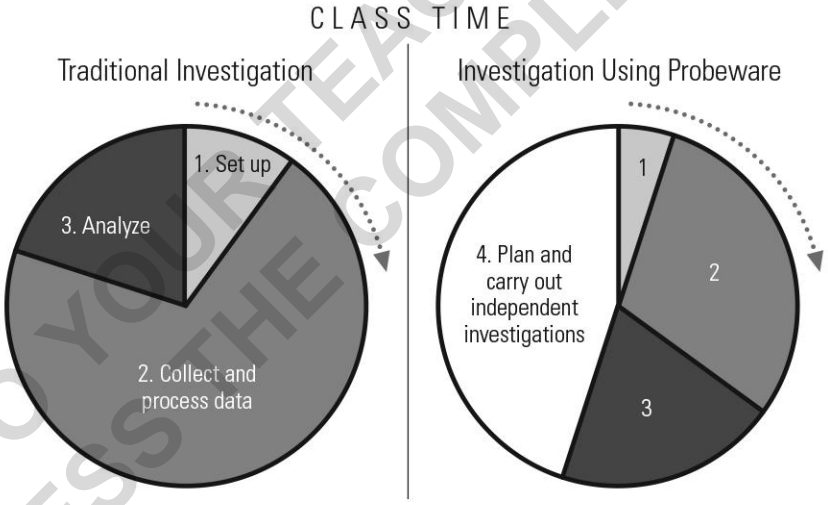
INTRODUCTION

PASCO scientific's *Advanced Biology through Inquiry* investigations move students from the low-level task of memorization or confirmation of science facts to higher-level tasks of experiment design, data analysis, concept construction, and application. For science to be learned at a deep level, it is essential to combine the teaching of abstract science concepts with "real-world" science investigations. Hands-on technology-based laboratory experiences serve to bridge the gap between the theoretical and the concrete, driving students toward a greater understanding of natural phenomena. Students also gain important science process skills that include: developing and using models, planning and carrying out independent investigations, interpreting data, and using mathematics—including statistics.

The lab activities in this manual are designed so students complete brief guided-inquiry investigations that help them become familiar with the use of a particular sensor or technique and engage them in thinking about a core topic of biology. Following these Initial Investigations, students are able to move more easily into designing and conducting open-inquiry investigations related to the topic under study.

The use of electronic sensors (probeware) in investigations greatly reduces the class time required for set up and data collection, increases the accuracy of results, allows for richer analysis of data, and provides more time in the classroom for independent investigations.



Additionally, using electronic-sensor data collection, display and analysis devices allows students to:

- observe or reveal phenomena that cannot be observed, or is difficult to observe, through other methods
- perform investigations with reliable equipment that can be used repeatedly for years, reducing the need for consumable items
- focus not on the tedium of collecting data, but rather focus on the trends, patterns, and relationships which become immediately discernible when gathering real-time data
- easily apply basic statistics to data
- carry out multiple trials in a single class period
- practice using equipment and interpreting data measured by equipment that is similar to what they might use in their college courses and future careers

Teacher Resources and Student Handouts

All teacher and student materials are on the storage device accompanying the printed lab manual. Teacher resources are in pdf format, but the student handouts are in Microsoft® Word format, allowing you to customize the labs for your curriculum, students, and equipment.

Teacher Resources. Teacher resource files and printed labs contain all sections of the student handouts, such as the Initial Investigation, Data Analysis, and Synthesis Questions sections, as well as teacher-specific sections including time requirements, alignment to the AP®[1] Biology learning objectives and science practices, and teacher tips to help ensure success. Sample data is provided for the Initial Investigations and sample answers are provided for all questions. Most labs also contain sample data for suggested student-designed investigations.

Student Handouts. The handouts begin with brief background information and a driving question for the Initial Investigation. In many labs, the responsibility is placed on the student to design appropriate data tables for the investigation and determine appropriate analysis methods to support their claims regarding the results. Following the Initial Investigation, most labs prompt students to design and carry out an experiment of their own. Students analyze the data from their experiment and answer synthesis questions that require an application of their knowledge and the results of the investigation.

Scaffolding Inquiry Investigations

The investigations in this manual support a teacher's need to differentiate the level of scientific inquiry. *Guided inquiry* can involve activities in which students are provided a driving question and lab procedure, but the results of the procedure are not known ahead of time. That is, the lab is not a confirmation lab, but rather one that requires decision-making in analysis of data, problem-solving, and critical thinking.

Open inquiry is typically seen as an activity in which students make all decisions: define a driving question, design a procedure, determine a method for collecting data, make all data analysis decisions, process data to create graphs and figures to summarize results, and communicate the results to others in the science community. However, teachers should not look at inquiry in their classroom simply as "guided" or "open," but rather as a spectrum that ranges from less to more learner self-direction, and more to less direction from the teacher. (Appendix D of the College Board's lab manual, *AP Biology Investigative Labs: An Inquiry-Based Approach* provides an example of this spectrum.)

The lab activities developed by PASCO allow teachers to easily modify the level of inquiry appropriate for their students (student files are fully editable). Three examples of modifications follow:

- To increase the level of inquiry for Enzyme Activity, remove the lab procedure from the Initial Investigation. Provide students with the Background, Driving Question, Materials and Equipment, and Safety sections, and leave only a data table and analysis questions in the Initial Investigation section. Students are then tasked with developing their own procedure to address the driving question, data table, and analysis questions.
- To increase the level of inquiry for Diffusion, only provide students with the Design and Conduct an Experiment Worksheet for the lab. Introduce students to the topic of diffusion and the use of a pH sensor to measure diffusion by performing a demonstration similar to the Initial Investigation. Ask students to answer the analysis questions collaboratively for the demonstration in groups. After assessing students' readiness for open inquiry with the topic, provide them copies of the worksheet to design and carry out independent experiments.
- To increase the level of inquiry for Fermentation, inform students that they will use an ethanol sensor for their experiments. Provide them with the Experiment Design Plan to design their independent investigations and no other directions.

