATORY INVESTIGATIONS

The instructional strategies that underlie the labs in this manual abandon the traditional teacher-directed content coverage model in favor of one that focuses on student-directed experimentation and inquiry. This approach enables students to identify the questions they want to answer, design experiments to test hypotheses, conduct investigations, analyze data, and communicate their results. As a result, they are able to concentrate on understanding concepts and developing the reasoning skills essential to the practices used in the study of biology.

■ How to Use the Lab Investigations in Your AP Biology Course

The revised AP Biology course emphasizes depth over breadth of content. The scope of the course affords educators time to develop students' conceptual understanding and engage them in inquiry-based learning experiences. It also enables teachers to spend time differentiating instruction and targeting the learning styles and interests of their students. This lab manual contains 13 student-directed, inquiry-based labs to offer at least three laboratory investigation options for each big idea. Because inquiry-based labs typically take more time than traditional labs, the number of required labs has been reduced from 12 to a minimum of eight. As per the AP Biology Course Audit requirements, teachers are required to devote 25 percent of instructional time to lab investigations, and this translates into a minimum of two investigations per big idea.


Instructors have the option of using the labs in this manual or updating their existing labs to make them inquiry based and student directed. Chapter 3 in this manual provides ideas for lab modifications. Implementing inquiry-based labs should not require a significant investment in new equipment.

Teachers and their students may perform the labs in any order. Each lab includes a section that explains alignment to the curriculum framework, and offers suggestions for when during the instructional year to conduct the lab. Each lab also includes a section about assessing students' understanding and work. Chapter 6 provides additional suggestions for ways for students to present their lab results, and for you to evaluate students' work.

■ What Is Inquiry?

Instructional practices that involve modeling the behavior of a scientist at work qualify as inquiry because the student conducts an authentic scientific investigation (Johnson 2009). It is unreasonable to think that every part of a particular lab in AP Biology will be completely student directed. However, as written, the labs lead to student-directed, inquiry-based investigations. The four levels of inquiry, adapted from Herron², are as follows:

2 Herron, M.D. (1971). The nature of scientific inquiry, *School Review*, 79(2), 171–212.

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- **Confirmation:** Students confirm a principle through an activity in which the results are known in advance.
 - **Structured:** Students investigate a teacher-presented question through a prescribed procedure.
 - **Guided:** Students investigate a teacher-presented question using student-designed/selected procedures.
 - **Open:** Students investigate topic-related questions that are formulated through student-designed/selected procedures.

In student-directed, inquiry-based laboratory investigations, students model the behavior of scientists by discovering knowledge for themselves as they observe and explore. Beginning with observations, students employ a variety of methods to answer questions that they have posed. These include conducting laboratory and field investigations; manipulating software simulations, models, and data sets; and exploring meaningful online research (Waterman 2008). By designing experiments to test hypotheses, analyze data, and communicate results and conclusions, students learn that a scientific method of investigation is cyclic, not linear; each observation or experimental result raises new questions about how the world works (Johnson 2009), thus leading to open-ended investigations. Students also appreciate that inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations (National Committee on Science Education Standards and Assessment and National Research Council 1996, 23).

Inquiry-based instruction encourages students to make connections between concepts and big ideas and allows scaffolding of both concepts and science practices to increase students' knowledge and skills, thus promoting deeper learning (see Appendix C for the science practices). As students work through their investigations, the teacher asks probing, follow-up questions to assess students' thinking processes, understanding of concepts, and misconceptions. Teachers can modify these and other labs to be more or less inquiry based to meet their students' needs. New challenges arise as students ask their own questions and perform their own experiments. By their very nature, inquiry-based investigations take longer to conduct, and additional materials and classroom space may be required. No new major lab equipment purchases are needed to conduct any of the labs in this manual, however. Students can work in small groups and share resources. If students do not achieve results at first, they may troubleshoot their experimental design, perhaps repeating a procedure several times before obtaining meaningful data. If time is a concern, instead ask your students what problems/errors they encountered, how these problems/errors could be avoided, and how the experiment would be different if it were to be repeated. Meaningful data are the goal, but students must be able to articulate nonmeaningful data and explain their causes. This is true science at its best. When students have the opportunity to mimic the practices of professional scientists, the benefits of an inquiry-based laboratory program far outweigh any challenges.



CHAPTER 1:

How to Use This Lab Manual

The lab period is a time for students to compare and refine their procedures, conduct their own experiments, and collect and analyze the data they obtain. This lab manual includes teacher and student versions of 13 student-directed, inquiry-based investigations that complement the curriculum framework for the revised course. The labs are categorized under the four big ideas, but they can be conducted in any order.

Although a “lab first” approach provides an opportunity for students to grapple with concepts on their own (Johnson 2009), you can introduce difficult concepts through lecture and discussion first, following with lab activities that range in difficulty and foster skills development. You are encouraged to develop your own inquiry-based labs, but be sure that the labs extend beyond confirmation, the first level of inquiry. If you want to modify a standard teacher-directed lab protocol, such as one included in the College Board’s 2001 *AP Biology Lab Manual*, you can eliminate the step-by-step procedure and instead ask students to develop their own procedure as a prelab activity. A template with a specific example is provided in Chapter 3 of this manual.

The following charts provide an overview of the investigative labs and a mapping to the curriculum framework. These charts are designed to help you decide the order in which to introduce the labs. Regardless of your approach, the key is to engage students in the investigative process of science: discovering knowledge for themselves in a self-reflective, organized manner.

OVERVIEW OF THE INVESTIGATIVE LABS

TIME ESTIMATE

(lab period = 45 min. unless otherwise noted)
Timing details are provided in each lab.

LAB	TIME ESTIMATE	LEVEL OF INQUIRY	QUANTITATIVE SKILLS
BIG IDEA 1: EVOLUTION			
1: Artificial Selection	7 weeks, including a 10-day growing period (See investigation for lab period breakdown.)	Guided, then open	Counting, measuring, graphing, statistical analysis (frequency distribution)
2: Mathematical Modeling	3 lab periods	Guided, then open	Mendelian genetics equations, Hardy-Weinberg equation, Excel and spreadsheet operations
3: Comparing DNA Sequences	3 lab periods	Guided, then open	Statistical analysis, mathematical modeling, and computer science (bioinformatics)
BIG IDEA 2: CELLULAR PROCESSES: ENERGY AND COMMUNICATION			
4: Diffusion and Osmosis	4–5 lab periods	Structured, then guided	Measuring volumes, calculating surface area-to-volume ratios, calculating rate, calculating water potential, graphing
5: Photosynthesis	4 lab periods	Structured, then open	Calculating rate, preparing solutions, preparing serial dilutions, measuring light intensity, developing and applying indices to represent the relationship between two quantitative values, using reciprocals to modify graphical representations, utilizing medians, graphing
6: Cellular Respiration	4 lab periods	Guided, then open	Calculating rate, measuring temperature and volume, graphing
BIG IDEA 3: GENETICS AND INFORMATION TRANSFER			
7: Cell Division: Mitosis and Meiosis	5–6 lab periods	Structured, then guided, then open	Measuring volume, counting, chi-square statistical analysis, calculating crossover frequency
8: Biotechnology: Bacterial Transformation	4–5 lab periods	Structured, then guided	Measuring volume and temperature, calculating transformation efficiency
9: Biotechnology: Restriction Enzyme Analysis of DNA	3–4 lab periods	Structured, then guided, then open	Measuring volume and distance, graphing/plotting data using log scale, extrapolating from standard curve
BIG IDEA 4: INTERACTIONS			
10: Energy Dynamics	4–5 lab periods	Structured, then guided, then open	Estimating productivity and efficiency of energy transfer, accounting and budgeting, measuring biomass, calculating unit conversions in simple equations
11: Transpiration	4 lab periods	Structured, then guided, then open	Measuring distance, volume, and mass; estimating surface area; calculating surface area; graphing; calculating rate
12: Fruit Fly Behavior	4 lab periods	Structured, then open	Preparing solutions, counting, graphing
13: Enzyme Activity	3–4 lab periods	Structured, then guided, then open	Measuring volume and mass, measuring color change, graphing, calculating rates of enzymatic reactions

ALIGNMENT TO THE AP BIOLOGY CURRICULUM FRAMEWORK

INVESTIGATION	LEARNING OBJECTIVE (LO)
BIG IDEA 1: EVOLUTION	
1: Artificial Selection	<p>LO 1.1 The student is able to convert a data set from a table of numbers that reflect a change in the genetic makeup of a population over time, and to apply mathematical methods and conceptual understandings to investigate the cause(s) and effect(s) of this change.</p> <p>LO 1.2 The student is able to evaluate evidence provided by data to qualitatively and quantitatively investigate the role of natural selection in evolution.</p> <p>LO 1.3 The student is able to apply mathematical methods to data from a real or simulated population to predict what will happen to the population in the future.</p> <p>LO 1.4 The student is able to evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time.</p> <p>LO 1.5 The student is able to connect evolutionary changes in a population over time to a change in the environment.</p>
2: Mathematical Modeling: Hardy-Weinberg	<p>LO 1.1 The student is able to convert a data set from a table of numbers that reflect a change in the genetic makeup of a population over time, and to apply mathematical methods and conceptual understandings to investigate the cause(s) and effect(s) of this change.</p> <p>LO 1.2 The student is able to evaluate evidence provided by data to qualitatively and quantitatively investigate the role of natural selection in evolution.</p> <p>LO 1.4 The student is able to evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time.</p> <p>LO 1.6 The student is able to use data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and effects of selection in the evolution of specific populations.</p> <p>LO 1.7 The student is able to justify data from mathematical models based on the Hardy-Weinberg equilibrium to analyze genetic drift and the effects of selection in the evolution of specific populations.</p> <p>LO 1.25 The student is able to describe a model that represents evolution within a population.</p> <p>LO 1.26 The student is able to evaluate given data sets that illustrate evolution as an ongoing process.</p>
3: Comparing DNA Sequences to Understand Evolutionary Relationships with BLAST	<p>LO 1.4 The student is able to evaluate data-based evidence that describes evolutionary changes in the genetic makeup of a population over time.</p> <p>LO 1.9 The student is able to evaluate evidence provided by data from many scientific disciplines that support biological evolution.</p> <p>LO 1.13 The student is able to construct and/or justify mathematical models, diagrams, or simulations that represent processes of biological evolution.</p> <p>LO 1.19 The student is able create a phylogenetic tree or simple cladogram that correctly represents evolutionary history and speciation from a provided data set.</p> <p>LO 3.1 The student is able to construct scientific explanations that use the structures and mechanisms of DNA and RNA to support the claim that DNA and, in some cases, RNA are the primary sources of heritable information.</p>

INVESTIGATION	LEARNING OBJECTIVE (LO)
BIG IDEA 2: CELLULAR PROCESSES: ENERGY AND COMMUNICATION	
4: Diffusion and Osmosis	<p>LO 2.6 The student is able to use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion.</p> <p>LO 2.7 Students will be able to explain how cell size and shape affect the overall rate of nutrient intake, and the rate of waste elimination.</p> <p>LO 2.10 The student is able to use representations and models to pose scientific questions about the properties of cell membranes and selective permeability based on molecular structure.</p> <p>LO 2.11 The student is able to construct models that connect the movement of molecules across membranes with membrane structure and function.</p> <p>LO 2.12 The student is able to use representations and models to analyze situations or solve problems qualitatively and quantitatively to investigate whether dynamic homeostasis is maintained by the active movement of molecules across membranes.</p>
5: Photosynthesis	<p>LO 1.15 The student is able to describe specific examples of conserved, core biological processes and features shared by all domains, or within one domain of life, and how these shared, conserved core processes and features support the concept of common ancestry for all organisms.</p> <p>LO 1.16 The student is able to justify the scientific claim that organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.</p> <p>LO 2.2 The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow, or to reproduce, but that multiple strategies exist in different living systems.</p> <p>LO 2.4 The student is able to use representations to pose scientific questions about what mechanisms and structural features allow organisms to capture, store, and use free energy.</p> <p>LO 2.14 The student is able to use representations and models to describe differences in prokaryotic and eukaryotic cells.</p> <p>LO 4.5 The student is able to construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions.</p> <p>LO 4.12 The student is able to apply mathematical routines to quantities that describe communities composed of populations of organisms that interact in complex ways.</p>
6: Cellular Respiration	<p>LO 1.15 The student is able to describe specific examples of conserved, core biological processes and features shared by all domains, or within one domain of life, and how these shared, conserved core processes and features support the concept of common ancestry for all organisms.</p> <p>LO 1.16 The student is able to justify the scientific claim that organisms share many conserved core processes and features that evolved and are widely distributed among organisms today.</p> <p>LO 2.2 The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow, or to reproduce, but that multiple strategies exist in different living systems.</p> <p>LO 2.4 The student is able to use representations to pose scientific questions about what mechanisms and structural features allow organisms to capture, store, and use free energy.</p> <p>LO 2.14 The student is able to use representations and models to describe differences in prokaryotic and eukaryotic cells.</p> <p>LO 4.5 The student is able to construct explanations based on scientific evidence as to how interactions of subcellular structures provide essential functions.</p> <p>LO 4.12 The student is able to apply mathematical routines to quantities that describe communities composed of populations of organisms that interact in complex ways.</p>

INVESTIGATION	LEARNING OBJECTIVE (LO)
BIG IDEA 3: GENETICS AND INFORMATION TRANSFER	
7: Cell Division: Mitosis and Meiosis	<p>LO 3.7 The student can make predictions about natural phenomena occurring during the cell cycle.</p> <p>LO 3.8 The student can describe the events that occur in the cell cycle.</p> <p>LO 3.9 The student is able to construct an explanation, using visual representations or narratives, as to how DNA in chromosomes is transmitted to the next generation via mitosis, or meiosis followed by fertilization.</p> <p>LO 3.10 The student is able to represent the connection between meiosis and increased genetic diversity necessary for evolution.</p> <p>LO 3.11 The student is able to evaluate evidence provided by data sets to support the claim that heritable information is passed from one generation to another generation through mitosis, or meiosis followed by fertilization.</p> <p>LO 3.12 The student is able to construct a representation that connects the process of meiosis to the passage of traits from parent to offspring.</p> <p>LO 3.28 The student is able to construct an explanation of the multiple processes that increase variation within a population.</p>
8: Biotechnology: Bacterial Transformation	<p>LO 1.5 The student is able to connect evolutionary changes in a population over time to a change in the environment.</p> <p>LO 3.5 The student can justify the claim that humans can manipulate heritable information by identifying at least two commonly used technologies.</p> <p>LO 3.6 The student can predict how a change in a specific DNA or RNA sequence can result in changes in gene expression.</p> <p>LO 3.13 The student is able to pose questions about ethical, social, or medical issues surrounding human genetic disorders.</p> <p>LO 3.21 The student can use representations to describe how gene regulation influences cell products and function.</p>
9: Biotechnology: Restriction Enzyme Analysis of DNA	<p>LO 3.5 The student can justify the claim that humans can manipulate heritable information by identifying at least two commonly used technologies.</p> <p>LO 3.13 The student is able to pose questions about ethical, social, or medical issues surrounding human genetic disorders.</p>
BIG IDEA 4: INTERACTIONS	
10: Energy Dynamics	<p>LO 2.1 The student is able to explain how biological systems use free energy based on empirical data that all organisms require constant energy input to maintain organization, to grow, and to reproduce.</p> <p>LO 2.2 The student is able to justify a scientific claim that free energy is required for living systems to maintain organization, to grow, or to reproduce, but that multiple strategies exist in different living systems.</p> <p>LO 2.3 The student is able to predict how changes in free energy availability affect organisms, populations, and ecosystems.</p> <p>LO 2.22 The student is able to refine scientific models and questions about the effect of complex biotic and abiotic interactions on all biological systems, from cells and organisms to populations, communities, and ecosystems.</p>


