College Environmental Science
Instructor Guide

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College Environmental Science

Instructor Guide
21st Century Science

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Introduction

PASCO scientific's probeware and laboratory investigations move students from the low-level task of memorization of science facts to higher-level tasks of 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 phenomenon. Students also gain important science process skills that include: developing and using models, carrying out investigations, interpreting data, and using mathematics.

At the foundation of teaching science are a set of science standards that clearly define the science content and concepts, the instructional approach, and connections among the science disciplines. The Next Generation Science Standards (2012)© are a good example of a robust set of science standards.

The Next Generation Science Standards (NGSS) position student inquiry at the forefront. The standards integrate and enhance science, technology, engineering, and math (STEM) concepts and teaching practices. Three components comprise these standards: Science and Engineering Practices, Disciplinary Core Ideas, and Crosscutting Concepts. The lab activities in PASCO's 21st Century Science Guides are all correlated to the NGSS (see http://pasco.com).

- The *Science and Engineering Practices* help students to develop a systematic approach to problem solving that builds in complexity from kindergarten to their final year in high school. The practices integrate organization, mathematics and interpretive skills so that students can make data-based arguments and decisions.

- *Disciplinary Core Ideas* are for the physical sciences, life sciences, and earth and space sciences. The standards are focused on a limited set of core ideas to allow for deep exploration of important concepts. The core ideas are an organizing structure to support acquiring new knowledge over time and to help students build capacity to develop a more flexible and coherent understanding of science.

- *Crosscutting Concepts* are the themes that connect all of the sciences, mathematics and engineering. As students advance through school, rather than experiencing science as discrete, disconnected topics, they are challenged to identify and practice concepts that cut across disciplines, such as "cause and effect". Practice with these concepts that have broad application helps enrich students' understanding of discipline-specific concepts.

PASCO's lab activities are designed so that students complete guided investigations that help them learn the scientific process and explore a core topic of science, and then are able to design and conduct extended inquiry investigations. The use of electronic sensors reduces the time for data collection, and increases the accuracy of results, providing more time in the classroom for independent investigations.

In addition to supporting the scientific inquiry process, the lab activities fulfill STEM education requirements by bringing together science, technology, engineering, and math. An integration of these areas promotes student understanding of each of these fields and develops their abilities to become self-reliant researchers and innovators. When faced with an idea or problem, students learn to develop, analyze, and evaluate possible solutions. Then collaborate with others to construct and test a procedure or product.

Information and computer tools are essential to modern lab activities and meeting the challenge of rigorous science standards, such as NGSS. The use of sensors, data analysis and graphing tools, models and simulations, and work with instruments, all support the science and engineering practices as implemented in a STEM-focused curriculum, and are explicitly cited in NGSS. PASCO's lab activities provide students with hands-on and minds-on learning experiences, making it possible for them to master the scientific process and the tools to conduct extended scientific investigations.

About the College Science Lab Manual

This manual presents teacher-developed laboratory activities using current technologies to help you and your students explore topics, develop scientific inquiry skills. Using electronic-sensor data collection, display and analysis devices in your classroom fulfills STEM requirements and provides several benefits. Sensor data collection allows students to:

- observe phenomena that occur too quickly or are too small, occur over too long a time span, or are beyond the range of observation by unaided human senses
- perform measurements with equipment that can be used repeatedly over the years
- collect accurate data with time and/or location stamps
- rapidly collect, graphically display, and analyze data so classroom time is used effectively
- practice using equipment and interpreting data produced by equipment that is similar to what they might use in their college courses and adult careers

The Data Collection System

"Data collection system" refers to PASCO's DataStudio®, the Xplorer GLX™, SPARKvue™, and SPARK Science Learning System™ and PASCO Capstone™. Each of these can be used to collect, display, and analyze data in the various lab activities.

Activities are designed so that any PASCO data collection system can be used to carry out the procedure. The DataStudio, Xplorer GLX, SPARKvue, or SPARK Science Learning System Tech Tips provide the steps on how to use the data collection system and are available on the storage device that came with your manual. For assistance in using PASCO Capstone, refer to its help system.

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 that are available on PASCO's website (www.pasco.com).