[1] AP is a trademark registered and/or owned by the College Board, which was not involved in the production of, and does not endorse, this product.

Lab Activity Components

This table identifies the sections in the teacher and student files.

TEACHER RESOURCES	STUDENT HANDOUT
Lab Overview	Background
Pacing and Length of the Lab	Driving Question
AP Connections	
Materials and Equipment	Materials and Equipment
Prerequisites	
Safety	Safety
Lab Preparation	
Teacher Tips	
Initial Investigation	Initial Investigation
Design and Conduct an Experiment[1, 2]	Design and Conduct an Experiment[1, 2]
Suggested Inquiry Questions	
Design and Conduct an Experiment: Data Analysis[2]	Design and Conduct an Experiment: Data Analysis[2]
Synthesis Questions	Synthesis Questions
Design and Conduct an Experiment Key	Design and Conduct an Experiment Worksheet
Sample Data	

[1]Some labs do not include a student-designed experiment.

[2]A few labs have a complex or lengthy Initial Investigation and these sections were reordered to account for this variation.

Overview of Lab Activity Components

LAB OVERVIEW OR BACKGROUND

The lab overview in the Teacher Resources provides a brief description of the lab and the topics addressed in the lab. For students, the lab activity begins with the Background, which provides a brief introduction to the topic and some prerequisite knowledge, and sets a purpose for the investigation.

DRIVING QUESTION(S)

This section, only in the Student Handouts, provides a specific, testable question that the Initial Investigation is designed to answer.

MATERIALS AND EQUIPMENT

This section lists all materials and equipment needed to carry out the activity procedure. If items in this list need to be created using additional materials, those are indicated as a footnote in the Teacher Resources version, and instructions for preparing them are in the Lab Preparation section. In the Teacher Resources, this section includes an additional table of items recommended for student-designed experiments.

SAFETY

This section lists the pertinent safety procedures for the lab.

INITIAL INVESTIGATION

The Initial Investigation is a guided investigation, as students are provided with the driving question, the basic procedural steps to complete the activity, and several embedded analysis questions. However, students are still tasked with higher-level thinking: deciding how to organize and present data in tables or graphs, deciding which analysis tools to use within the data collection software and whether to process the data further outside of the data collection system, and

answering analysis questions that require data interpretation and application of biological knowledge to explain data and support claims.

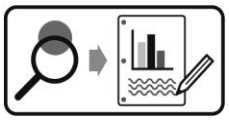
The Initial Investigation serves two main purposes: (1) to give students experience using a particular sensor or laboratory technique, and (2) to engage students in thinking deeply about a biological topic to help them construct meaningful questions they can pursue answers to through their student-designed experiments. Most of the Initial Investigations are brief, requiring a single lab period or less. As the school year progresses and students become more skilled in the science practices and more familiar with probeware, teachers may choose to reduce the amount of scaffolding in the Initial Investigation or remove this section entirely.

Embedded in this section of the Teacher Resources are sample data tables, graphs, computations and analysis, and answers to support teachers in their implementation of each lab activity with students.

DESIGN AND CONDUCT AN EXPERIMENT

This section directs students to plan and carry out an additional experiment. For teachers, the description of the experiment to be designed is more specific and includes suggested inquiry questions. Students are encouraged to come up with their own testable questions; however, teachers may choose to provide suggestions to students for labs performed early in the school year, or for labs in which additional equipment is limited.

This section contains the following instructions:



Design and carry out your experiment using either the Design and Conduct an Experiment Worksheet or the Experiment Design Plan. Then complete the Data Analysis and Synthesis Questions.

A *Design and Conduct an Experiment Worksheet* is included in all labs that have a student-designed experiment option; it appears at the end of the Student Handout and provides questions to guide students in the planning of their experiment.

A more open-ended option is to provide students with the *Experiment Design Plan* handout. This page accomplishes the same goal as the worksheet, providing students some structure for planning an investigation, but it is not lab-specific. (The symbol shown above appears on both the worksheet and the Plan page to indicate their connection.) The Experiment Design Plan is included after this Introduction.

DESIGN AND CONDUCT AN EXPERIMENT: DATA ANALYSIS

Students are encouraged to analyze and present their data in various ways: perform calculations to average data from numerous trials, organize data tables to summarize results, and create graphs (either of the dependent variable as it appears on the sensor-measurement display or of processed data exported to Microsoft Excel® or other programs). For most labs the Data Analysis questions are open-ended, allowing students to determine how to evaluate the meaning and significance of their results. A few labs contain complex or lengthy Initial Investigations; these labs have Data Analysis sections devoted to the data of the Initial Investigation instead of a student-designed experiment.

NOTE: The College Board's AP® Biology Quantitative Skills Guide *is a good resource for supporting students' application of statistical methods to evaluate the significance of the results of their experiments.*

The Teacher Resources version of this section contains sample answers based on analysis of data collected for a sample inquiry that is described in detail in the Design and Conduct an Experiment Key. The data for the sample inquiry is presented as the first data set in the final section of Teacher Resources, entitled "Sample Data."

SYNTHESIS QUESTIONS

These questions require students to develop a deeper understanding of concepts and assesses whether students can transfer the knowledge learned in the lab to other situations. The questions are modeled after short-answer and free-response questions typical of advanced biology exams.