INVESTIGATION	LEARNING OBJECTIVE (LO)
10: Energy Dynamics <i>continued</i>	<p>LO 2.23 The student is able to design a plan for collecting data to show that all biological systems (cells, organisms, populations, communities, and ecosystems) are affected by complex biotic and abiotic interactions.</p> <p>LO 2.24 The student is able to analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system (cells, organisms, populations, communities, or ecosystems).</p> <p>LO 4.14 The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy.</p> <p>LO 4.16 The student is able to predict the effects of a change of matter or energy availability on communities.</p>
11: Transpiration	<p>LO 1.5 The student is able to connect evolutionary changes in a population over time to a change in the environment.</p> <p>LO 2.6 The student is able to use calculated surface area-to-volume ratios to predict which cell(s) might eliminate wastes or procure nutrients faster by diffusion.</p> <p>LO 2.8 The student is able to justify the selection of data regarding the types of molecules that an animal, plant, or bacterium will take up as necessary building blocks and excrete as waste products.</p> <p>LO 2.9 The student is able to represent graphically or model quantitatively the exchange of molecules between an organism and its environment, and the subsequent use of these molecules to build new molecules that facilitate dynamic homeostasis, growth, and reproduction.</p> <p>LO 4.9 The student is able to predict the effects of a change in a component(s) of a biological system on the functionality of an organism(s).</p> <p>LO 4.14 The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy.</p> <p>LO 4.15 The student is able to use visual representations to analyze situations or solve problems qualitatively to illustrate how interactions among living systems and with their environment result in the movement of matter and energy.</p>
12: Fruit Fly Behavior	<p>LO 2.22 The student is able to refine scientific models and questions about the effect of complex biotic and abiotic interactions on all biological systems, from cells and organisms to populations, communities, and ecosystems.</p> <p>LO 2.23 The student is able to design a plan for collecting data to show that all biological systems (cells, organisms, populations, communities, and ecosystems) are affected by complex biotic and abiotic interactions.</p> <p>LO 2.24 The student is able to analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system (cells, organisms, populations, communities, or ecosystems).</p> <p>LO 2.38 The student is able to analyze data to support the claim that responses to information and communication of information affect natural selection.</p> <p>LO 2.39 The student is able to justify scientific claims, using evidence, to describe how timing and coordination of behavioral events in organisms are regulated by several mechanisms.</p> <p>LO 2.40 The student is able to connect concepts in and across domain(s) to predict how environmental factors affect responses to information and change behavior.</p>

INVESTIGATION	LEARNING OBJECTIVE (LO)
12: Fruit Fly Behavior <i>continued</i>	<p>LO 4.14 The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment, which result in the movement of matter and energy.</p> <p>LO 4.15 The student is able to use visual representations to analyze situations or solve problems qualitatively to illustrate how interactions among living systems and with their environment result in the movement of matter and energy.</p> <p>LO 4.16 The student is able to predict the effects of a change of matter or energy availability on communities.</p> <p>LO 4.19 The student is able to use data analysis to refine observations and measurements regarding the effect of population interactions on patterns of species distribution and abundance.</p>
13: Enzyme Activity	<p>LO 2.23 The student is able to design a plan for collecting data to show that all biological systems (cells, organisms, populations, communities, and ecosystems) are affected by complex biotic and abiotic interactions.</p> <p>LO 4.3 The student is able to use models to predict and justify that changes in the subcomponents of a biological polymer affect the functionality of the molecule.</p> <p>LO 4.17 The student is able to analyze data to identify how molecular interactions affect structure and function.</p>

■ Safety, Safety Contracts, and Supervision

Teachers have an obligation to provide a safe environment for their students to learn and explore. The equipment and chemicals used in the laboratory investigations for AP Biology could cause harm if not used appropriately. Therefore, it is very important that you follow the following guidelines:

1. Know the regulations for your school, district, and state, and follow them! Ask for safety training if your school does not require it. You should insist on having basic safety equipment available in your classroom: a fire extinguisher, fire blanket, eyewash, safety goggles or glasses for every student, and a first-aid kit.
2. Develop a safety contract for your students. Questions regarding allergies or special health conditions might be included in a safety contract. (Many lab kits come with latex gloves, and teachers may not know that their students are allergic to latex.) The students and their parents or guardians should sign the contract before beginning any laboratory work. Consider giving your students a quiz so that you can evaluate their understanding of the contract. Sample safety contracts are available through scientific supply companies and school districts.
3. Engage the students in a conversation about lab safety. Ask the students what could go wrong during the execution of a lab investigation. Teach about safety each time you begin a lab activity. Explain what could happen if safety instructions are not followed correctly. With more student-directed lab activities, it is even more important to provide strict guidelines because different groups of students will be



doing different activities, and using different materials and equipment. Students should never embark on a new activity, or use new chemicals or a new approach, without notifying the teacher.

4. Be consistent with enforcing the safety guidelines.

■ Materials and Equipment

This course presents a college-level biology curriculum, and the equipment needed for the labs in this guide is reasonable. Your school district should support you and your classroom in order to provide an adequate learning environment in which to conduct laboratory investigations. Each laboratory investigation in this guide includes a list of materials and equipment, and it is assumed that each class has access to basic lab equipment (e.g., beakers, pipettes, and balances) in addition to some specialized equipment, such as gel boxes for electrophoresis. However, it is recognized that many classes do not have access to more expensive equipment, such as probes and sensors with computer interfaces. For labs utilizing such equipment, a lower-cost alternative is provided so that all students can initiate and follow through on their own investigations.

Biotechnology companies often have equipment for classrooms to borrow. Local colleges or universities may allow your students to borrow equipment or complete a lab as a field trip on their campus, or they may even donate their old equipment to your school. Some schools have partnerships with local businesses that can help with laboratory equipment and materials.

CHAPTER 2: The Labs at a Glance

Although each lab investigation in this manual is unique and focuses on specific concepts and science practices, the formats are similar, as the labs are designed for clarity and consistency. As shown below, the teacher version (blue) for each investigation includes the enduring understandings and science practices that align to the learning objectives outlined in the curriculum framework; you are encouraged to use this model when you develop your own student-directed, inquiry-based investigations. Each investigation provides suggestions for prelab assessments that are designed to determine students' prior understanding, knowledge of key concepts, and skills. Each lab investigation also provides suggestions for summative assessments, which measure students' understanding of the concepts, development of science practices, and gain in thinking skills after they conduct their lab investigations and analyze their results.

Interactions Big Idea 4

INVESTIGATION 12
FRUIT FLY BEHAVIOR

What environmental factors trigger a fruit fly response?

BACKGROUND

Drosophila melanogaster, the common fruit fly, is an organism that has been studied in the scientific community for more than a century. Thomas Hunt Morgan began using it for genetic studies in 1907. The common fruit fly lives throughout the world and feeds on fruit and the fungi growing on rotting fruit. It is a small fly, and one could question why scientists have spent so much time and effort on this tiny insect. It is about the size of President Roosevelt's nose on a dime, but despite its small size, the fly is packed with many interesting physical and behavioral characteristics. Its genome has been sequenced, its physical characteristics have been charted and mutated, its meiotic processes and development have been investigated, and its behavior has been the source of many experiments. Because of its scientific usefulness, *Drosophila* is a model research organism. Its name is based on observations about the fly; the fly follows circadian rhythms that include sleeping during the dark and emerging as an adult from a pupa in the early morning. This latter behavior gave rise to the name *Drosophila*, which means "lover of dew." The explanation for the species name *melanogaster* should be clear after observing the fly's physical features. It has a black "stomach," or abdomen. No doubt the dew-loving, black-bellied fly will continue to make contributions to the scientific community and to student projects.

We begin our investigation with a few simple questions. What do you know about fruit flies? Have you seen fruit flies outside the lab and, if so, where? Describe where and when you have noted fruit flies.

Investigation 12 S146

The **primary question(s)** for students to investigate is generated from the enduring understandings in the AP Biology Curriculum Framework.

Interactions Big Idea 4

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These investigations explore the environmental choices that fruit flies make. A choice chamber is designed to give fruit flies two choices during any one test, although students could also think about how to build an apparatus that would give fruit flies more than two choices. Adult fruit flies are attracted to substances that offer food or an environment in which to lay eggs and develop larvae. Typically those environments are rotting or fermenting fruit. Adult fruit flies are attracted to bright light, and their larvae move away from bright light. Adult fruit flies also demonstrate a negative geotaxis; they climb up in their chambers or vials against gravity. Movement toward a substance is a positive taxis. Consistent movement or orientation away from a substance is a negative taxis. In most cases, the experiments done in the choice chamber will be chemotactic experiments, as indicated by the number of flies that collect on one end of the chamber or another in response to a chemical stimulus. At some point, students may wish to investigate if the chemotactic response is greater than a geotactic or phototactic

Investigation 12 T203

Background is drawn from the elements of the curriculum framework. Background information explains how the lab provides opportunities for students to review, scaffold, and apply concepts.

Learning objectives indicate what students should know and be able to do as they conduct their laboratory investigations. In the Teacher Manual, the learning objectives come directly from the AP Biology Curriculum Framework. Each learning objective integrates science practices with specific concepts and enduring understandings outlined in the curriculum framework.

■ ALIGNMENT TO THE AP BIOLOGY CURRICULUM FRAMEWORK

This investigation can be conducted during the study of concepts pertaining to interactions (big idea 4) or to cellular processes (big idea 2), specifically the capture, use, and storage of free energy. In addition, some of the questions are likely to connect to big idea 1 if students explore the evolution of observed behaviors. As always, it is important to make connections between big ideas and enduring understandings, regardless of where in the curriculum the lab is taught. The concepts align with the enduring understandings and learning objectives from the AP Biology Curriculum Framework, as indicated below.

■ Enduring Understandings

- 2D1: Reinforce the concept that all biological systems from cells and organisms to populations, communities, and ecosystems are affected by complex biotic and abiotic interactions involving exchange of matter and free energy.
- 2E3: Timing and coordination of behavior are regulated by various mechanisms and are important in natural selection.
- 4A6: Interactions among living systems and with their environment result in the movement of matter and energy.
- 4B4: Interactions between and within populations influence patterns of species distribution and abundance.

■ Learning Objectives

- The student is able to refine scientific models and questions about the effect of complex biotic and abiotic interactions on all biological systems from cells and organisms to populations, communities, and ecosystems (2D1 & SP 1.3, SP 3.2).
- The student is able to design a plan for collecting data to show that all biological systems (cells, organisms, populations, communities, and ecosystems) are affected by complex biotic and abiotic interactions (2D1 & SP 4.2, SP 7.2).
- The student is able to analyze data to identify possible patterns and relationships between a biotic or an abiotic factor and a biological system (cells, organisms, populations, communities, or ecosystems) (2D1 & SP 5.1).
- The student is able to analyze data to support the claim that response to information and communication of information affect natural selection (2E3 & SP 5.1).
- The student is able to justify claims, using evidence, to describe how timing and coordination of behavioral events in organisms are regulated by several mechanisms (2E3 & SP 6.1).
- The student is able to connect concepts in and across domain(s) to predict how environmental factors affect response to information and change behavior (2E3 & SP 7.2).
- The student is able to apply mathematical routines to quantities that describe interactions among living systems and their environment that result in the movement of matter and energy (4A6 & SP 2.2).

T206 Investigation 12

For the Student Manual version, the learning objectives appear in more student-friendly vernacular.

■ Learning Objectives

- To investigate the relationship between a model organism, *Drosophila*, and its response to different environmental conditions
- To design a controlled experiment to explore environmental factors that either attract or repel *Drosophila* in the laboratory setting
- To analyze data collected in an experiment in order to identify possible patterns and relationships between environmental factors and a living organism
- To work collaboratively with others in the design and analysis of a controlled experiment
- To connect and apply concepts (With the fruit fly as the focal organism, your investigation could pull together many topics, such as genetics, animal behavior, development, plant and animal structures from cells to organs, cell communication, fruit ripening, fermentation, and evolution.)

■ General Safety Precautions

- Do not add substances to the choice chamber unless your teacher has approved them.
- If the substance you add is flammable, such as ethanol, use precaution and do not conduct your experiment near a heat source or flame.
- Many of the substances used in this experiment are food items, but you should not consume any of them.
- Fruit flies are living organisms that should not be released to the environment. After all the investigations are complete, flies should be tapped into a "morgue" through a funnel. The morgue typically is a 150-mL beaker that contains about 50 mL of salad oil or 70% alcohol.

S146 Investigation 12

least 30–40 flies into the chamber, lift up the culture vial, and immediately plug the vial and cap the chamber. If a culture vial is upside down even with flies in it, very few flies will escape before it is plugged again.

An additional technique to avoid the problem of flies escaping is to refrigerate them before the transfer. If vials are chilled for at least 15–30 minutes before tossing, they are easier to transfer. Be sure that the chilling does not add moisture to the culture, as moisture can make the flies stick to the vials.

Students may have the misconception that fruit flies are attracted to fruit, but they will determine that it is not the fruit but rather the *rotting* fruit and the accompanying chemotaxis to various products, such as vinegar or alcohol, of this decomposition process that prompts the fly's behavior. How can you help students identify the difference without telling them? Is the chemotaxis a strong taxis? Does a geotaxis or phototaxis override the chemotaxis?

THE INVESTIGATIONS

Getting Started: Prelab Assessment

You may assign the following as a think, pair/group, share activity, in which pairs or small groups of students brainstorm ideas and then share them with other groups, or as a whole-class discussion to assess students' understanding of key concepts pertaining to fruit flies:

Day 1

1. During this discussion, you can assess if your students know what fruit flies are and when and where they have seen them. The class should make a list of when and where they notice fruit flies. They should generate a list that may include a bowl of fruit, a picnic dinner, and someone's glass of wine. Students should also view pictures of fruit flies to recall previous experiments with these model research organisms used in genetics or population studies.
2. Have the students make observations about fruit fly behavior by conducting the following very simple geotactic experiment. Students can work in small groups.
 - a. Using fruit fly cultures, toss at least 10 flies into an empty vial. Do not anesthetize the flies before this or any of the behavior experiments.
 - b. Observe the position of the flies in an upright vial sitting in a test tube rack on the lab table. Do not touch the vial while making observations.
 - c. Invert the vial and observe the position of the flies after 15 seconds and after 30 seconds. Make a list of observed behaviors.
 - d. Observations should generate questions, including *What was the flies' response? Was there an orientation movement? If so, what was the stimulus? Could this be considered a taxis?* Explain your answers.

Investigation 12

Getting Started is designed to help you determine your students' prior knowledge, understanding of key concepts, and skill level. Although you are encouraged to develop your own means of assessment, the lab investigations in this manual include suggestions. Assessments can include question sets that you assign for homework, collaborative activities, and interactive online simulations.

BIG IDEA 4: INTERACTIONS

THE INVESTIGATIONS

Getting Started

This procedure is designed to help you understand how to work with fruit flies. You may start with general information about how to determine the sex of a fruit fly. How do you tell the difference between male and female flies? Is the sex of the fly important to your investigations? Look at the female and male fruit flies in Figure 1. Then look at the fruit flies in Figure 2. Can you identify which ones are female and which ones are male? Focus on the abdomen of the flies to note differences.



Figure 1. Determining the Sex of Fruit Flies

Figure 2. Fruit Flies

Step 1 Using fruit fly cultures, carefully toss 10 to 20 living flies into an empty vial. Be sure to plug the vial as soon as you add the flies. Do not anesthetize the flies before this or any of the behavior experiments.

Step 2 When flies are tossed, they are tapped into an empty vial. Tap a culture vial (push the vial down on a solid surface several times) on the table to move the flies to the bottom of the vial. Quickly remove the foam or cotton top and invert an empty vial over the top of the culture vial. Invert the vials so that the culture vial is on the top and the empty vial is on the bottom, and tap the flies into the empty container by tapping it on a solid surface several times. Be sure to hold the vials tightly to keep them together. You must then separate the vials and cap each separately. Do not try to isolate every fly from the original culture. It is difficult to separate flies, and you may lose a fly or two in the process.

Step 3 After your lab group has the flies in a vial without food, observe the position of the flies in your upright vial.

Step 4 Invert the vial, and observe the position of the flies after 15 seconds and after 30 seconds.