In addition to requiring students to synthesize information from different topics of biology, the questions often require students to use quantitative reasoning skills and apply mathematical or statistical knowledge. Most labs include data from a published scientific article, providing students an opportunity to analyze real and complex data for experiments difficult to carry out in the typical high school classroom.

DESIGN AND CONDUCT AN EXPERIMENT WORKSHEET OR KEY

The questions included on this Worksheet are designed to guide students in the development of a testable question and hypothesis, and in planning a controlled experiment to test their hypothesis. It offers a great opportunity for formative assessment before students embark on their independent investigations. When students are ready for a more open-ended option for planning their experiments, teachers should eliminate the Worksheet and provide students with copies of the Experiment Design Plan.

The Design and Conduct an Experiment Key provides a model of planning an investigation; it contains sample answers specific to one of the suggested inquiry questions listed in the Teacher Resources of a lab.

Additional sections in the Teacher Resources

PACING AND LENGTH OF THE LAB

This section provides teachers with estimated times that inform their lesson planning. For most labs, time estimates are provided for the Initial Investigation and for the time required for students to plan and carry out their own investigations.

AP CONNECTIONS

There are three components to the table provided in this section: Essential Knowledge, Science Practices, and Learning Objectives. The references in the table, such as "2.D.1" correspond to the *2012–2013 AP Biology Curriculum Framework* published by the College Board®[2].

The correlations table at the end of this introduction summarizes the connections between the Big Ideas of the curriculum framework and the labs included in this manual. The connections to the Big Ideas occur either directly in the data collection and analysis in the Initial Investigation or through the Synthesis Questions that require students to apply their understanding of concepts across domains.

PREREQUISITES

Students should have the prerequisite knowledge listed before performing the lab activity. These labs are *not* confirmation labs, so students can perform the lab without a large amount of prior knowledge in the topic. Through completion of the lab, they acquire content and deepen their understanding.

LAB PREPARATION

Directions for preparing solutions and other materials are provided in this section. Read through this section carefully in advance of the lab; some labs require materials to be prepared either the day before a lab or immediately before a lab. Most investigations make use of household items or materials that can be easily acquired or are common to a high school science stockroom. Some labs

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do require materials that may need to be purchased by the school and the teacher should plan for this in advance.

TEACHER TIPS

This section provides a variety of information such as tips on the use of a particular sensor, or tips on a pedagogical approach for the activity. All tips help support the teacher in a successful implementation of the lab in the classroom.

SAMPLE DATA

The sample data is presented in tables or graphs that display expected patterns based on PASCO trials of sample inquiry questions. However, if students design experiments that address the same independent variable, their data may vary. Use these events for discussions of variation in scientific data as well as variation in approaches (experiment designs) taken to answer the same scientific question.

The Data Collection System

In this manual, "data collection system" refers to the system employed by students to record, visualize, and analyze sensor data during their experiments. The system consists of all components necessary to connect a sensor to a device containing the software that detects the sensor measurement and collects, records, and displays this data.

Some systems, such as the Xplorer GLX® or SPARK Science Learning System™, are stand-alone systems. These contain built-in software applications, and students simply attach a sensor and begin collecting data. Other systems use a computer or tablet with downloaded software applications. In these systems a USB or Bluetooth® interface is used to connect a sensor to the device. Software options for these include SPARKvue® 2 and PASCO Capstone™ software.

The activities are designed so that any PASCO data collection system can be used to carry out the procedures.

Getting Started with Your Data Collection System

To help you and your students become familiar with the many features of your data collection system, start with the tutorials and instructional videos available in the video library on PASCO's website (www.pasco.com). Each system's software also has a built-in help system.

There are free SPARKlab™ activities included in the SPARKvue software and performing one of these activities can be a good starting place for students to familiarize themselves with connecting a sensor, viewing data, saving their work, and other tasks related to probeware use.

PASCO scientific also has a terrific technical and teacher support team. They pride themselves on providing timely and comprehensive help to teachers and students using PASCO products.

Phone: 1-800-772-8700

Email: support@pasco.com

Web: www.pasco.com/support

Electronic Materials

A USB storage device was included with the purchase of this manual and is attached to its inside cover. Please view Overview.pdf for a list of the included resources.

In addition to the teacher and student versions of all lab activities, the storage device contains electronic files needed to perform the Mathematical Modeling of Evolution and BLAST into Bioinformatics activities.

International Baccalaureate Organization (IBO) Support

IBO Diploma Program

The International Baccalaureate Organization (IBO) uses a specific science curriculum model that includes both theory and practical investigative work. While this lab guide was not produced by the IBO and does not include references to the IB standards or internal assessment rubrics, the lab activities can be adapted easily to the IB classroom. For example, students can complete an Initial Investigation and the teacher grades their work using the "Data collection and processing" internal assessment rubric. The labs in this manual correlate closely to curriculum topics of the IB Biology higher level program: statistical analysis, cells, cell respiration and photosynthesis, genetics, human health and physiology, and others.

By the end of the IB Diploma Program students are expected to have completed a specified number of practical investigative hours and are assessed using the specified internal assessment criteria. Students should be able to design a lab based on an original idea, carry out the procedure, draw conclusions, and evaluate their results. These scientific processes require an understanding of laboratory techniques and equipment as well as a high level of thinking, skills that are developed and sharpened by completing the investigations in this manual.

AP Biology Correlations

The Big Ideas of the curriculum framework

Big Idea	Description
1	The process of evolution drives the diversity and unity of life.[3]
2	Biological systems utilize free energy and molecular building blocks to grow, to reproduce, and to maintain dynamic homeostasis.[3]
3	Living systems store, retrieve, transmit, and respond to information essential to life processes.[3]
4	Biological systems interact, and these systems and their interactions possess complex properties.[3]

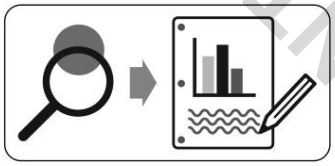
Connection between the Big Ideas and the activities in this manual

Activity	Lab Activity	Big Ideas			
		1	2	3	4
1	Enzyme Activity *Students use an oxygen gas sensor or pressure sensor to investigate the catalyzed decomposition of hydrogen peroxide by catalase.*	X	X		X
2	Diffusion *Students use a pH sensor to investigate the diffusion of hydrogen ions through a semipermeable membrane, comparing the rates of diffusion for two solutions that differ in their acidity.*		X		
3	Osmosis *Students use a colorimeter to determine which extracellular fluid is hypertonic to a model cell and which solution is hypotonic.*		X	X	
4	Plasmolysis *Students use a conductivity sensor to explain the results of different concentrations of salt water on plant tissue before they design an experiment to compare the water potential of different plant tissues.*		X		
5	Cell Size *Students use temperature probes to measure the effect of cell size on cell cooling rate using cubes of potato tissue.*	X	X		
6	Homeostasis *Students use multiple temperature probes simultaneously to investigate the body's ability to maintain homeostasis when subjected to a cold stimulus.*			X	X
7	Cellular Respiration *Students use a carbon dioxide gas sensor to investigate the rate of cellular respiration of germinating seeds.*	X	X		X
8	Fermentation *Students use an ethanol sensor to determine the ability of yeast to use different types of carbohydrates—sucrose and starch—for fermentation.*		X		X
9	Photosynthesis *Students use a carbon dioxide gas sensor to test the effect of the color of light on the rate of photosynthesis.*		X		X
10	Plant Pigments *Students analyze spinach pigments and chloroplasts using paper chromatography, a colorimeter, and a spectrometer to understand how plants capture light for photosynthesis.*		X		X

[3] *AP Biology Curriculum Framework: 2012–2013,* The College Board, 2011.iii.

Activity	Lab Activity	Big Ideas			
		1	2	3	4
11	Transpiration *Students use a low pressure sensor (barometer) and a weather sensor to investigate the rate of transpiration in plants under normal and humid conditions.*		X		X
12	Mitosis *After learning the technique for growing roots and preparing root tip squashes for microscope analysis, students observe the root tips for evidence of mitosis and statistically analyze the data.*			X	
13	Meiosis *Students use physical models of chromosomes to explore meiosis and genetic variation, and use cross over rates observed in Sordaria to calculate gene distance from the centromere.*			X	
14	Transformation *Students transform bacteria with a plasmid that contains an ampicillin resistance gene and a gfp gene that is regulated so only some transformed cells produce the green fluorescent protein.*			X	
15	Understanding Inherited Mitochondrial Disorders *Students use pedigree analysis and DNA analysis (electrophoresis) to confirm or refute the initial diagnosis of MELAS for two patients.*		X	X	X
16	Sickle Cell Gene Detection *Students use electrophoresis to analyze DNA samples from a child and the child's parents to determine if the child has inherited a mutation in the gene for hemoglobin B.*			X	X
17	Energy Dynamics *Students use EcoChamber containers and a carbon dioxide gas sensor to estimate energy flow and carbon cycling within a variety of detritus-based ecosystems.*		X		X
18	Artificial Selection *Students follow the growth and development of Wisconsin Fast Plants and determine if limiting cross-pollination to certain plants with a desired trait affects the frequency of that trait in the second generation.*	X			
19	BLAST Bioinformatics *Students analyze the DNA and protein sequences of beta globin of five mammalian species to determine their evolutionary relatedness.*	X			
20	Population Genetics *Students determine their phenotype for the PTC (phenylthiocarbamide) tasting trait and use class data to derive allele frequencies for a population.*	X			
21	Mathematical Modeling of Evolution *Students work with a mathematical model and computer simulation to explore how inheritance patterns and gene frequencies change in a population.*	X			
22	Animal Behavior *Students use a choice chamber to test the response of fruit flies to different stimuli and determine if there is a significant change in their behavior.*		X		X

Experiment Design Plan



Title:

Driving Question:

Hypothesis (If...then...):

Independent Variable:

Dependent Variable:

How will you manipulate the independent variable in each experimental group?

Experimental Group 1:

Experimental Group 2:

Experimental Group 3:

Experimental Group 4:

Control Group:

Controlled Variables
(quantify where possible):

Data Collection Details:

Dependent Variable:

Number of Trials (provide justification):

What data analysis will you perform
to evaluate your results and hypothesis?

Use the space below to create an outline of the experiment.

In your lab notebook, write the steps for the procedure of the lab. (Another student or group should be able to repeat the procedure and obtain similar results.)

MASTER MATERIALS AND EQUIPMENT LIST

Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group. NOTE: The activities also require protective gear for each student (for example, safety goggles, gloves, apron, or lab coat).

Teachers can conduct some lab activities with sensors and probes other than those listed here. For assistance with substituting compatible sensors and probes for a lab activity, contact PASCO Teacher Support (800-772-8700 inside the United States or http://www.pasco.com/support).