Investigation 12 S147

The **Getting Started** section of the Student Manual aligns with the prelab assessment in the Teacher Manual.

In the Teacher Manual, **Designing and Conducting Independent Investigations** provides suggestions for guiding your students through the student-directed portion of the investigation.

Designing and Conducting Independent Investigations

Day 2

When developing their own investigations, students should choose substances to test that are interesting to them. They may have experiences with fruit flies in their home and can think about what attracts flies. They also may want to find a substance that would repel a fly. They can bring substances from home to test, but make sure they obtain your permission to use the substances before they conduct their tests. The students should work in groups to determine the chemotactic response to various food items. They should share and graphically illustrate their results.

Days 3–4+

The following are suggestions for the student-directed lab activities based on questions students ask during their preliminary study of the fruit flies. Their questions might include the following: *Does the age of a fruit fly affect the speed of their negative geotactic response? What wavelengths of light stimulate a phototactic response in fruit flies?*

Possible investigations generated from students' observations and questions include the following. However, it is suggested that students generate their own questions to explore.

- From an ingredient list, select substances (such as vinegar) that students think might be affecting fly behavior. Isolate the materials and give the flies a choice.
- Determine if the sex of the fly makes a difference in their choice. (An F1 population of flies with white-eyed males and red-eyed females could be made available.)
- Determine if the sight of the material makes a difference by covering up the cotton ball in parafilm.
- Find the effect of light by changing the light source at different ends of the chamber or by studying how flies make choices in different colors of light. (Different ends of the chambers could be wrapped in transparent colored films or acetate.)
- Determine if the ripeness of the fruit makes a difference. For example, ripe bananas could be compared to green bananas.
- Determine if fruit flies are attracted to or repelled by carbon dioxide by placing pieces of Alka-Seltzer in moist cotton balls.
- Determine the effect of age or the developmental stage of the fruit fly on choice by using newly emerged flies in the chamber and/or the third instar larva on a glass slide.
- Work with different mutants of fruit flies to determine if vestigial or white-eyed flies (or other mutants) make the same choices. Determine if the Adh-negative mutant affects the flies' response to alcohol. Determine if mutant eye colors (white, cinnabar, brown) affect the flies' response to light.
- Are there other organisms that respond like fruit flies? Can you think of any organisms that respond differently?

Students should verify the results of their experiment by conducting several trials and changing the position of the substances at the ends of the chamber.

Investigation 12 T211

In the Student Manual, **Procedure** is the first, more teacher-directed part of the investigation. This preliminary investigation familiarizes students with the subject matter, and prepares them for the student-directed part of the investigation.

Step 5 What was the flies' response? Did most/all of the flies move in the same general direction? If so, this might be an "orientation movement," which is a movement that is in response to some stimulus. Based on how you manipulated the vial, to what stimulus might the flies be responding? Do you think that they were responding to some chemical change in the vial? Did your observations generate other questions? Explain your answers.

Procedure

Animals move in response to many different stimuli. A chemotaxis is a movement in response to the presence of a chemical stimulus. The organism may move toward or away from the chemical stimulus. What benefit would an organism gain by responding to chemicals in their environment? A phototactic response is a movement in response to light. A geotactic response is a movement in response to gravity.

You will investigate fruit fly movement using a choice chamber that exposes the flies to different substances that you insert into the chamber. Because flies are very common in households (in fact, fruit flies live almost everywhere that humans live), think about using foods or condiments that might result in a positive or a negative chemotactic response from the flies. What foods or condiments do you think would attract or repel flies? Why? Do fruit flies exhibit a response to light or to gravity? How can you alter the chamber to investigate those variables?

Step 1 Prepare a choice chamber by labeling both ends with a marker — one end "A" and the other "B" (see Figure 3). Cut the bottom of the bottles, dry the interior thoroughly, and tape them together. Remove any paper labels.



Figure 3. Choice Chamber

Place a cap on one end of a chamber before adding flies. Insert a small funnel in the open end of the chamber and place the chamber upright on the capped end. Tap 20–30 fruit flies into the choice chamber using the funnel.

S148 Investigation 12

■ Designing and Conducting Your Investigation

Now that you have discovered the preferences for individual substances, design an experiment using the choice chamber to compare the preferences of fruit flies to all test substances or the chemotactic responses of your flies. Create a table that includes the results comparing all of the substances you tested.


The following are questions that you could investigate; however, as you worked through the beginning of this lab, you should have developed your own question and an investigation to answer that question:

- Are all substances equally attractive or repellant to the fruit flies?
- Which substances do fruit flies prefer the most?
- Which substances do fruit flies prefer the least?
- Do preferred substances have any characteristic in common?
- What other factors might affect whether or not the fruit flies moved from one part of your choice chamber to another?
- Do you think that it is the fruit itself that attracts the flies? Should they be called *fruit flies* or something else?
- Some experiments could be designed using fruit fly larvae. Do larvae respond the same way that adults respond? Are there other factors in the environment that affect the choice?
- What factors must be controlled in an experiment about environmental variables and behavior?
- What is the difference among phototaxis, chemotaxis, and geotaxis? Do fruit flies demonstrate all of them?
- Does a phototactic response override a chemotactic response?
- Does the age of the fruit fly change its geotactic response?
- Are there other organisms that respond the same as fruit flies? Are there other organisms that respond differently from fruit flies?

■ Analyzing Results

Look for patterns in fly behavior based on the number and ratio of fruit flies on different ends of your choice chamber. How will you determine which of the substances stimulate the greatest negative chemotactic response and positive chemotactic response? Do you see any patterns about materials or forces to which fruit flies are attracted?

Develop a method for sharing your results and conclusions to classmates — and then share them!

 S150 Investigation 12

Designing and Conducting Your Investigation is the student-directed, inquiry-based portion of the investigation. It typically begins with questions that students might want to investigate. Students should strive to connect the questions that they pose, the hypothesis that they generate, or the results of their investigations with the central biological concepts and big ideas most related with their experiment.

In the Student Manual, **Analyzing Results** prompts further thought and discussion about causes and effects and patterns noted during the investigation, and **Evaluating Results** leads students to reflect on their investigative methods, draw conclusions, and make note of potential follow-up investigations.

Summative Assessment

This section describes suggestions for assessing students' understanding of the concepts presented in the investigation, but you are encouraged to develop your own methods of postlab assessment. Each student (or group of students) should present data from a repeated, controlled experiment with graphic representation and quantitative analysis of fruit fly choices.

1. Have students record their experimental design, procedures, data, results, and conclusions in a lab notebook, or have them construct a mini-poster to share with their classmates.
2. Revisit the learning objectives for the investigation and develop strategies (e.g., questions or activities) that can help determine whether or not the learning objective has been met. For example, one learning objective is *The student is able to analyze data to identify possible patterns and relationships between a biotic or abiotic factor and a biological system* (2D1 and 5.1). The student might be asked to complete a data grid of choice for fruit flies, analyze the data, and draw conclusions. Table 1 is an example of a data table that students could construct for themselves as they use the choice chamber (x = number of flies at one of the two ends of the chamber). The students may need to adjust the table to indicate multiple trials.

Table 1. Fruit Fly Choices

Substance	1		2		3		4		5		6		7	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B
1	X	X												
2	X		X	X										
3	X	X	X		X	X								
4		X	X	X	X	X	X	X						
5	X		X	X	X	X		X	X	X				
6	X	X	X		X		X		X	X	X			
7	X	X	X	X	X		X		X	X	X	X	X	X

3. Complete a chi-square analysis of the results to determine if the distribution of the flies is significant.
4. Released AP Exams have several multiple-choice and free-response (essay) questions based on the concepts studied in this investigation. One good example is the free-response question about *Bursatella leachii* (sea slug) from the 1997 AP Biology Exam. These questions could be used to assess students' understanding.

T212 Investigation 12

The **Summative Assessment** section (Teacher Manual) offers suggestions for evaluating students' understanding of the concepts, development of science practices, and gain in thinking skills after students conduct their lab investigations and analyze their results.

BIG IDEA 4: INTERACTIONS

Where Can Students Go from Here?

One possible extension for this investigation is to ask students to identify another organism that behaves similarly to the fruit fly and one that they expect would behave differently. For example, students could substitute ladybugs, houseflies, or mealworms for fruit flies and construct choice chambers using other substances that they think might be attractive to these organisms.

SUPPLEMENTAL RESOURCES

www.fruitfly.org The Berkeley *Drosophila* Genome Project includes links to images and other resources for teachers and students. Teachers should consider looking through this website before beginning the lab to appreciate the breadth of information about *Drosophila*.

Flagg, Raymond. *The Carolina Drosophila Manual*. Burlington, NC: Carolina Biological Supply Company, 1988.

This is a useful manual that comes with each *Drosophila* culture order from Carolina. It may be ordered separately (order number 45-2620 from Carolina Biological Supply Company). Excellent photographs help teachers and students identify different mutants and give guidance for sexing the flies.

<http://www.flybase.org> This is a classic database of *Drosophila* genes and genomes used extensively by researchers and educators. This resource is cited on many other sites, including the Berkeley *Drosophila* Genome Project. It is a general database that could be used by teachers or students who would like to have more information about any particular mutant.

Gargano, Julia Warner, Ian Martin, Poonam Bhandari, and Michael S. Grotewiel. Rapid iterative negative geotaxis (RING): a new method for assessing age-related locomotor decline in *Drosophila*. *Experimental Gerontology* 40, no. 5 (May 2005): 386–395.

Fruit flies' negative geotaxis response declines with age. This resource would be helpful for teachers or students who have designed experiments that use the age of the fruit fly as a variable.

<http://www.hmi.org> The Howard Hughes Medical Center includes multiple resources for teachers about fruit flies. This is a general resource that could lead to ideas for experiments or general information about fruit flies before the class begins the experiments. It includes links to other resources for general information and the scope of research about *Drosophila*. This resource includes very accessible material that would be helpful as a teacher begins the experiments.

Investigation 12 T213

Many of the investigations also provide suggestions for extending the investigation(s) (**Where Can Students Go from Here?**). These suggestions appear in both the Teacher Manual and Student Manual versions of the labs.

CHAPTER 3:

Creating Student-Directed, Inquiry-Based Lab Investigations

Laboratory investigations should engage students, promote critical thinking and active learning, and encourage collaboration among students and between student and teacher (Johnson 2009). The focus of the laboratory experience is not on students achieving predetermined results, but on students making their own observations, raising questions, and strategizing how to investigate them.

The benefits to students of conducting their own investigations outweigh any disadvantages. Advantages include more rapid development of thinking processes and application skills. The biggest disadvantage is the amount of time that may be required for students to conduct their own investigations. With this in mind, it is important to provide students with a timeline for each lab, with options that allow them to perform sections of the lab if finding adequate time is problematic.

■ How to Begin Creating a Student-Directed, Inquiry-Based Lab

In *Inquiry and the National Science Education Standards: a Guide for Teaching and Learning*, the National Research Council (NRC) identifies the following five essential responsibilities of learners conducting inquiry-based labs:

1. Engaging in scientifically oriented questions
2. Giving priority to evidence in responding to questions
3. Formulating explanations from evidence
4. Connecting explanations to scientific knowledge
5. Communicating and justifying explanations

When creating a new lab or modifying a familiar one to be more student directed, inquiry based, and open ended, you should consider these five expectations of students. In addition, when creating a new inquiry-based lab investigation or modifying a familiar lab, you need to identify how the investigation aligns with concepts and science practices outlined in the curriculum framework. You should consider what prior knowledge and skills students must have to perform the investigation, what skills the lab develops, and how the investigation connects back to and builds upon concepts that the student has studied previously.

You also should provide students with guidelines and/or procedures for using particular instruments and equipment. This can be accomplished through prelab demonstrations, online tutorials, or other appropriate methods. In addition, you must consider any safety and housekeeping issues, and determine if the school has resources (e.g., materials, supplies, computers, or other equipment) to conduct a particular investigation. The following table is useful for identifying components and challenges when creating a new student-directed, inquiry-based lab or modifying a familiar one.

■ One Way to Develop a New Inquiry-Based Investigation

Concept:
Big idea focused on:
Enduring understanding(s) addressed:
Goal (What will students learn?):
Resources <i>available</i> to help teach this concept:
Resources <i>needed</i> to help teach this concept:
Some instructional activities that I currently use that could work with this concept:
Lab to be used to support this concept:
Learning objective(s) addressed:
Science practices tied to the learning objective(s):
The level of inquiry reached in this lab (e.g., confirmation, structured, guided, open):
The lab/quantitative skills that my students will need in order to successfully complete this lab:

The content knowledge that my students will need in order to successfully complete this lab:

To help students develop these skills, I will sequence instruction in the following way:

The challenges I foresee:

Some possible solutions to these challenges:

You can use the four-level inquiry model and the NRC's five expectations of students as a tool for a simple, yet effective, method of transitioning your traditional labs to inquiry. Begin by exploring the lab you want to modify. Think about the following question as you read the lab: *What characteristics make this lab "cookbook" rather than inquiry?* Once you have a list of characteristics, write down three to five that you'd like to modify. It's a good idea to incorporate the NRC inquiry model into this step. Ask yourself, *At what inquiry level is the lab currently? Toward what inquiry level do I want the lab to move?* Remember, the important thing is that you're making small changes that will provide your students with inquiry experiences.

Eventually, you may choose to move to a more thorough model. The Matrix for Assessing and Planning Scientific Inquiry (MAPSI) is an inquiry model that describes inquiry labs as specific tasks along a continuum that address four cognitive processes and their subprocesses (see Appendix D). MAPSI is a particularly useful tool for AP science teachers, as each of the cognitive processes and subprocesses addresses two or more of the science practices. If you modify your traditional labs with MAPSI as your guide, you will be addressing several science practices.

The Next Steps

The investigations in this manual support concepts, enduring understandings, and science practices described in the curriculum framework. Many of the labs are new, while others are modifications of familiar labs that have been revised to reflect the shift toward more student-directed and inquiry-based investigations. The following table shows how the current Lab 11: Transpiration differs from Lab 9: Transpiration from the College Board's 2001 *AP Biology Lab Manual*. The differences highlight elements that should be considered when creating an inquiry-based investigation.

■ Transpiration Investigation: New Versus Old

	INVESTIGATION 11: TRANSPIRATION (CURRENT MANUAL)	INVESTIGATION 9: TRANSPIRATION (2001 MANUAL)
Primary Question	There is a primary question for students to investigate.	There is no primary question for students to investigate.
Questions for Investigation	Questions are provided as suggestions, but students generate their own additional questions for investigation.	Students do not generate their own questions for investigation.
Design of Investigation	Students design and conduct their own experiments to investigate their questions.	Students follow step-by-step procedures (“Do this. Do that.”) listed in the investigation.
Alignment to the AP Biology Curriculum Framework	The alignment of the investigation to the big ideas, enduring understandings, science practices, and learning objectives described in the curriculum framework is clear.	The alignment of the investigation to the course is not explicit.
Prelab Assessment	There are suggestions for assessment of prelab knowledge.	There are no suggestions for assessment of prelab knowledge.
Variables for Investigations	The investigation asks students to choose a variable(s) to investigate.	Exercise 9A tells students what environmental variable(s) they will investigate.
Analysis of Results	The investigation instructs students to make observations and analyze their results. The questions in Analyzing Results guide students to communicate their findings.	Exercise 9B instructs students to observe cross-sections of plant tissues under the microscope, draw what they see, and identify the cell and tissue types without asking them to make the connection to the roles of plant tissues in transpiration.
Recording of Data	The investigation recommends that teachers instruct their students to determine appropriate methods of recording data.	The investigation provides tables and graphs and instructs students to fill them out.
Communication of Results	The investigation suggests means by which students can communicate their findings, including lab notebooks, lab reports, and mini-posters.	The investigation instructs students to answer a specific set of questions.
Mathematical Equations	Students are directed to resources, and the prelab assessment includes a question on water potential that is geared toward students with advanced math skills.	All mathematical equations are provided with step-by-step instructions on how to use them.
Skill Development	The investigation provides a list of skills developed and/or reinforced.	The investigation lacks information about skills developed and/or reinforced.
Extension Activities	The investigation suggests extension activities.	There are no suggestions for how students can extend the investigation based on additional questions that they raise.