Lab	Title	Materials and Equipment	Qty
1	ENZYME ACTIVITY	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Oxygen Gas Sensor or PASCO Pressure Sensor	1
		Sampling bottle, 250-mL*	1
		Graduated cylinder, 25-mL	1
		Pipet, 1-mL	1
		Magnetic stirrer and stirring bar	1
		Base and support rod	1
		3-Finger clamp	1
		1.5% Hydrogen peroxide (H_2O_2)	20 mL
		Catalase suspension prepared from dried bakers' yeast	2 mL
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Hot plate or water bath	As needed
		Buffers, pH 3 to pH 10	As needed
		3.0% Hydrogen peroxide	As needed
		Catalase or peroxidase suspension from other sources (beef liver, turnips, rutabaga, other plants.)	As needed
		Ice	As needed

Lab	Title	Materials and Equipment	Qty
2	DIFFUSION	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO pH Sensor	1
		Graduated cylinder, 25-mL	1
		Beaker or cup, 250-mL–400-mL	1
		Dialysis tubing, 1 inch × 28-cm[1]	1
		Disposable pipet or 10-mL syringe	1
		Paper clip or binder clip	1
		Small cup to capture the 25 mL (or less) of fluid from the dialysis bag	1
		Apple cider vinegar	25 mL
		Pickle juice	25 mL
		Magnetic stir bar and plate (if available)	1
		Spring water (or distilled water)	200 mL
		Plastic wash bottle with distilled water	1
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		PASCO Conductivity Sensor	1
		Other commercially available solutions, such as: olive juice, jalepeño juice, beet juice	As needed
		Hot plates or warm water baths	As needed
		Other "extracellular" solutions to replace water	As needed
		Additional dialysis tubing , including tubing of a different diameter or with different pore sizes	As needed
		Ice	As needed
		Food coloring, different colors	As needed
3	OSMOSIS	**FOR EACH STUDENT STATION**	
		Data collection system	1
		PASCO Colorimeter	1
		Sensor extension cable*	1
		Cuvettes*	4
		Cups or beakers, 250-mL	2
		Small funnel	1
		Graduated cylinders, 25-mL	2
		Dialysis tubing, 12-cm piece	2
		Solution A (tap water)	100 mL
		Solution B (0.8 M sucrose)	20 mL
		Solution C (1.0 M sucrose)	100 mL
		Solution D (0.1 M sucrose)	20 mL
		Plastic pipets	2
		Small binder clips	2

Lab	Title	Materials and Equipment	Qty
4	PLASMOLYSIS	**FOR EACH STUDENT STATION**	
		Data collection system	1
		PASCO Conductivity Sensor	1
		Microscope, 400× magnification	1
		Microscope slides and cover slips (4)	4
		Plastic pipet or eye dropper	1
		Three NaCl salt solutions of unknown concentration	Several drops
		Red onion	Section
		Water	Several drops
		Paper towel	1
		TEACHER DEMONSTRATION	
		Electronic balance	1
		Celery stalks	2
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Sucrose solutions (1.0 M)	2 L
		Distilled water	600 mL
		Containers for preparing sucrose dilutions	As needed
		Electronic balance	1
		Small cups	As needed
		White potatoes	As needed
		Sweet potatoes or yams	As needed
		Celery, carrots, or other vegetables	As needed
		Apples or other fruits	As needed
5	CELL SIZE	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Quad Temperature Sensor	1
		PASCO Fast-response temperature probes*	3
		Metric ruler	1
		Small knife or scalpel	1
		Cutting board or other appropriate surface	1
		Potato	1
		Plastic containers (for ice water), 24 oz or larger (approximately 700 mL)	1
		Water	~500 mL
		Toothpicks	2
		Permanent marker	1
		Tape	As needed
		Ice	~100 mL
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENT	
		Melon baller (to form spherical potato "cells")	1
		Shortening (or similar solid fat source)	As needed
		Cork borer (to form cylindrical potato "cells")	1
		Additional potatoes	As needed

Lab	Title	Materials and Equipment	Qty
6	HOMEOSTASIS	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Quad Temperature Sensor	1
		PASCO Fast-response temperature probes *	2
		Large shallow bowl or pan[2] (for submerging a hand in ice water)	1
		Ice	As needed
		Water	As needed
		Adhesive bandages or medical tape for securing temperature probes to the skin	2 pieces
		Paper towel	As needed
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Non-latex disposable gloves	As needed
		PASCO physiology sensor(s) such as a hand-grip heart rate sensor, EKG sensor, spirometer sensor, and blood pressure sensor and cuff	As needed
7	CELLULAR RESPIRATION	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Carbon Dioxide Gas Sensor	1
		Sensor extension cable*	1
		Sample bottle, 250 mL*	1
		Balance, readability: 0.01 g	1
		Paper towel	1
		Germinating pinto beans	20
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		PASCO Fast-response Temperature Sensor	1
		PASCO Oxygen Gas Sensor	1
		Solutions of different pH or salinity levels	As needed
		Additional germinating pinto beans	As needed
		Germinating and dormant seeds of other species, or small animals[3]	As needed

Lab	Title	Materials and Equipment	Qty
8	FERMENTATION	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Ethanol Sensor	1
		Sampling bottle* or glass flask (125-mL or 250-mL)	2
		Graduated cylinders (2), 50-mL	1
		Plastic pipet	1
		Small beaker	1
		Magnetic stir plate and stir bar	1
		Rod stand and 3-finger clamp (optional)	1
		1% Ethanol (derived from anhydrous ethanol)	25 mL
		Yeast suspension, derived from active dry yeast	40–60 mL
		2% Sucrose solution	30 mL
		2% Starch solution	150 mL
		Iodine indicator (IKI)	5–10 drops
		Water from germinating seeds	5 mL
		2% Starch solution mixed with amylase (optional)	30 mL
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		PASCO Oxygen Gas Sensor	1
		PASCO pH Sensor	1
		PASCO EcoChamber™ container	1
		Additional yeast suspension	As needed
		Different types of yeast	As needed
		Additional energy sources: glucose, fructose, lactose, artificial sweeteners	As needed
9	PHOTOSYNTHESIS	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Carbon Dioxide Gas Sensor	1
		Sensor extension cable*	1
		Sampling bottle, 250-mL*	1
		Box, foil, or cloth for shading the setup	As needed
		Light source	1
		Compact fluorescent light bulb, 60 W equivalent(or higher), red	1
		Compact fluorescent light bulb, 60 W equivalent (or higher) green	1
		Fresh spinach leaves[2]	As needed
		Forceps or pencil	1
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		PASCO Oxygen Gas Sensor	1
		PASCO EcoChamber container (to accommodate larger plants)	1
		Variety of leaf types, such as: non-green or less-green, and needles	As needed
		Variety of light sources, such as a grow light and other types of fluorescent bulbs	1