■ Assessing Student Understanding

Learning occurs most effectively at “teachable moments,” and when one thinks of a good teacher, one often does so in terms of such experiences. As a student-directed investigation progresses, you should circulate among the student groups and ask probing questions to provoke students’ thinking (e.g., *How are you changing the temperature? How are you recording the temperature?*). You may also ask about data and evidence (e.g., *Is there an alternative way to organize the data? Is there some reason the data may not be accurate? What data are important to collect? What are you hoping to find out? How will you communicate your results?*). This strategy will allow you to diagnose and address any misconceptions immediately, and to assess the depth of student understanding of key concepts.



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CHAPTER 4:

Managing the Investigative Experience

■ The Role of the Teacher in Inquiry-Based Instruction

Effective inquiry-based instruction requires the teacher to guide and facilitate laboratory investigations, making the lab experience a vital, engaging component of the course experience. You must be careful not to know (or reveal) the results of the experiments, but rather be genuinely interested in student discoveries and conclusions. The classroom atmosphere should be one where students feel comfortable to observe, hypothesize, predict, and explore new concepts. You must consider any constraints, such as the following:

- **Space:** Where, when, and how will the experiment be performed? Space is often the limiting factor for student-directed, inquiry-based experiences, especially when students extend the lab and begin to ask their own questions. Determine if parts of the experiment can be performed outside the classroom. For example, plants can be grown at home and brought in for the experiment in order to save space.
- **Experimental organism(s):** The experimental organism needs to be readily available. For example, insects can be caught or cultured, and plants can be grown on site. Many classrooms have resources for mice or snakes, but be aware of regulations involving the care and safety of laboratory organisms. Some states have rigorous guidelines, such as not using vertebrate animals for experiments in the classroom. You should demonstrate a respect for all life and insist that your students do the same.
- **Access to materials and equipment:** Students may need to coordinate the sharing of materials and equipment, and/or coordinate with the teacher for access to specialized equipment. Also, they may need to understand the permutations of a student-directed lab, and the need for variations in materials.

You must also model the actions and behavior expected of students (e.g., wear safety glasses or goggles when appropriate, admit when you do not know the answer to a question, refer to books or websites to obtain information, ask questions, and communicate clearly). In short, you should model inquiry as an ongoing, lifelong process.

■ Conducting Inquiry-Based Labs

First, determine students' prior skills and understanding of the key concepts that are addressed in the lab. Most students come to AP Biology with some practical skills (e.g., using a balance, graduated cylinder, ruler, or microscope) and laboratory experience, but the experience may have consisted of demonstrations or investigations with known or expected outcomes, rather than investigations that were inquiry based. The laboratory exercises in this guide might begin with teacher-directed demonstrations of the techniques involved, but lead to questions that students can investigate by designing and conducting their own follow-up experiment(s). It is crucial that students not skip the

open inquiry part of the lab. A student who always stops after the first or second level has not had a full lab experience, and will not have a strong sense of the nature of science.

Second, build up to the inquiry investigation, keeping in mind the four levels of inquiry. It is not reasonable to think that every part of a particular lab in AP Biology will be completely student directed. However, as written, the labs lead to a student-directed, inquiry-based investigation(s). As a reminder, the levels of inquiry are as follows:

- **Confirmation:** Students confirm a principle through an activity in which the results are known in advance.
- **Structured:** Students investigate a teacher-presented question through a prescribed procedure.
- **Guided:** Students investigate a teacher-presented question using student-designed/selected procedures.
- **Open Inquiry:** Students investigate topic-related questions that are formulated through student-designed/selected procedures.

The following table indicates whether the lab questions, procedures, and solutions are teacher provided or student generated for each level of inquiry.

LEVEL OF INQUIRY	QUESTION	PROCEDURE	SOLUTION
Confirmation	Teacher provided	Teacher provided	Teacher provided
Structured	Teacher provided	Teacher provided	Student generated
Guided	Teacher provided	Student generated	Student generated
Open	Student generated	Student generated	Student generated

AP inquiry instruction focuses primarily on the continuum between guided inquiry and open inquiry. Some structured inquiry may be required as students learn particular skills needed to conduct more student-directed forms of inquiry. Student activities that support the learning of science concepts through scientific inquiry in AP classrooms may include reading about known scientific theories and ideas, generating scientifically oriented questions, making predictions or posing preliminary hypotheses, planning investigations, making observations, using tools to gather and analyze data, proposing explanations, reviewing known theories and concepts in light of empirical data, and communicating the results (National Committee on Science Education Standards and Assessment and National Research Council 1996, Grady 2010, and Windschitl 2008).

Third, start with familiar activities, especially if you and your students are just beginning to use more student-directed, inquiry-based laboratory investigations. For example, use common substances (such as tomatoes, apples, or radishes) and have students make observations that lead to a question. Students typically can find something interesting about something familiar within ten minutes of observation. Follow up by having students develop a question about that observation. Questions can be as simple as *Where is the red color located in a tomato?* and *How do the colors of a tomato change?*, or *How will I know if the tomatoes ripen faster?* and *How do I define “ripen”?* Help students determine how they might go about investigating their questions. Simple questions may lead to other questions and hypotheses that can be investigated through experiments.

■ Preparing the Student


Model the inquiry process. As students begin their investigations, you can help them by modeling inquiry as they work through their experimental design. Before students begin the lab, you can ask them about the structure of their investigation. Discuss the following terms:

- **Hypothesis:** The simplest form of a hypothesis is an *If ... then* format. Ask students what they are trying to determine with their experiment, and how they will know if their hypothesis is supported. For example, *We know that tomatoes are fruits, that many fruits produce ethylene, and that ethylene promotes fruit ripening. If tomatoes produce ethylene, then placing them in a container that traps ethylene will cause the tomatoes to ripen faster.*
- **Procedure:** Ask students for the reason behind the lab setup. Have them explain how their procedure will answer the question posed by their hypothesis. Questions to consider include *What kind of information will the procedure give? How will the information be provided? What about reproducibility? Are enough trials being done to have confidence in the results?* In the example above, a student could ask, *How many tomatoes do I need to use? What kind of container? Is the size of the container important? How will I know if the tomatoes ripen faster?*
- **Variables:** What variables are being controlled? Many students know that controls are necessary, but they do not really understand how to allow the manipulation of just one variable at a time. Probe more deeply as to which variable is being controlled and how. For example, in this investigation questions could be *Do I need to control for mass of the tomatoes, or volume of containers, or both? How?*
- **Data collection:** Provide sample data, if needed, and ask what the data mean and how the results support an answer(s) to the question posed.
- **Claims and evidence:** Students should make and justify claims about unnatural phenomena based on evidence produced through reasoning and scientific practices.

After the lab, explore with students the results of their investigation. Do the discrepancies or results lead to more questions? What are they? These questions may form the basis for additional independent follow-up experiments. With these follow-up experiments, you can determine whether your students have acquired the practical skills of measurement and use of equipment.

■ Teaching Techniques for Inquiry-Based Labs

Inquiry requires that students learn to ask questions, pursue answers, and understand that instead of finding answers, they may have more questions as the result of their investigations. The following sentences and phrases, taken from specific free-response questions in the AP Biology Exam that pertain to the lab experience, give a sense of what students should know and be able to demonstrate after completing a laboratory investigation of their own design. These statements provide good prompts for teachers to use as they guide students in their own inquiry. These phrases indicate what students should understand and be able to demonstrate for each of their laboratory activities:

- 
- Explain the purpose of each step of your procedure.
 - Describe how you could determine whether ...
 - Summarize the pattern.
 - Choose one of the variables that you identified, and design a controlled experiment to test ...
 - Explain how the concept _____ is used to account for _____.
 - Describe variables that were not controlled in the experiment, and describe how those variables might have affected the outcome of the experiment.
 - Describe a method to determine...
 - Indicate the results you expect for both the control and the experimental groups.
 - Describe the results depicted in the graph.
 - Describe the essential features of an experimental apparatus that could be used to measure ...
 - Graph the data ... On the same axis, graph additional lines representing ... (a prediction)

CHAPTER 5:

Teaching Quantitative Skills in AP Biology

Which would you choose? A brain biopsy or a CAT/MRI scan? A vaccine for 90%+ of the population with a risk of 0.001% suffering from side effects, or no vaccine at all? Fresh vegetables sprayed with competing bacteria, or vegetables sprayed with sterilants that are hazardous to ecosystems? To risk conviction of a crime based on a detective's hunch, or to be acquitted based on evidence provided by DNA markers? These are routine questions affected by the use of mathematics in science, including biology, medicine, public health, and agriculture.

To have a rich foundation in biology, your students need to apply quantitative methods to the study of biology. This is particularly true for a laboratory experience. Quantitative reasoning is an essential part of inquiry in biology. Many mathematical tools (e.g., statistical tests) were developed originally to work out biological problems.

The pyramid of quantitative reasoning in biology (Figure 1), serves as a framework to help design curricula and lesson plans that incorporate quantitative skills in the study of biology. This framework is inspired by Bloom's Taxonomy of cognitive development. (Bloom's starts with knowledge as basal, and then moves to comprehension, application, analysis, synthesis, and finally, evaluation.) It is hoped that this taxonomy will help you organize your instructional strategies for introducing students to quantitative skills in biology investigations.

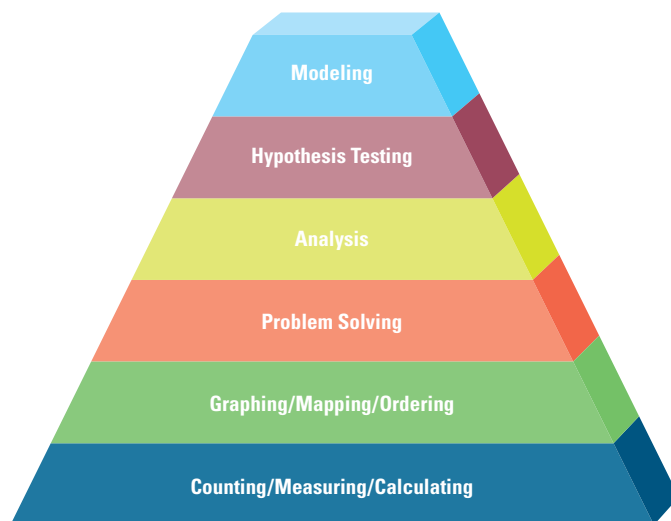


Figure 1. Pyramid of Quantitative Reasoning

This chapter will focus on each of the levels of quantitative reasoning to provide you with a framework to help develop various quantitative skills in biology. For many instructors, quantitative skills were not part of their own background in biology. For this reason, a few specific examples of how quantitative skills inform various areas of biology are included to provide background context. The hope is that these examples will serve to stimulate your own further investigations into quantitative biology with your students.



■ Counting, Measuring, and Calculating

Counting is one of the most common activities of biological observation, yet it is often undervalued. For example, each of the following is a routine operation: counting colonies on a petri plate, fruit flies with a particular set of traits, the number of rings in a tree slice, the trichome hairs on a petiole of a Wisconsin Fast Plant®, or the number of stomata on a leaf. However, more difficult counts involve the number of individuals in a population, such as ants in an anthill, the number of red blood cells in a milliliter of blood on a hemocytometer slide, or the number of leaves on a tree. These counts often involve sampling a subpopulation, using a technique such as capture-mark-and-recapture, or employing a quadrat or transect in field work followed by simple calculations, such as the Lincoln-Peterson estimator³ of population size. Encourage students to develop and justify their own sampling procedures. Explore the strengths and shortcomings of various sampling strategies and techniques in order to instill in your students an understanding of the reasoning that goes into such decisions.

One of the fundamental quantitative expectations of biology teachers is to help their students gain an appreciation for dimensions and the appropriate units of measurement. Too often, students have learned mathematical skills without the context of units. It is doubtful that you can overemphasize the importance of keeping track of units of measurement. It is only through extensive practice with, and attention to, units in calculations that a student begins to develop an intuitive understanding of scale between various levels of biology. For example, the calculations in Investigation 10: Energy Dynamics are relatively simple, but making sure that the units of energy and mass are accounted for is often a challenge for students.

Students (and the general public) typically lack an intuitive understanding of exponential processes, such as compounded interest, population growth, or radioactive decay. Exponential processes abound in biology. Measurement of these processes often involves log scales. We use a logarithmic scale for pH measurements, where a simple 0.3-unit change represents a five-fold change in the concentration of hydrogen ions, or a 2-unit change represents a one-hundred-fold change in the concentration of hydrogen ions. Without an explicit connection to the logarithmic scale of pH measurement, the student often develops an understanding of pH scale that is deficient and overly simplistic — a mental model that will not hold up if the student is asked to compare the acidity of various soils or rain water, for example.

Serial dilutions are another example of a lack of student understanding; somehow it seems counterintuitive to most students to add one mL of media to 9 mL of water to get a 1-to-10 dilution. Or, if they compound two successive serial dilutions by adding 10 mL to 1 mL, mix, remove a 1 mL aliquot, and then dilute with 10 mL of water, students will get a 1-to-121 dilution instead of the 1-to-100 dilution they were anticipating.

The point is to emphasize that mathematics underlies almost every biological experiment performed, even before any analysis of results. Too often, laboratory investigations are designed and implemented in a manner where most of these preliminary calculations are done for the student. By having the students work through these skills, you are laying the foundation for further work.

3 $N = MC/R$, where N = estimate of total population size, M = total number of animals captured and marked on the first visit, C = total number of animals captured on the second visit, and R = number of animals captured on the first visit that were then recaptured on the second visit.

■ Graphing, Mapping, and Ordering

Students need to graph different data sets, and graphing by scatter plots is an ordinary scientific activity (see Figure 2).

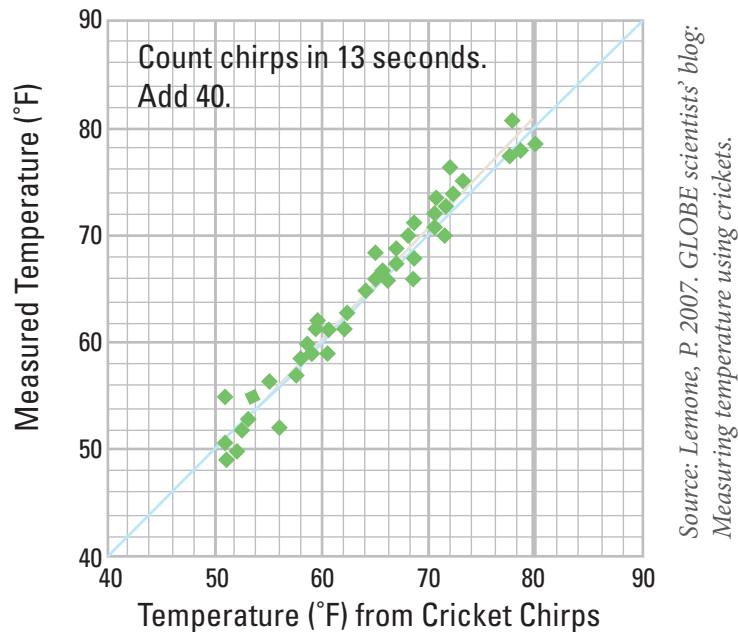


Figure 2. Sample Scatter Plot Graph. Often we would like a straight-line relationship between our predicted value (temperature) based on actual measurements of another variable (number of chirps) and our observed value (temperature).

The more data students graph, the sooner students begin to understand that certain plot shapes or forms are easily associated with models that make it easier to infer causal mechanisms. For example, a bell-shaped curve (see Figure 3) is associated with random samples and normal distributions; a concave upward curve is associated with exponentially increasing functions, such as occur in the early stages of bacterial growth; an S-shaped curve is associated with a carrying capacity of the environment (a logistic curve); and a sine-wave-like curve (see Figure 4) is associated with a biological rhythm. Such shapes are quite familiar to a biologist, and with more frequent exposures, your students will become familiar with these shapes and their biological implications.

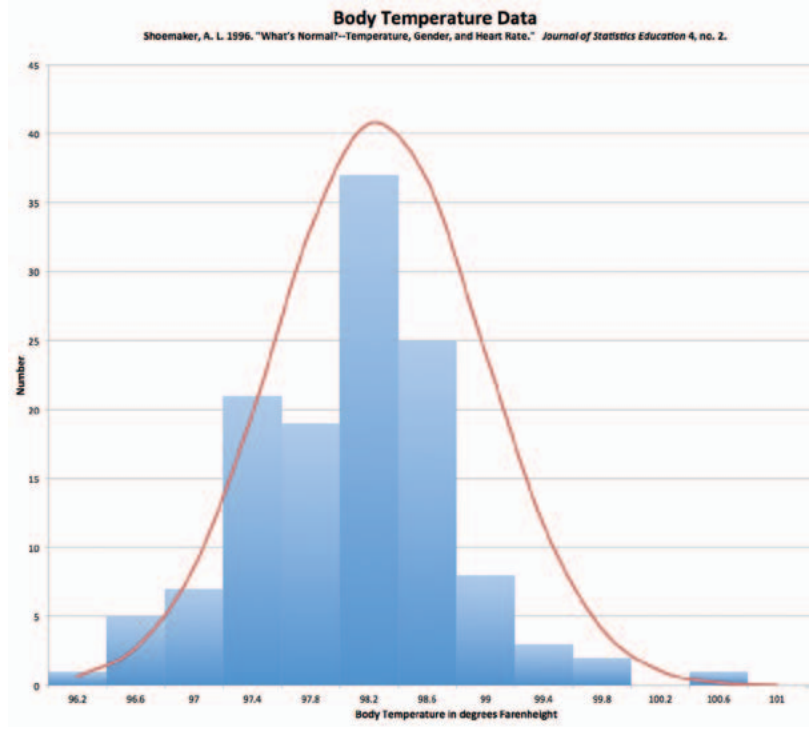


Figure 3

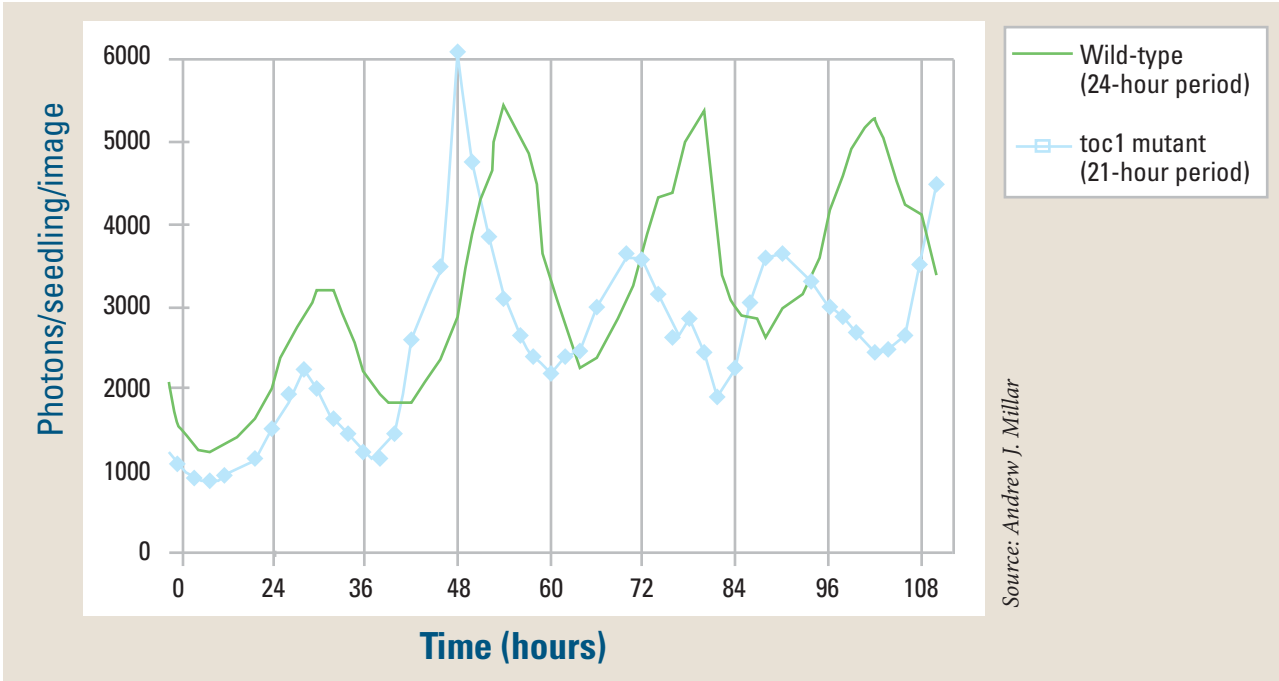



Figure 4. A graph of circadian rhythms in Arabidopsis (Note the sinusoidal behavior over time.)




Mapping is an extremely important tool in biology — from localization of organelles in a cell to world mapping of biodiversity. Some of the easily adopted and adapted activities that help students visualize relationships are (1) looking at the spread of a disease, such as the West Nile virus arriving in New York City and then spreading across the nation over the course of a few years (the data are available from the Center for Disease Control in Atlanta, Georgia); (2) noting the rate of neonatal infant mortality by country (the data are available from the World Health Organization); (3) looking at international malnutrition (such data are available from the Worldmapper website); (4) analyzing the location of hospitals with respect to socioeconomic status of residents in a local community with GIS software, such as that available from the National Geographic Society; (5) mapping bird nests in a park, or ant hills in an individual lawn; and (6) noting intracellular location of organelles (easily mapped out with the use of fluorescent-stained images and tools).

Another important skill is ordering, such as understanding the sequence of a protein or a nucleic acid; the sequence of genes along a chromosome; the pecking order of a hierarchically organized social group within a chicken coop; the trophic levels from producers to primary, secondary, tertiary consumers in a food chain; or the substrate-product series of metabolic pathways or signal cascades.

■ Problem Solving

Students learn to become good problem solvers by *doing* problem solving, rather than just hearing or reading about how scientists solve problems. This requires a great deal of practice, with students working on many different types of problems, such as (1) determining the sequence of a nucleic acid from a series of overlapping fragments generated by the use of fragments by restriction endonucleases; (2) determining the frequency of an allele in a population from electrophoretic analysis of enzymes or DNA fragments from several individuals; (3) determining the genotype of an individual given its phenotype and the genotypes of several ancestors, such as parents or grandparents; or (4) making the forensic identification of an individual using genetic markers. Even so-called “plug-and-chug” problem solving, where students follow an algorithm or apply a formula, helps students to develop an intuition about how sensitive or robust a model is. Interactive software, which lets students vary parameters over wide ranges with multiple variables and visualize results, provides a particularly effective tool to help students better draw inferences about the fit of a particular model to a biological problem.

As you design your instruction, consider making a connection between game strategies and problem-solving strategies. An excellent example is the game Mastermind, where students develop strategies and methods to deduce the colors and sequence of an unknown or hidden sequence of colored pegs (<http://www.mah-jongg.ch/mastermind/mastermind.html>). The goals of this game are directly applicable to sequencing a protein or nucleic acid. Thus, an acid digestion of a protein followed by column or thin layer chromatography can be used to determine the amino acid composition (combination), while the use of a biochemical procedure can be used to determine the sequence (permutation) of that same protein with that particular composition.



As students work through various problems, it is important for them to discuss the heuristics or algorithms that they are developing. Likewise, they should share visual tools, such as concept maps, Punnett squares, forked-lined diagrams, pedigrees, maps, graphs, trees, charts, and tables that help them identify goals, patterns, wrong avenues, or blind alleys; eliminate possibilities; or search for alternatives.

■ Analysis


How does one prepare students for discovering meaningful patterns in the masses of biological information that are readily available in public databases (and that grow larger every day)? One such area emphasized in the current AP Biology laboratory investigations is *bioinformatics*. In Investigation 3: Comparing DNA Sequences to Understand Evolutionary Relationships with BLAST, students will use the Basic Local Alignment Search Tool (BLAST) to collect information to construct cladograms. A cladogram, also called a phylogenetic tree, is a visualization of the evolutionary relatedness of species.

If we use BLAST to compare several genes and use the information to construct cladograms, which parameters are likely to produce a relevant result? If we construct a multiple sequence alignment, how much do we affect our result by our choice of what counts as a chemically similar side chain of an amino acid in a protein? What if we assign different penalties for opening or closing a gap, or use different length chains for the size of gaps? Do the databases change sufficiently in a given time, so that we get a very different result from day to day? What if we use a different database? Is the database well curated and annotated? These are all questions that are relevant to BLAST analysis, or any study involving a public database.

One biologically important example that illustrates some of the quantitative issues in constructing meaningful patterns from complex data sets is evolutionary tree construction from nucleic acid or protein sequences. Phylogenetic analysis of human mitochondrial DNA has allowed us to construct a history of human migration from Africa, to track down the origins of AIDS, and to produce more effective flu vaccines. Phylogenetic analysis is a particularly good mathematical tool to make sense of enormous data sets. Working through this type of analysis allows students to evaluate how the different biological assumptions of mutation rate, adaptation, conservation of characters, parallelism, and convergence affect our construction and interpretation of ancestry, or of any organism.

Do we construct phylogenetic trees from distances (measures of similarity or difference of sequences) or characters (deletions, or structural features like alpha helices)? It is important for students to develop their own metrics for determining the distances between two or more sequences. Doing this allows students to see how the sensitivity of our inference of similarity or dissimilarity is dependent upon the metric used.

Every phylogenetic tree is a hypothesis. How do we interpret the tree? How many trees could be constructed from the same data with a similar degree of fit? How do we visualize a tree? Science education researchers have examined how students interpret phylogenetic trees. The mathematical distinction between geometry and topology are particularly useful here. A tree is like a baby's mobile, with various baby animals dangling above the crib. We can swivel the mobile in the air, or lay the tree down flat



on a table without changing its topology — the links are the same even though which components are next to each other can vary greatly depending upon which nodes we swivel. On the other hand, we can change the topology by simply switching which pendant from which we hang a particular animal.

The use of statistics is widespread in biology. Some examples include (1) examining whether the heights or weights of individuals are normally distributed, (2) testing with a chi-squared goodness-of-fit test whether the results of a dihybrid testcross fit a ratio such as 1:1:1:1, (3) using a student's T-test to see whether two distributions are different from one another, (4) testing whether bird nests are randomly distributed spatially in a prairie or woods, and (5) visually testing the correlation of two variables with linear regression to infer whether a causal relationship might exist (with all of the precautions of not confusing correlation and causation). Your students will employ some of these uses of statistics in Investigation 2: Mathematical Modeling: Hardy-Weinberg. Powerful statistical packages, spreadsheets, and many Web tools are readily available to compute these statistics.

Thus, your focus should not be on teaching computation, but should instead be on helping students develop the skills for using statistics to inform their investigations. For example, students should select appropriate tests before data are collected in order to inform experimental design. They should consider, for example, whether the sample size is sufficiently large to test the hypotheses, how to minimize type I (false positive) and type II (false negative) errors, and whether outliers should be included. Statistics builds on all of the counting, measuring, graphing, data mining, analysis, and problem solving previously described; statistics also facilitates the development of keen judgment to deal with the ambiguous and unwarranted assumptions that are typical of an investigation. As with problem solving, it is essential that students practice and work with several different types of problems that employ statistical analysis of data.

■ Hypothesis Testing

Hypothesis testing is informed with statistical analysis, which helps to distinguish between multiple working hypotheses. Students just beginning to design and carry out their own investigations tend to propose only a single hypothesis as a causal model. However, nature is not always so cooperative. It is important that students, as they develop more expert inquiry skills, learn to propose and investigate all possibilities for a particular phenomenon wherever possible, and to design experiments to eliminate all but one competing hypothesis. Within this manual there are several labs in which students will engage in hypothesis testing. However, discrete examples for application can be used to prepare students.

Here's an example: Leopard frogs have polymorphic patterns on their skins designated as *pipiens*, *mottled*, *burnsi*, or *kandiyohi* phenotypes. How are these patterns inherited? In a classic study, Steven C. Anderson and E. Peter Volpe (Anderson and Volpe 1958) reported the results from experiments to determine how skin pattern is inherited in leopard frogs.

The segregation observed in the progeny of the cross, *kandiyohi* female x *burnsi* male, was 15 *kandiyohi*, 11 *burnsi*, 10 *pipiens*, and 14 *mottled burnsi* (see Figure 5). The reciprocal cross, *burnsi* female x *kandiyohi* male, yielded 10 *kandiyohi*, 7 *burnsi*, 8 *pipiens*, and 5 *mottled burnsi* (see Figure 6). Neither of these ratios differs significantly

from 1:1:1:1 ($p > 0.70$ in the former, $p > 0.50$ in the latter). The results are interpretable on the basis that the parental *kandiyohi* and *burnsi* frogs in each cross were heterozygous. The p-values were calculated from a chi-square test for goodness of fit.

What is the underlying genetic causal model? There are actually two hypotheses that could account for an observed ratio in the offspring of a cross.

1. A one locus-three alleles model similar to the ABO blood type inheritance pattern. The Punnett squares in Figure 5 and Figure 6 display the results of this model.

	Male	C^B	C^S
Female			
C^K	mottled burnsi 14 $C^B C^K$	kandiyohi 15 $C^S C^K$	
C^S	burnsi 11 $C^B C^S$	pipiens 10 $C^S C^S$	

Figure 5

	Male	C^K	C^S
Female			
C^B	mottled burnsi 5 $C^K C^B$	burnsi 7 $C^S C^B$	
C^S	kandiyohi 10 $C^K C^S$	pipiens 8 $C^S C^S$	

Figure 6

GENOTYPE	PHENOTYPE
$C^B C^K$	mottled burnsi
$C^B C^B$	burnsi
$C^B C^S$	burnsi
$C^K C^K$	kandiyohi
$C^K C^S$	kandiyohi
$C^S C^S$	pipiens

2. A two locus-two alleles model (a more typical dihybrid cross). What if the two parents were $Aabb$ and $aaBb$ (using a different notation)? If they are crossed, they would have generated four genotypes ($AaBb$, $Aabb$, $aaBb$, and $aabb$) in a one-to-one-to-one-to-one ratio.

There is a problem — both hypotheses (1 and 2) can account for the data. How could you challenge your students to resolve this issue? What kind of strategies or further investigations could distinguish between the two hypotheses?

Modeling

How does one teach modeling? In this lab manual, one of the exercises walks the students through the steps necessary to begin developing a spreadsheet-based Hardy-Weinberg population genetics model. Throughout this process, students will be making claims and evaluating evidence in support of them, engaging in both reasoning and rebuttal. It is important, though, that you work through these models beforehand to get a feel for the process. To give you an idea of how you might approach modeling instruction, the following is an example of the steps you could take to develop a model of predator-prey cycles with students — as a game and as a mathematical model.

Modeling from Words to Equations to Graphs

The interaction of a predator and a prey population is a fairly straightforward biological system to model because we can begin with a simple accounting of the birth and death of each species. In the following example, there are four main stages: (1) constructing a model game, (2) writing assumptions out as word equations, (3) abstracting the word

equations into arithmetic equations, and (4) generating a calculator or spreadsheet graphic model of the game played over time. Afterward, there are the following summative activities: (1) checking the model against real data, (2) considering alternative models, and (3) recognizing the limitations of the model.

■ Part 1: The FOXRAB Game: The Construction of a Model Game

Construct a game board by modifying a checkerboard/ chessboard with colored tape, so that it is divided into 16 sets of four cells (2 X 2) (see Figure 7). This represents the environment. You will also need beans (or other markers) of two different colors to represent “Foxes and Rabbits.”