Lab	Title	Materials and Equipment	Qty
10	PLANT PIGMENTS	**FOR EACH STUDENT STATION – PART 1**	
		Data Collection System	1
		PASCO Colorimeter	1
		PASCO Wireless Spectrometer and spectrometry software	1
		Colorimeter cuvette	2
		Spectrometer cuvette (1-cm glass cuvette)	2
		Plastic pipets, 1-mL	3
		Capillary tube or eye dropper without a bulb	1
		Chromatography chamber with solvent[2,3]	1
		Chromatography paper	1 sheet
		Ethanol	30 mL
		Pigment extract:	10 mL
		Spinach leaves	3
		Ethanol	5–10 mL
		Beaker, small	1
		Mortar and pestle	1
		Cheesecloth or coffee filter paper	1
		Scissors	1
		Small stapler or paper clips	1
		Ruler	1
		Pencil	1
		Kimwipes®	As needed
		FOR EACH STUDENT STATION – PART 2	
		Data Collection System	1
		PASCO Colorimeter	1
		Colorimeter cuvettes	3
		Plastic pipets (4), 1-mL	4
		Chloroplast suspension:	9 drops
		Spinach leaves	Handful
		0.5 M Sucrose	100–200 mL
		Cheesecloth	1
		0.1 M Phosphate buffer (KH_2PO_4 and K_2HPO_4[3]	3 mL
		DPIP (2,6-dichlorophenolindophenol) solution,	2 mL
		Lamp with a compact fluorescent (CFL) light bulb	1
		Kimwipes	As needed
		Aluminum foil, to cover a cuvette	Small piece
		Distilled water	10 mL
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Different types of leaves	As needed
		Different light sources: different colored lightbulbs or lightbulbs of different wattage	As needed
		Additional chromatography paper and solvent	As needed
		Hot plate	1
		Frozen or canned spinach	As needed

Lab	Title	Materials and Equipment	Qty
11	TRANSPIRATION	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Barometer/Low Pressure Sensor	1
		PASCO Weather Sensor	1
		Sensor extension cables	2
		*Quick-release connector**	1
		*Clear plastic tubing, 40–50 cm**	1
		One-hole rubber stopper that goes on tubing	1
		Large tub or bucket (for water)	1
		Paraffin film or petroleum jelly (if available)	As needed
		Plant sample containing numerous leaves, such as ornamental pear, oleander, hydrangea, and gardenia	1
		Base and support rod	1
		3-finger clamps	2
		Test tube clamp	1
		Clear plastic bag, 1 gallon	1
		Spray bottle with water	1
		Electronic balance, centigram	1
		Small syringe, 60-mL or larger, without needle	1
		Pipet	1
		Metric ruler	1
		Large scissors or small pruning shears	1
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		PASCO EcoChamber containers, including stoppers	At least 2
		PASCO Weather Sensor for each EcoChamber container	At least 2
		PASCO Carbon Dioxide Gas Sensor	1
		Small plants that fit in the EcoChamber container, such as pansy, marigold, and impatiens	As needed
		Clear plastic bags and twist-ties to cover the root ball (or quart or gallon zip-close bags)	As needed
		Additional plant samples (different species) that fit in the tubing of the potometer[2]	As needed
		Electronic balance, centigram	1
		Small fan	1
		Lamp with incandescent or UV bulb that provides heat	1
		Lamp with a CFL bulb that remains cool	1
		Lamp with a CFL bulb that remains cool	1

Lab	Title	Materials and Equipment	Qty
12	MITOSIS	**FOR EACH STUDENT STATION**	1
		Dissection scissors	1
		Forceps	1
		Razor blade or scalpel	1
		Glass test tube	1
		Glass microscope slides	3
		Cover slips	2
		Compound microscope with 400× magnification	1
		Disposable pipets 1-mL	2
		Plastic cup, 16-oz	1
		Spot plate	1
		Personal protective equipment: Disposable gloves and chemical apron	1
		Carbol fuchsin solution	1 mL
		1 M Warm hydrochloric acid (HCl), 1 mL	1 mL
		Onion bulb (green onion, small white onion, or garlic)	1
		Paper towel	As needed
		Large toothpicks	4
		Pencil with eraser	1
		Plastic wrap	As needed
		Disposable plastic gloves	1 pair
		Permanent marker	1
		Distilled water	As needed
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Data Collection System	1
		PASCO Conductivity Sensor	1
		PASCO pH Sensor	1
		Herbicide samples	As needed
		Additional onion bulbs, or other plant samples (such as garlic)	As needed
		Plant food samples: fertilizers or root growth stimulants	As needed
13	MEIOSIS	**FOR EACH STUDENT STATION**	
		Drosophila *Chromosome Sheet (included in the lab)*	1
		Karyotype of Offspring Fly Sheet (included in the lab)	1
		Scissors	1
		Tape	1
		Pop beads for chromosomes (4), 2 colors, 2 sizes, plus enough to make sister chromatids	150 (75 of each color)
		String, approximately 1 m and 0.5 m	2 pieces
		Cards with images or photographs of Sordaria *asci (Cards with images or photographs can be purchased from supply companies such as Flinn Scientific or Ward's Science.)*	As specified
		or	
		Sordaria *crossing over kit (Crossing-over kits can be purchased from many different science supply companies. Refer to the documentation included with the kit for additional preparation directions if students prepare their own slides to observe asci.)*	1