- Each team starts with a board and 20 beans of one color (rabbits) and 20 beans of a second color (foxes).
- Mix the bean populations thoroughly, and randomly spread the beans around on the board. (Let students determine how to randomly distribute their beans.)

Apply the rules of FOXRAB.

1. Rabbits reproduce (births): When a rabbit lands on a dark blue square, add a rabbit.
2. Foxes die (deaths): When a fox lands on white square, remove it.
3. If a fox lands in a patch of four (outlined in green border) with a rabbit, then remove the rabbit (death), and add a fox (birth).
4. Count the new number of foxes and rabbits after these three steps.
5. For the next generation, remove all beans, mix the surviving beans thoroughly together, and then randomly spread the beans around on the board again.
6. Repeat (iterate) this procedure numerous times to represent new generations.

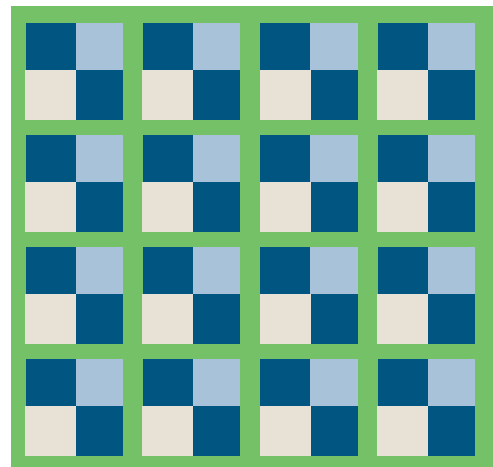


Figure 7. The FOXRAB Game Board

■ Part 2: The FOXRAB Game: Writing Out Assumptions as Word Equations

By looking at the board and game rules, since one-half of all space is covered by dark blue squares, you can presume that one-half of all rabbits will reproduce in a given generation. Similarly, since one-quarter of all space is covered by white squares, you can presume that one-quarter of all foxes will die in a given generation. When a fox eats a rabbit, increase the fox population by one and decrease the rabbit population by one. During the process, the environment does not change in favor of one species, and the genetic adaptation is sufficiently slow. The extent of interaction of the two populations (how often a fox eats a rabbit) can be estimated by playing the board game many times.

Some less obvious assumptions that students may raise include a number of assumptions about the environment and the behavior of each population, such as the following:

- The prey population finds ample food at all times.
- The food supply of the predator population (which makes fertility, reproduction, and survival possible) depends entirely on the prey population.
- The rate of change of a population is proportional to its size.

Generally, these assumptions will not affect the basic generation of a model because they are embedded implicitly.

■ Part 3: The FOXRAB Game:

Abstracting the Word Equations into Arithmetic Equations

Word equation (1): *The change in the rabbit population is equal to plus one-half the original number of rabbits minus an estimate of the interaction between rabbits and foxes in this environment.*

$$\text{Arithmetic equation (1): } \Delta R = +(1/2)R_i - (1/40)R_i F_i$$

Where R_i is the initial number of rabbits and F_i is the initial number of foxes, ΔR is the change in the size of the rabbit population.

Similarly, word equation (2): *The change in the fox population is equal to minus one-quarter the original number of foxes plus an estimate of the interaction between rabbits and foxes in this environment.*

$$\text{Arithmetic equation (2): } \Delta F = -(1/4)F_i + (1/40)R_i F_i$$

As before, F_i is the initial number of foxes and R_i is the initial number of rabbits. Similarly, ΔF is the change in the size of the fox population.

■ Part 4: The FOXRAB Game:

Generating a Calculator or Spreadsheet Graphic Model of the Game Played over Time

The next step of this model-building process would be to have the students create a calculator or spreadsheet graphic model. Spreadsheets are particularly appropriate for this work. Simply reinterpret the two arithmetic equations into a spreadsheet form to calculate the change in the rabbit and the fox populations. If each row of the spreadsheet represents a single generation, you can model multiple generations by using the results from the previous row to calculate the next row, thereby iterating the same generational process that students went through in the physical game version of the model.

Have the students construct a variety of graphs, such as the following, from the spreadsheet or calculator results to develop a deeper understanding of the model:

- Number of foxes vs. generation number
- Number of rabbits vs. generation number
- A combination of the two graphs (i.e., with two y-axes) to see coupled oscillations
- A graph of foxes versus rabbits to examine/observe cycles



Some questions that you might pursue with students include the following:

1. What is the sensitivity to different initial conditions? (That is, starting with different numbers of foxes and rabbits, what is the impact of slightly perturbing the system?)
2. If you start with the same numbers as in your first experiment, do your results look the same?
3. In reality, some rabbits and foxes may die, or be infertile for other reasons. Should we treat such factors as random or not? How might we incorporate them into the game versus in the model?
4. In general, how can we modify the above equations to make a model with the realistic outcomes of the board game?
5. How does the model change if the board configuration changes?

■ Why Model?

The following are five pragmatic uses for models in biology⁴:

1. Simple models help biologists explore complex systems.
2. Models can be used to explore various possibilities.
3. Models can lead to the development of conceptual frameworks.
4. Models can make accurate predictions.
5. Models can generate explanations.

But why engage students in modeling? The University of Wisconsin's Project MUSE: Modeling for Understanding in Science Education proposes that students work at the following four levels of problem solving:

1. Model-Less Problem Solving
2. Model-Using Problem Solving
3. Model-Revising Problem Solving
4. Model-Building Problem Solving

The MUSE taxonomy helps us recognize that as students learn to build models, they also develop an enhanced ability to solve problems at an expert level, rather than at a novice level. Students who use models develop a much better sense of epistemology (how do we know that we know), and they are able to transfer their modeling insights to other subject areas (Svoboda 2010). The impact of working with models on student learning makes modeling instruction well worth the time invested.

4 Jay Odenbaugh, "The strategy of model building in population biology," *Biology and Philosophy* 21 (2006): 607–621.

CONCLUSION

The pyramid model for quantitative reasoning in biology (see Figure 1) demonstrates that there are various biological activities that are useful in many laboratory contexts and student learning. However, from a teaching standpoint, it must be stressed that the pyramid can be easily misconstrued as stressing activities at the bottom because that portion of the pyramid is larger, or that the only goal is to get all students to be good modelers. An alternative structure, such as the interconnected network, would be an equally valid organizational tool (see Figure 8). It is realistic because all of the arenas interact and reinforce one another. Furthermore, both students and scientists have heterogeneous talents and interests that are crucial to the advancement of science.

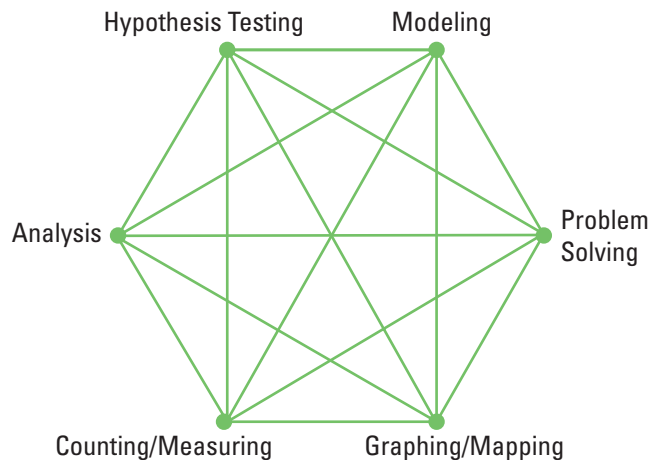


Figure 8. Interconnected Network. Quantitative reasoning in biology requires a series of skills that simultaneously intersect and mutually support one another.

Mathematics is an essential element of improvement in biology education. Which would you choose? A brain biopsy or a CAT/MRI scan? A vaccine for 90%+ of the population with a risk of 0.001% suffering from side effects, or no vaccine at all? Fresh vegetables sprayed with competing bacteria, or vegetables sprayed with sterilants that are hazardous to ecosystems? To risk conviction of a crime based on a detective's hunch, or to be acquitted based on evidence provided by DNA markers? These are routine questions affected by the use of mathematics in biology, medicine, public health, and agriculture. Will your students be prepared to address these issues as well as important global problems affecting their futures?

CHAPTER 6:

Written, Verbal, and Graphic Communication

For laboratory investigations to be positive learning experiences, students must be able to communicate their experimental results to peers. Communication begins with small-group or class discussions of the primary question(s) and possible means of exploring answers. This tactic helps students understand the relationship among their hypotheses, procedures, and results, while allowing them to consider potential sources of errors and changes in methodology. Since many of the laboratory investigations described in this guide contain suggestions for additional study, discussing a given experiment serves as a launching pad for independent work, culminating in a formal presentation and summative assessment.

Suggestions for presentations are described below. A combination of methods allows for flexibility in the classroom; not all investigations merit a lab report, mini-poster, or inclusion in a portfolio. However, students conducting an independent investigation, either alone or in a small group, should learn how to organize and present their work in an appropriate, formal manner. Students should be encouraged to choose a means of presentation that effectively describes their question for investigation, background information, hypothesis, experimental results, conclusions, and literature cited. Regardless of the format in which students present their work, an opportunity for peer review should be provided.

Peer Review

Peer review provides an opportunity for students to ask critical questions. Students who question the work of others sharpen their own thinking skills in the process. The nature of the review can mirror what is called scientific argumentation. It focuses on the experimental design, data, and conclusions, but not on the personalities of the scientists. At first, students may need guidance, perhaps beginning with a list of questions (such as the following) to consider as they review others' work:

- Equivalency of sources for comparison:
 - Is there the same amount of material (e.g., tissue) in each experiment?
 - How was the amount of material measured? Dry weight? Wet weight?
 - Was the activity (e.g., reaction) reported per unit measure?
 - Was the experimental procedure repeated several times?
 - Was the sample size sufficient?
- Confounding variables:
 - What conditions were controlled in the experiment?
 - How were these conditions controlled?
 - Were any variables overlooked?

- Results and conclusions:
 - Are the results significant? Do they support or refute the original hypothesis?
 - Are the results reproducible?
 - Are the conclusions supported by the data?
 - Are there alternative conclusions?
 - What additional questions can be asked that lend themselves to further investigation?

Different experiments will undoubtedly lead to different questions. However, knowing that their work will be reviewed by peers will encourage students to plan and execute lab investigations on their own.

■ Mini-Posters and Presentations

At scientific conferences, many experiments are presented as posters. However, requiring students to construct detailed posters for every lab investigation would be very time consuming. An alternative is to have students prepare “mini-posters” that confer a degree of authenticity to their investigative process, and incorporate peer review. The materials used to create mini-posters are easily accessible; students can use file folders and sticky notes rather than large poster boards. Mini-posters are an effective way for students to articulate the essential elements of their research clearly and briefly: title; abstract; introduction with primary question, background context, and hypothesis; methodology; results, including graphs, tables, charts, and statistical analysis; conclusions and discussion; and literature cited.

Poster work can be done by groups or by individuals. To conserve time, one strategy is to divide the class in half by groups. Half of the groups stay with their posters to explain their original work, while the other half play the part of a critical audience. To guide this audience, the teacher provides a one-page rubric for scoring each poster. This audience of evaluators circulates around the room, and after a few rounds, the groups switch places; the poster presenters become the critical audience, and the evaluators become presenters. Before formal evaluation by the teacher, students revise their posters based on peer review. More information can be found at <http://www.nabt.org/blog/2010/05/04/mini-posters-authentic-peer-review-in-the-classroom>.

■ Lab Notebooks/Lab Portfolios

Notebooks and portfolios make for easy assessment of a student’s work. A lab notebook should contain information necessary for making a formal report, including a prelab experimental outline. Before students conduct their investigations, the teacher must review each group’s experimental design to identify any safety issues, and to ensure that the student-directed investigation is challenging and aligns with the goals of inquiry and conceptual context (Johnson 2009). The prelab outline should contain the following information:

- Members of work group
- Primary question for investigation
- Background observations and contextual information
- Hypothesis and rationale for the investigation

- Experimental design — strategies for testing hypothesis, using appropriate controls and variables
- Materials required
- Safety issues

In addition, for each investigation the lab notebook should contain the following:

- Results, including graphs, tables, drawings or diagrams, statistical analysis
- Conclusions and discussion — Was the hypothesis supported? What additional questions remain for further investigation? Are there alternative interpretations or conclusions?
- References

After the initial lab, you may choose to evaluate laboratory notebooks randomly, thus lessening the grading load. Such random checking keeps the responsibility on the students to enter their work carefully and completely.

Portfolios typically contain representative work chosen by the student that shows evidence of learning, plus a narrative by the student that reflects on that evidence and ties it together (Johnson 2009). A lab portfolio might contain finished lab reports, notes on individual projects, library research, essays, excerpts from exams, and reflections on particular lab experiences and the problems that were encountered, as well as connections with other parts of the course, or a combination of these elements. Although portfolios provide a means for the teacher to monitor students' progress over an extended period, finding the time needed to help students learn to showcase their work and to find an appropriate way to evaluate students' work can present a challenge.

■ Lab Reports/Papers

A formal report, or paper, provides an effective method for students to organize their work, and prepares them for doing research papers in scientific journals. A formal report would include several elements in addition to the information in the lab notebook, such as an introduction that may be prefaced by an abstract, and perhaps a discussion before the conclusion. The introduction gives a context for the experiment, and the discussion may include information from other sources that pertain to the experiment. Advantages of this type of report include the experience in writing clearly, as well as the opportunities for students to reflect on their work. Many teachers use a rubric, such as the following, for evaluation.

■ Sample Lab Report Rubric (100 points available)

TITLE	-Concise explains the purpose of the investigation (e.g., the effect of additional nitrogen fertilizer on the growth rate of corn)	3 pts
ABSTRACT	-A summary of the lab investigation -Fewer than 100 words (This should mirror abstracts for articles in scientific journals.)	3 pts
INTRODUCTION	-Background information -Purpose of the investigation; how the investigation answers a specific question; curricular context -Hypothesis(es) (“if ... then”)	5 pts 5 pts 5 pts
MATERIALS AND PROCEDURES	-Materials/supplies listed -Procedures clearly stated	5 pts 5 pts
RESULTS/DATA COLLECTION/ ANALYSIS	-Data recorded in tables (tables titled, calculations completed) -Graphs (X-Y and histograms) present -Graphs titled -Axes labeled correctly -Statistical analysis	10 pts 10 pts 2 pts 3 pts 5 pts
CONCLUSIONS AND DISCUSSION	-Results summarized -Errors identified -Results compared to hypothesis and primary question -Conclusions stated/results interpreted -Suggestions for improvement	2 pts 2 pts 2 pts 10 pts 4 pts
QUESTIONS	-What are questions for further investigation? What new questions arise from the results of the investigation?	12 pts
LITERATURE CITED	-Cited within write-up -Accuracy of citation information	2 pts 2 pts
CORRECT USE OF LANGUAGE	-Grammar -Punctuation -Spelling	1 pt 1 pt 1 pt

Students should complete the rubric, and hand this in with their report as a form of self-analysis. You can then complete the rubric, and compare your critique with your students’.

■ Technology

Numerous sites are available for posting class data that produce a larger sample for analysis, comparison of different conditions in the experiment, or collaboration between students in different class sections or different schools. Wikispaces is one readily available Web-based instrument, but your technology center may recommend others.

CHAPTER 7:

Making AP Biology Inclusive for All Learners

■ Safety

All students, including those with learning differences, must have the opportunity to participate in the laboratory investigations. The inclusion of students with special needs can be implemented successfully when you are given proper materials to assist students in the lab (as needed), and are provided with support from professionals who specialize in various disabilities.

The primary concern for teachers is the safety of students in the lab. Because you may need to spend more time with a special-needs student, attention should be given to the number of students you will supervise during lab activities. You should know and adhere to the laboratory occupancy load limit. These limits are based on building and fire safety codes, the size and design of the laboratory, the teaching facility, and chemical/physical/biological hazards. Accidents are more likely to happen when limits are ignored. Having special-needs students in the lab may require that the load limit be reduced to ensure that you can give proper supervision to all students in the lab.


A team of educators (counselors, science teachers, special-education teachers, and school administrators) should discuss reducing the teacher/student ratio. When needed, teacher aides should accompany students in the lab. Special equipment should be made available to assist the students, as recommended by the team of educators making these decisions.

■ Accommodations

Both physical and nonphysical accommodations that enhance learning can be made for students with special needs. The most common special needs relate to (1) vision, (2) mobility, (3) learning and attention, (4) hearing, and (5) health. Consultation with educational professionals who specialize in the particular need is important. Awareness of organizations such as DO-IT (Disabilities, Opportunities, Internetworking, and Technology) can provide teachers with information about working in the laboratory/classroom with students with special needs. Many students with learning issues have individualized education programs (IEPs), which can guide the accommodations.

You may want to consider including the following suggestions:

- **Students with vision impairments** might benefit greatly from enhanced verbal descriptions and demonstrations. Lab equipment can be purchased with Braille instructions, promoting independent participation for visually impaired students. Students with visual challenges might also benefit from preferential seating that allows them to see demonstrations more easily. If possible, you should provide students with raised-line drawings and tactile models for illustrations. You might also consider using technology to increase accessibility to the lab experience. For example, video cameras attached to a computer or television monitor can be used to enlarge microscope images.

- 
- **Students who have mobility challenges** may need a wheelchair-accessible field site. You should keep the lab uncluttered, and make sure that aisles are wide enough for wheelchair movement. Students often can see a demonstration better if a mirror is placed above the instructor. Lab adaptations are available for students with mobility problems to assist them in most lab activities. You will need to know a student's limitations before planning a successful lab experience.
 - **Students with hearing difficulty** might benefit from preferential seating near you when you give demonstrations. It is also helpful to provide hearing-impaired students with written instructions prior to the lab, and to use instructor captioning when showing videos and DVDs.
 - **Students who have learning and attention disabilities** may need a combination of oral, written, and pictorial instruction. Scaffolding instruction increases learning, and safety issues and procedural instructions may need to be repeated. Having audio-taped instructions may be helpful to allow students to hear them as often as needed for comprehension. Some students who have attention difficulties need frequent breaks to allow them to move around and refocus. Providing students with preferential seating to avoid distractions is also helpful. Students with reading and writing deficiencies often require more time to prepare for lessons and to complete the follow-up activities. Students with learning and attention disabilities sometimes benefit greatly from the use of technology, such as scanning and speaking pens that help with reading. Other students might benefit from using laptops to take notes during class.
 - You should be knowledgeable of **students with health issues**, such as allergies or insulin-dependent diabetes. Care should be taken to avoid risking a student's health because of exposure to chemicals or allergens while conducting laboratory investigations.

■ Universal Design

Creating a laboratory environment that is universal in design should address most concerns and accommodations for students with disabilities. In addition, most of the suggested changes should improve learning opportunities for *all* students in the lab. You should be proactive whenever possible by implementing accommodations, including the following:

- Providing both written and oral directions
- Giving students adequate time to prepare for labs and to complete follow-up activities
- Making the aisles wide enough for wheelchairs
- Installing a mirror above the area where demonstrations are performed
- Using tables that can be adjusted for height


■ Developing a Community of Learners

You must foster the creation of a learning environment that includes and respects all students. For example, creating cooperative learning groups provides students with the opportunity to share their knowledge and skills, and to learn from each other. This is particularly advantageous for special-needs students. An inclusive learning environment also provides a variety of types of learning opportunities that accommodate differences in background knowledge, and address the needs of visual, auditory, and kinesthetic learners.

Teachers may find it helpful to talk with students to discover firsthand what accommodations they need to make their lab experience successful. By modeling attitudes and behaviors expected from students, you can develop activities that help *all* students build meaningful academic and personal relationships.

■ REFERENCES

- Counsel of State Science Supervisors. “General Lab Safety Recommendations.” n.d. Accessed September 8, 2010.
<http://www.csss-science.org/recommendations.shtml>
- Ost, David H. 1987. “Models, Modeling and the Teaching of Science and Mathematics.” *School Science and Mathematics* 87 (5): 363–370.
- Grady, J. 2010. “The Inquiry Matrix.” *The Science Teacher* 21 (1): 32–37.
- Johnson, A. D. 2009. *40 Inquiry Exercises for the College Biology Lab*. Arlington, VA: NSTA Press.
- Lemone, P. 2007. GLOBE scientists’ blog: *Measuring temperature using crickets*.
<http://www.globe.gov/fsl/scientistsblog/2007/10/05/measuring-temperature-using-crickets>
- National Committee on Science Education Standards and Assessment and National Research Council. 1996. *National Science Education Standards*. Washington, D.C.: The National Academic Press.
- NSELA (National Science Education Leadership Association). 2009. “Occupancy Loads in School Science Laboratories.” October 21. Accessed September 5, 2010.
http://www.nsela.org/index.php?option=com_content&view=article&id=71:psoc_cupan_cy&catid=37:ps&Itemid=60
- NSTA (National Science Teachers Association). “The Integral Role of Laboratory Investigations in Science Instruction.” n.d. Accessed September 5, 2010.
<http://www.nsta.org/about/positions/laboratory.aspx>
- Olson, Steve, and Susan Loucks-Horsley, eds. 2000. *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning*. Washington, D.C.: The National Academic Press.



Svoboda, Julia Marie. 2010. Modeling Science: Supporting a More Authentic Epistemology of Science. PhD diss., University of California, Davis. ProQuest (AAT 3422753).

University of Washington. 2009. "Making Science Labs Accessible to Students with Disabilities." March 3. Accessed September 8, 2010.

http://www.washington.edu/doit/Brochures/Academics/science_lab.html

Waterman, M., and E. Stanley. 2008. *Biological Inquiry: A Workbook of Investigative Cases for Campbell and Reece Biology*. 8th ed. San Francisco, CA: Benjamin Cummings.

Windschitl, M. 2008. "What Is Inquiry? A Framework for Thinking About Authentic Scientific Practice in the Classroom." In *Science as Inquiry in the Secondary Setting*, eds. J. Luft, R. L. Bell and J. Gess-Newsome, 1–20. Arlington, VA: NSTA Press.

Introduction

■ GOALS OF THE LABORATORY INVESTIGATIONS

Knowing a collection of facts about biology is beneficial only if you can use that information to understand and investigate a particular aspect of the natural world. AP® Biology lab investigations allow you to explore the natural world, and provide opportunities for you to choose to study what interests you most about each concept. Science is about the process of investigating, and should be a central part of your experience in AP Biology. Performing labs also gives you insight into the nature of science, and helps you appreciate the investigations and processes that result in the collection of facts that your textbook and your teacher often present to you.

This suite of AP Biology laboratory investigations helps you gain enduring understandings of biological concepts and the scientific evidence that supports them. The investigations allow you to develop and apply practices and skills used by scientists. You make observations, ask questions, and then design plans for experiments, data collection, application of mathematical routines, and refinement of testable explanations and predictions. As you work through your experiments, your teacher will ask follow-up questions to assess how well you understand key concepts. Finally, you will communicate your findings and your interpretation of them to your classmates and instructor(s).

For each investigation in this manual, you will find the following:

- Background information and clear learning objectives for each investigation
- Prelab questions, activities, software simulations, and other supplemental resources
- “Checklists” of prior skills and skills that will be developed
- Tips for designing and conducting investigations
- Safety concerns
- Lists of materials and supplies
- Methods of analyzing and evaluating results
- Means of communicating results and conclusions
- Postlab questions and activities
- Suggestions for extending the investigation(s)

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CHAPTER 1:

What Is Inquiry?

How do we know what we know? Inquiry begins with observations you make about the natural world — a bare spot under a tree, a bird chirping repeatedly, or an unusual spot on your skin. If you follow such observations by a question, such as *What is causing that?*, you have begun an inquiry. Inquiry-based laboratory investigations allow you to discover information for yourself, and model the behavior of scientists as you observe and explore. Through inquiry, you use a variety of methods to answer questions you raise. These methods include laboratory and field investigations; manipulation of software simulations, models, and data sets; and meaningful online research. By designing experiments to test hypotheses, analyze data, and communicate results and conclusions, you appreciate that a scientific method of investigation is cyclic, not linear; each observation or experimental result raises new questions about how the world works, thus leading to open-ended investigations.

There are four levels of inquiry that lead to the student question. It is not reasonable to think that every part of a particular lab in AP Biology will be completely student directed. However, as written, the labs lead to a student-directed, inquiry-based investigation(s). The four levels of inquiry are as follows:

- **Confirmation.** At this level, you confirm a principle through an activity in which the results are known in advance.
- **Structured Inquiry.** At this level, you investigate a teacher-presented question through a prescribed procedure.
- **Guided Inquiry.** At this level, you investigate a teacher-presented question using procedures that you design/select.
- **Open Inquiry.** At this level, you investigate topic-related questions that are formulated through procedures that you design/select.

As you work on your investigations, your teacher may walk around the room and ask probing questions to provoke your thinking (e.g., *How are you changing the temperature? How are you recording the temperature?*). Your teacher may also ask about data and evidence (e.g., *Is there an alternative way to organize the data? Is there some reason the data may not be accurate? What data are important to collect? What are you hoping to find out? How will you communicate your results?*). This strategy will allow your teacher to diagnose and address any misconceptions immediately.

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CHAPTER 2:

Written, Verbal, and Graphic Communication

Experimental results must be communicated to peers to have value. To understand the relationship among your hypothesis, procedures, and results, you should first take part in an informal small-group or class discussion of the experiment, including possible errors, changes in procedures, and alternative explanations for your data. Since many of the laboratory experiences described in this manual contain suggestions for further investigation, discussion of a given experiment can be a launching pad for independent work, culminating in a formal written report, poster, or oral presentation. Some possibilities for more permanent presentations are described below.

■ Mini-Posters and Presentations

At scientific conferences, many experiments are presented orally or via posters. Posters provide the advantage of clarity and brevity that articulate the essential elements of the research. In a class, an alternative to the standard oral presentation or a full-sized poster is a mini-poster session, which requires fewer materials and less time than a formal presentation. You can include the most important elements of a full-sized poster, present your work, and get feedback from your classmates in an informal setting. The essential elements of a mini-poster are as follows:

- Title
- Abstract
- Introduction with primary question, background context, and hypothesis
- Methodology
- Results, including graphs, tables, charts, and statistical analyses
- Conclusions, or your interpretation of your results based on your hypothesis
- Literature cited

An example of a mini-poster session can be found at <http://www.nabt.org/blog/2010/05/04/mini-posters-authentic-peer-review-in-the-classroom>.

Such a session allows you to evaluate information on your own, and then discuss it with other students, mimicking authentic presentations and peer review.



■ Lab Notebooks/Portfolios

A lab notebook allows you to organize your work so that you have the information for a more formal report. Your lab notebook should contain the information necessary for making a formal report, which may include a prelab experimental outline with the following information:

- Members of work group
- Primary question for investigation
- Background observations and contextual information
- Hypothesis and rationale for the investigation
- Experimental design — strategies for testing hypothesis, using appropriate controls and variables
- Materials required
- Safety issues
- Procedure in sufficient detail so that someone could replicate your results

In addition, your lab notebook should contain the following:

- Results, including graphs, tables, drawings or diagrams, and statistical analysis
- Conclusion and discussion — Was the hypothesis supported? What additional questions remain for further investigation?
- References

A lab portfolio might contain finished lab reports, notes on individual projects, library research, reflections on particular lab experiences, and connections with other parts of the course, or a combination of these elements as requested by your teacher.

■ Lab Reports/Papers

A formal report or paper provides an effective method for you to organize your work, and mimics papers in scientific journals. Your teacher might provide a rubric for what information should be included. This type of report gives you writing experience and opportunities to reflect on your work. (Refer to page 10 for tips on constructing informative graphs to include in your report.) The writing center at the University of North Carolina has published an excellent guide for writing lab reports. Find it at http://www.unc.edu/depts/wcweb/handouts/lab_report_complete.html.

You also can see a good example of a descriptive lab report, “Examination of Protozoan Cultures to Determine Cellular Structure and Motion Pattern,” at <http://www.ncsu.edu/labwrite/res/labreport/sampledescriptlab.html>.

Technology

There are numerous websites for posting class data, which can then provide a larger sample for analysis, comparison of different conditions in the experiment, or collaboration between students in different class sections and different schools. Your school's technology or media center personnel may recommend appropriate Web-based options.


Graphs

A graph is a visual representation of your data, and you want your graph to be as clear as possible to the reader for interpretation. First, you have to decide whether to use a scatter plot in order to draw a “best fit” line through data points, a bar graph, or some other representation with appropriate units. Use a line graph if your data are continuous (e.g., the appearance of product over time in an enzyme reaction). If your data are discontinuous (e.g., the amount of water consumption in different high schools), use a bar graph. Your teacher might have other suggestions.

A graph must have a title that informs the reader about the experiment. Labeling a graph as simply “Graph Number Four” doesn't tell the reader anything about the experiment, or the results. In comparison, the title “The Effect of Different Concentrations of Auxin on Root Growth” tells the reader exactly what was being measured. Make sure each line or bar on your graph is easily identifiable by the reader.

Axes must be clearly labeled with units.

- The x-axis shows the independent variable. Time is an example of an independent variable. Other possibilities for an independent variable might be light intensity, or the concentration of a hormone or nutrient.
- The y-axis denotes the dependent variable, or what is being affected by the condition (independent variable) shown on the x-axis.
- Intervals must be uniform. For example, if one square on the x-axis equals five minutes, each interval must be the same and not change to ten minutes or one minute. If there is a break in the graph, such as a time course over which little happens for an extended period, note this with a break in the axis and a corresponding break in the data line.
- For clarity, you do not have to label each interval. You can label every five or ten intervals, or whatever is appropriate.
- Label the x-axis and y-axis so that a reader can easily see the information.



More than one condition of an experiment may be shown on a graph using different lines. For example, you can compare the appearance of a product in an enzyme reaction at different temperatures on the same graph. In this case, each line must be clearly differentiated from the others — by a label, a different style, or color indicated by a key. These techniques provide an easy way to compare the results of your experiments.

Be clear as to whether your data start at the origin (0,0) or not. Do not extend your line to the origin if your data do not start there. In addition, do not extend your line beyond your last data point (extrapolation) unless you clearly indicate by a dashed line (or some other demarcation) that this is your prediction about what may happen.

For more detailed information about graphs, see Appendix B: Constructing Line Graphs.

CHAPTER 3:

Quantitative Reasoning in AP[®] Biology

Which would you choose? A brain biopsy or a CAT/MRI scan? A vaccine for 90%+ of the population with a risk of 0.001% suffering from side effects, or no vaccine at all? Fresh vegetables sprayed with competing bacteria, or vegetables sprayed with sterilants that are hazardous to ecosystems? To risk conviction of a crime based on a detective's hunch, or to be acquitted based on evidence provided by DNA markers? These are routine questions affected by the use of mathematics in science, including biology, medicine, public health, and agriculture.

To have a rich foundation in biology, you need to include and apply quantitative methods to the study of biology. This is particularly true for a laboratory experience. Quantitative reasoning is an essential part of inquiry in biology. Many mathematical tools (e.g., statistical tests) were developed originally to work out biological problems.

Mathematics can help biologists (and biology students) grasp and work out problems that are otherwise:

- Too big (such as the biosphere)
- Too slow (macroevolution)
- Too remote in time (early extinctions)
- Too complex (human brain)
- Too small (molecular structures and interactions)
- Too fast (photosynthesis)
- Too remote in space (life in extreme environments)
- Too dangerous or unethical (how infectious agents interact with human populations)

The laboratory investigations in this manual were chosen to provide you with an opportunity to do biology — to explore your own questions and try to find answers to those questions. Many of the investigations provide a preliminary, guided exploration to introduce you to a way of looking at a biology problem, or method for studying it, providing just enough familiarity with the topics so that you can begin asking your own questions and investigating them. An essential part of that exploration includes an introduction to various quantitative skills — mathematical routines, concepts, methods, or operations used to interpret information, solve problems, and make decisions — that you will need in order to explore the investigative topic adequately.