Lab	Title	Materials and Equipment	Qty
14	TRANSFORMATION	**FOR TEACHER PREPARATION**	
		Edvotek™ EDVO-Kit: 223/AP08	1
		Water bath, 60 °C	1
		Pipet pump and 10 mL glass pipet (optional)	1
		Sterile water	50 µL
		Micropipet with sterile tips (to aliquot plasmid)	1
		Microwave or hot plate and beaker with water	1
		Heat-resistant glove	1 pair
		Incubator	1
		Permanent marker, fine	1
		FOR EACH STUDENT STATION	
		LB (Luria Broth) Petri plate	1
		LB/Amp Petri plate (2)	2
		LB/Amp/IPTG Petri plate	1
		Inoculating loops (2), sterile	2
		Transfer pipets (4), 1-mL, sterile	4
		Micropipet with a sterile tip	1
		Microcentrifuge tubes (2)	2
		Small cup or beaker, 100-mL, for ice	1
		Tube with 0.5 M Calcium chloride ($CaCl_2$), 1 mL	1
		Tube with Recovery Broth, 1.5 mL	1
		Tube with pFluoroGreen™ (pGFP) plasmid, 12 µL	1
		Toothpick, sterile	1
		Ice	50 mL
		Permanent marker, fine	1
		Masking tape	As needed
		ONE PER CLASS	
		E. coli *host cells*	5 large Petri plates
		Warm water baths, 37 °C and 42 °C	2
		Incubator (37 °C)	1
		Long wave UV light source	1
		Disinfectant	As needed
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Additional E. coli *and other bacteria species*	As needed
		Additional Petri plates and LB agar	As needed
		Filter paper	As needed
		Hole punch	1
		Other antibiotics: kanamycin, penicillin, or others	As needed
		Other plasmids: pUC18, pBLU®, pKAN, or others	As needed
		Sterile forceps	As needed

Lab	Title	Materials and Equipment	Qty
15	UNDERSTANDING INHERITED MITOCHONDRIAL DISORDERS	**FOR TEACHER PREPARATION**	
		Mitochondrial Genetics Kit (BP-6946)	1
		Erlenmeyer flasks, 500-mL	2
		Large beaker or container, 3-L (to dilute buffer)	1
		Balance	1
		Microwave or hot plate	1
		Heat-resistant gloves	1 pair
		Gel casting trays	1 per group
		Scissors	1
		Plastic wrap or aluminum foil	1
		Distilled water, 3 L	3 liters
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		QuickStrip™ DNA samples	1
		InstaStain® Blue card	1
		Horizontal gel electrophoresis apparatus	1
		DC power supply	1
		Automatic micropipet, 5 to 50 µL, with tips	1
		Tray with 0.8% agarose gel	1
		Plastic tray for gel staining	1
		Plastic wrap	1 piece
		Graduated cylinder, 100-mL	1
		Waste receptacles (for used tips)	1
		Disposable gloves	1 pair
		Distilled water or buffer for staining	75–100 mL
		OPTIONAL	
		Camera (USB or other)	1
		Permanent marker	1
		Transparency film (for tracing the results)	1
		ONE PER CLASS	
		DNA visualization system (white light)	1
		Spatula	1

Lab	Title	Materials and Equipment	Qty
16	SICKLE CELL GENE DETECTION	**FOR TEACHER PREPARATION**	
		Genetically Inherited Disease Detection Kit (BP-6947)	1
		Balance	1
		Distilled water, 3 L	3 L
		Erlenmeyer flasks, 500-mL	2
		Gel casting trays	1 per group
		Heat-resistant gloves	1 pair
		Large beaker or container, 3-L (to dilute buffer)	1
		Microwave or hot plate	1
		Plastic wrap or aluminum foil	1
		Scissors	1
		FOR EACH STUDENT STATION	
		InstaStain® Blue card[1]	1
		QuickStrip™ DNA samples[1]	1
		Automatic micropipet, 5 to 50 µL, with tips	1
		DC power supply	1
		Disposable gloves	1 pair
		Distilled water or buffer for staining	75–100 mL
		Graduated cylinder, 100-mL	1
		Horizontal gel electrophoresis apparatus	1
		Plastic tray for gel staining	1
		Plastic wrap	Piece
		Tray with 0.8% agarose gel	1
		Waste receptacles (for used tips)	1
		OPTIONAL	
		Camera (USB or other)	1
		Permanent marker	1
		Transparency film (for tracing the results)	1
		ONE PER CLASS	
		DNA visualization system (white light)	1
		Spatula	1

Lab	Title	Materials and Equipment	Qty
17	ENERGY DYNAMICS	**FOR EACH STUDENT STATION**	
		Data Collection System	1
		PASCO Carbon Dioxide Gas Sensor	1
		PASCO Sensor extension cable*	1
		EcoChamber container, with lid and stoppers	1
		Electronic balance, centigram	At least 1 per class
		Weigh boat	1
		Plastic pipet, 1-mL	1
		Disposable gloves	1 pair
		Small knife (for cutting fruit)	1
		Filter paper or coffee filter (9 cm diameter)	1
		Yeast suspension or water (yeast is used in 2 of the 3 chamber configurations, water is used in the third)	5 mL
		Mealworms (used in 2 of the 3 chamber configurations)	20
		Detritus: organic material such as apples and banana peels	60 g
		Plastic wrap (ditritus of one of the two control chambers is wrapped in plastic wrap)	As needed
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Additional sensors such as a PASCO Oxygen Gas Sensor or PASCO Temperature Sensor	One or more
		Additional EcoChamber containers	One or more
		Different detritivores (earwigs, earthworms, crickets, ants, and similar organisms)	As needed
		Different sources of detritus (various fruit or vegetable scraps such as potato)	60 g per chamber

Lab	Title	Materials and Equipment	Qty
18	ARTIFICIAL SELECTION	**FOR EACH STUDENT STATION**	
		Wisconsin Fast Plants® seeds, standard	18
		Seed-starting soil or germinating mix (such as Jiffy Mix®) (This type of soil mix is not *potting soil)*	Enough to set up 3 growing systems twice
		Fertilizer, Osmocote™ pellets or a water-soluble fertilizer (use as directed)	24 pellets
		Wicking material, #18 nylon mason twine	3 pieces
		Recycled plastic bottles, 0.5 L to 1 L	3
		Soda bottle cap with hole (or aluminum foil with holes, held in place with a rubber band)	3
		Plant vermiculite	Enough to set up 3 growing systems twice
		Labeling tape and markers	1
		Black plastic to cover the water reservoir(optional)	3 pieces
		Water in a rinse bottle	As needed
		Lighting system with fluorescent lights	1 per class
		Bee sticks or cotton applicators (for pollination)	3
		Plastic plant labels (3)	3
		Scissors	1
		12-inch ruler	1
		Stakes and holders (wooden splints and plastic straws)	As needed
		Dechlorinated water or nutrient solution (for the reservoir), if water-soluble fertilizer is used.	As needed
		Hand-held plastic magnifier	1
		Petri dish lid	1
		Paper envelope, small	1
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Data Collection System	1
		PASCO pH Sensor	1
		Transfer pipets	As needed
		1 M nitric acid (HNO_3)	As needed
		1 M sulfuric acid (H_2SO_4)	As needed
19	BLAST BIOINFORMATICS	**FOR EACH STUDENT STATION**	
		Computer with Internet access	1
		DNA Sequences Worksheet	1
		ABI BLAST Sequences.docx	1
		Highlighter	1
		Scissors (optional)	1
		Ruler or large index cards	1
20	POPULATION GENETICS	**FOR EACH STUDENT**	
		PTC (phenylthiocarbamide) paper	1
		Control paper (optional)	1
		Calculator with square root function	1
		Allele cards from the gene pool	2
		Class data page	1 per class
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Beads, 2 or more contrasting colors	100 or as needed
		Large cups	2 or more

Lab	Title	Materials and Equipment	Qty
21	MATHEMATICAL MODELING OF EVOLUTION	**FOR EACH STUDENT STATION**	
		Computer	1
		Mathematical model spreadsheet file: ABI Mathematical Modeling Spreadsheet.xlsx	1
		Spreadsheet program (such as Microsoft Excel®, Numbers®[4], or Google Docs™[5])	1
22	ANIMAL BEHAVIOR	**FOR EACH STUDENT STATION**	
		Clear drinking straw	1
		Droppers	2
		Cotton swabs	10
		Timer	1
		Sheet of white paper	1
		Wingless fruit flies , or similar small organism	10
		Mashed ripe banana	10 mL
		Mashed unripe banana	10 mL
		Distilled water	10 mL
		ADDITIONAL EQUIPMENT FOR STUDENT-DESIGNED EXPERIMENTS	
		Cold and warm packs	1
		Aluminum foil	As needed
		Light source	As needed
		Condiments (such as ketchup and mustard)	As needed
		Solution with low pH (HCl)	As needed
		Solution with high pH (NaOH)	As needed
		Ammonia	As needed
		Soil or sand	As needed

* These items are included with the specific kit, apparatus, or sensor used in the experiment.

[4] Numbers is a trademark of Apple Inc., registered in the U.S. and other countries.

[5] © 2012 Google Inc. All rights reserved. Google Docs is a trademark of Google Inc.

ACTIVITY BY PASCO SENSORS

This table indicates which lab activity uses the sensors or special equipment listed.

Items Available from PASCO	Qty	Activity Where Used
PASCO EcoChamber Container	1	8, 9, 17
PASCO EcoChamber Container	2+	11
PASCO Barometer/Low Pressure Sensor	1	11
PASCO Carbon Dioxide Gas Sensor	1	7, 9, **11**, 17
PASCO Colorimeter	1	3, 10
PASCO Conductivity Sensor	1	**2**, 4, **12**,
PASCO Ethanol Sensor	1	8
PASCO Oxygen Gas Sensor	1	1, 7, 8, 9, **17**
PASCO pH Sensor	1	2, **8**, **12**, **18**
PASCO Physiology Sensors such as a hand-grip heart rate sensor, EKG sensor, spirometer sensor, and blood pressure sensor and cuff	1	**6**
PASCO Pressure Sensor	1	1
PASCO Quad Temperature Sensor	1	5, 6
PASCO Temperature Sensor	1	**17**[1]
PASCO Weather Sensor	1+	11
PASCO Fast-Response Temperature Sensor	1	**7**
Mitochondrial Genetics Kit (BP-6946)		15
Genetically Inherited Disease Detection Kit (BP-6947)		16

[1]In this activity either the fast-response temperature sensor or the stainless steel temperature sensor can be used. A stainless steel temperature sensor fits in the hole in the stoppers that are used with the EcoChamber container. The fast-response temperature probe could be used under the filter paper close to the contents.

NOTE: **Bolded** lab numbers indicate the sensor may be used for student-designed experiments.

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