The quantitative skills you'll apply as you carry out the investigations in this lab manual are for the most part the same skills you have been acquiring in your mathematics courses. For many of the skills required in these labs, you already understand how to do the math, and these investigations simply extend the application of those math skills. Your teacher can help to guide you as you supplement and review the quantitative skills required for the various laboratory investigations in this manual.

To conceptually organize the scope and nature of the skills involved, refer to Figure 1:

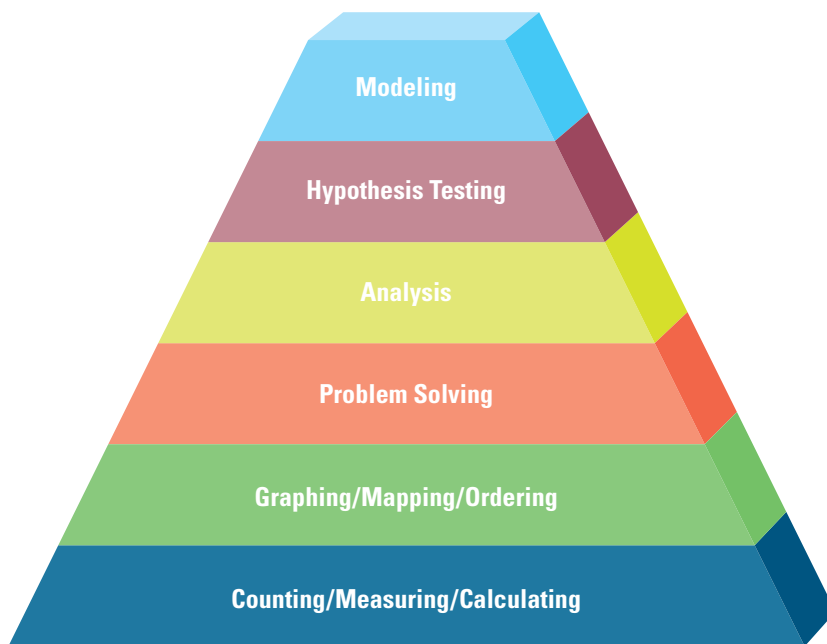



Figure 1. Pyramid of Quantitative Reasoning

The figure graphically organizes the quantitative skills featured in this lab manual. The skills labeled on the bottom of the pyramid are generally less complex, and require the application of standard procedures. As you move up the pyramid, the applications become more complex as you try to make sense out of data and biological phenomena. One of the important lessons about quantitative reasoning is that real data are “messy.” The increasing complexity as you move up this pyramid does not necessarily indicate that the mathematical operations themselves are more complex. Good, first approximations of mathematical models often require only simple arithmetic. This chapter describes how the quantitative skills listed in the pyramid are applied when answering questions generated by various lab topics in this manual.

■ Counting, Measuring, and Calculating

At this point in your education, you may not feel that counting, measuring, and calculating represent much in the way of a “skill.” And you’d be right in a theoretical world. The problem is that your investigation will explore the real world of biology, and that is messy.

For example, Investigation 1: Artificial Selection presents the problem of selection of quantitative variation in a population of plants. You identify a trait that can be quantified (counted), and then measure the variation in the population of plants by



counting. This is not always as easy as it sounds. You will notice that some of the plants in your population are more hairy than others, so this is the trait you select. What do you count? All the hairs? Some of the hairs on specific parts of the plant? On how many plants? After observing one of your plants more closely, you see that it has very few (if any) hairs, but another plant has hundreds. These hairs are small. You have a limited amount of time to make your counts. How do you sample the population? After discussion with your lab partner(s), you and your class decide to count just the hairs on the first true leaf's petiole (stalk attaching the blade to the stem) — a much smaller and more reasonable amount to count, but you'll still need to work out whether or not it is a representative sample.

Measuring phenomena in the real world presents similar challenges. Investigation 10: Energy Dynamics introduces you to energy dynamics by measuring the biomass of growing organisms. How do you measure the mass of a small caterpillar? What about the water in the organism? Is water included in “biomass”? It is your challenge to come up with solutions to these problems, and to define all measurements carefully so that someone could measure in the same way you did and replicate the experiment. Perhaps you could measure a quantity of caterpillars and sacrifice a few caterpillars to estimate how much the “wet mass” of a caterpillar is biomass, and how much is water. You will have to perform relatively simple calculations, including percentages, ratios, averages, and means.

Nearly every lab investigation requires these kinds of operations and decisions. What is different about this manual is that the decisions are up to you. The manual doesn't make the decisions for you. There are almost always a number of reasonable, productive solutions to such problems. Make sure that your decisions are reasonable and provide a good solution to the problem you are studying.

Precision needed in the experiment is also a consideration and a decision you have to make. Increasing precision requires more time and resources. How precise do your data need to be for you to support or reject your hypothesis?

■ Graphing, Mapping, and Ordering: Histograms of Variation and/or Energy Flow Diagrams

To build on the previous two examples, consider how the data counted and measured should be represented — not numerically, but with graphs or diagrams. For example, consider the examination of the variation of a quantitative trait in a population of plants. How do you best represent these data? If you count the hairs (trichomes) in a population of 150 plants, do you present each data point on a graph, or do you compile the data into an overall picture? If all data points are the same, then there would be no need to present data graphically, but the messy reality is that the counts likely could vary from 0 to more than 50 hairs per plant. For this reason, a histogram (see Figure 2) is often used to represent the variability and distribution of population data.

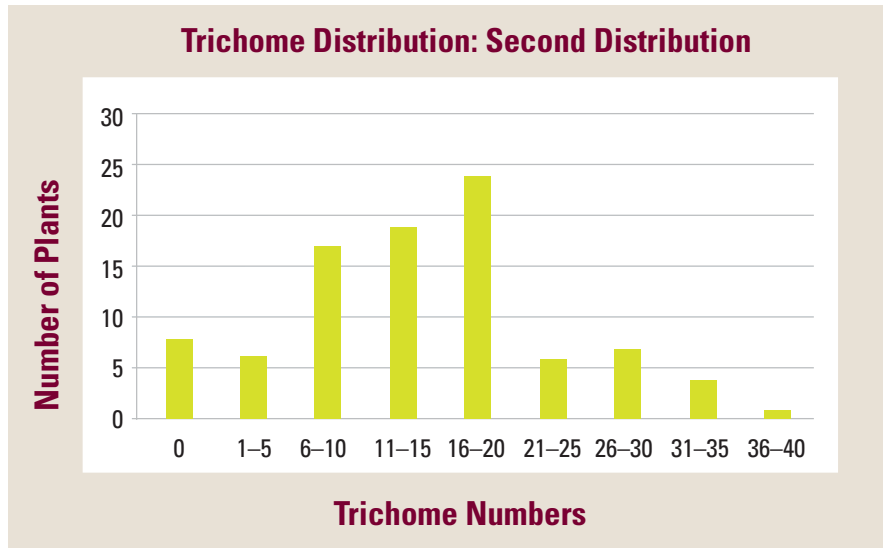


Figure 2. Trichome Distribution: Second Distribution

In a histogram, the data are organized into bins with a defined range of values. For example, for the hairy plants the bin size might be 10 hairs, and bins defined in this manner might include 1–10 hairs, 11–20 hairs, 21–30 hairs, and so on. You simply count the number of plants that fall into each bin, and then graph the distribution as a bar graph — or in this case, a histogram. There are several challenges and decisions you’ll have to make where your quantitative skills will be tested. For instance, what should you do about plants with 0 plant hairs? Do you include a separate bin for this one plant? How do you know what the “correct” bin size is? It is usually best to try several bin sizes, but you’ll have to make the decision which bin size best captures the nature of the variation you are working with — messy.

■ Creating Diagrams, Charts, and Maps

Biology is the study of systems at several levels of organization, from molecules and cells to populations and ecosystems. When exploring a topic, such as energy dynamics in Investigation 10, creating a chart or map can help you to logically define the system components and the flows between those components, while simplifying a very complicated process. Creating such a chart is an exercise in logic and graphic design. Such a graphic representation of your work helps to communicate your thinking, and organizes your analysis and modeling structure. Figure 3 is one model of how a disease might infect a population.



Figure 3. A Disease's Infection of a Population

Your teacher may have suggestions on investigations of graphic representation methods you may want to employ to summarize your data and thoughts.


■ Problem Solving

All sorts of questions and problems are raised and solved during biological investigations. Such questions include the following:

- What is the inheritance pattern for a particular trait?
- What is the critical population size that will ensure genetic diversity in an isolated population?
- How are genes linked to each other on the same chromosome?
- How often do spontaneous mutations occur in a species of yeast?
- What is the Q_{10} temperature coefficient¹ for invertebrates in the Arctic?
- How does a change in ambient temperature affect the rate of transpiration in plants?
- How can the efficiency of transformation be calculated in bacteria exposed to plasmids containing a gene for antibiotic resistance?

Problem solving involves a complex interplay among observation, theory, and inference. For example, say that for one of your investigations you explore a typical dihybrid genetic cross like one you may have studied earlier in an introductory biology course. This time, however, you collect data from the F₂ generation, and note four different phenotype combinations (observation). You count the number of each combination. Using your understanding of the role of chromosomes in inheritance, you work to make a theoretical prediction of what your results might be assuming independent assortment of genes (hypothesis). However, you find that the observed results don't quite match your expected results. Now what? You've been using quantitative thinking, and now it is time to extend the thinking into possible solutions to this problem.

1 Q_{10} temperature coefficient: a measure of the rate of change of a biological or chemical system as a consequence of increasing the temperature by 10 °C.



In this case, the deviation from expected may be due to random chance, or it may be due to a phenomenon known as linkage, where two genes are located close together on the same chromosome instead of on separate chromosomes. There is not enough space here to fully explore the strategies for solving such a problem, but realize that the challenge requires a different level of commitment on your part to work through the problem and solve it. Instead of the instructions for each lab investigation walking you through such problems step by step, this manual provides you with opportunities to explore problems you can solve on your own, which will give you a deeper learning experience.

■ Analysis

When you start to design your own investigations to answer your own questions, you may find that appropriate and adequate data analysis is a challenge. This is the result of having done too many investigations that have the analysis scripted for you. From the very first inkling of the question that you plan to investigate, you also should consider how you plan to analyze your data. Data analysis describes your data quantitatively. Descriptive statistics help to paint the picture of the variation in your data; the central tendencies, standard error, best-fit functions, and the confidence that you have collected enough data. Analysis helps you to make your case when arguing for your conclusion that your data meet accepted standards for reliability and validity. Data analysis is complex. Obviously, there is not enough space in this overview to do the topic justice, but do not let this deter you. Data analysis is an essential component of each investigation in this manual, and is integral to the communication process. Your teacher will be a valuable guide in this process.

■ Hypothesis Testing

In the investigations in this manual, you are asked to modify your question into an appropriate hypothesis. Your experimental design should provide evidence that will help you to conclude whether or not your hypothesis should be accepted. Part of the evidence needed to produce such a conclusion is based on a number of statistical tests that are designed for specific situations. You may be familiar with a statistical hypothesis test, such as a chi-square test or a T-test. These tests can help you to determine probability that the data you have sampled are significantly different from a theoretical population. You've undoubtedly read about such tests, as they are applied when testing new drug treatments or medical procedures. Your teacher can help guide you as you select the methods appropriate to your study. Deciding on the appropriate methods for hypothesis testing (statistical tests) before you carry out your experiment will greatly facilitate your experimental design.

Modeling

Not all biological research involves wet lab investigations². Investigations also can involve a quantitative model. Quantitative models are often computer based. Thinking about and developing computer models may seem to be a new way of thinking and doing biology, but actually you've been constructing mental models of biological phenomena since you first began your study of biology. Models are simplifications of complex phenomena, and are important tools to help drive prediction and identify the important factors that are largely responsible for particular phenomena.

To develop a mathematical model, you must first define the relevant parameters or variables. For example, if you were creating a model of disease in a population, you might divide the population into three components: the part of the population that is susceptible but not infected, the part of the population that is infected, and the part of the population that has recovered from the disease. The probability of transmitting the infection and the probability for recovery are important parameters to define as well. The next step would be to graphically define these parameters and their relation to one another, as you did previously (see Figure 3).

With this graphic, you can imagine word equations that step through the process of a disease cycle in a population. These word equations can then be interpreted into the language of a spreadsheet to get something like Figure 4.

Source: Shodor/Project SUCCEED workshops

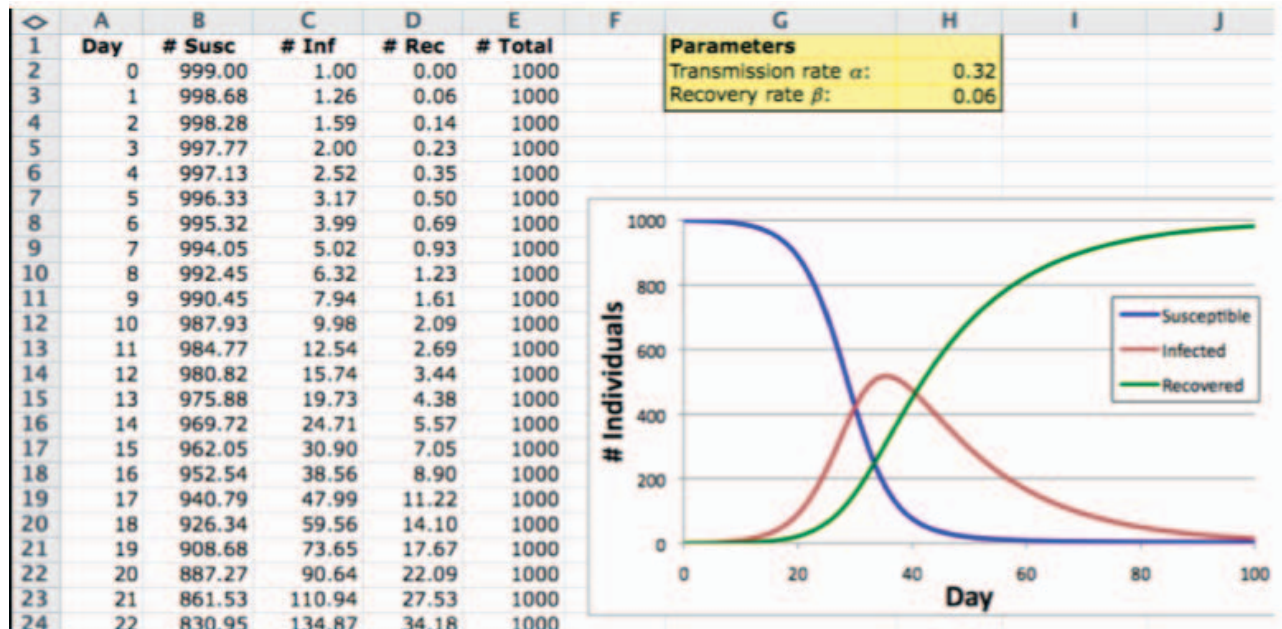



Figure 4. A Disease Cycle in a Population

2 Wet lab investigation: laboratories in which chemicals, drugs, or other material or biological matter are tested and analyzed requiring water, direct ventilation, and specialized piped utilities, as opposed to a computer-based lab.



Models help to provide insight and guidance for an investigation. They help to focus the investigation on parameters that are most influential. Models have to be checked against real data. The assumptions and the limitations of any model should be explicitly articulated. Building models is a challenge, but it is a challenge that, when met, pays very large dividends in learning.

■ REFERENCES

Johnson, A.D. 2009. *40 Inquiry Exercises for the College Biology Lab*. Arlington, VA: NSTA Press.

<http://shodor.org/succeed/curriculum/apprenticeship/Modeling/Excel/LessonPlan2/>
Microsoft Excell II activity, Project Succeed workshops, Shodor.

Waterman, M., and E. Stanley. 2008. *Biological Inquiry: A Workbook of Investigative Cases for Campbell and Reece Biology*. 8th ed. San Francisco, CA: Pearson/Benjamin Cummings.