Included on the storage device accompanying your manual is a Scientific Inquiry activity that acts as a tutorial for your data collection system. Each data collection system (except for PASCO Capstone) has its own custom Scientific Inquiry activity. The activity introduces students to the process of conducting science investigations, the scientific method, and introduces instructors and students to the commonly used features of their data collection system. Start with this activity to become familiar with the data collection system.

Instructor and Student Guide Contents

All the instructor and student materials are included on the storage device accompanying the instructor's lab manual.

Lab Experiment Components

Each activity has two components: Instructor Information and Student Inquiry Worksheets.

Instructor Information is in the instructor's version of the lab manual. It contains information on selecting, planning, and implementing a lab, as well as the complete student version with answer keys. Instructor Information includes all sections of a lab activity, including objectives, procedural overview, time requirements, and materials and equipment at-a-glance.

Student Inquiry Worksheets begin with a driving question, providing students with a consistent scientific format that starts with formulating a question to be answered in the process of conducting a scientific investigation.

This table identifies the sections in each of these two activity components.

INSTRUCTOR INFORMATION	STUDENT INQUIRY WORKSHEET
Objectives	Driving Questions
Procedural Overview	Background
Time Requirement	Pre-Lab Activity
Materials and Equipment	Materials and Equipment
Concepts Students Should Already Know	
Related Labs in This Guide	
Using Your Data Collection System	
Background	
Pre-Lab Activity	
Lab Preparation	
Safety	Safety
Sequencing Challenge	Sequencing Challenge
Procedure With Inquiry	Procedure (+ conceptual questions)
Data Analysis	Data Analysis
Analysis Questions	Analysis Questions
Synthesis Questions	Synthesis Questions
Multiple Choice Questions	Multiple Choice Questions
Extended Inquiry Suggestions	

Electronic Materials

The storage device accompanying this manual contains the following:

- Complete instructor and student versions of the lab manual (with Student Inquiry Worksheets in PDF format).
- The Scientific Inquiry activity for SPARK™, SPARKvue™, Xplorer GLX®, and DataStudio® and the Student Inquiry Worksheets for the laboratory activities are in an editable Microsoft™ Word format. PASCO provides editable files of the student lab activities so that instructors can customize activities to their needs.
- Tech Tips for the SPARK, SPARKvue, Xplorer GLX, DataStudio, and individual sensor technologies in PDF format.
- User guides for SPARKvue and GLX.
- DataStudio and PASCO Capstone® Help is available in the software application itself.

About Correlations to Science Standards

The lab activities in this manual are correlated to a number of standards, including United States National Science Education Standards, the Next Generation Science Standards, and all State Science Standards. See http://pasco.com for the correlations.

Global Number Formats and Standard Units

Throughout this guide, the International System of Units (SI) or metric units is used unless specific measurements, such as air pressure, are conventionally expressed otherwise. In some instances, such as weather parameters, it may be necessary to alter the units used to adapt the material to conventions typically used and widely understood by the students.

Reference

NGSS Lead States. 2013. Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

Master Materials and Equipment List

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

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

Lab	Title	Materials and Equipment	Qty
1	**Determining Soil Quality** Use a carbon dioxide gas sensor, a pH sensor, and a conductivity sensor to analyze the capacity of soil to support plant growth by examining the physical, chemical, and biological characteristics of different types of soil.	Data Collection System	1
		PASPORT Carbon Dioxide Gas Sensor and sampling bottle	1
		PASPORT pH Sensor	1
		PASPORT Conductivity Sensor	1
		PASPORT Sensor Extension Cable	1
		Beaker, 100-mL	4
		Beaker, 50-mL	1
		Digging tool	1
		Dissecting microscope	1
		Distilled or deionized water	300 mL
		Graduated cylinder, 100-mL	1
		Labeling tape	1 roll
		Microscope slides and cover slips	3
		Microscope with magnification up to 400x	1
		Microwave oven	1 per class
		Permanent marker	1
		pH calibration standard solution, pH 4	25 mL
		pH calibration standard solution, pH 7 or 10	25 mL
		Pipet, disposable, 1-mL	1
		Plastic bags	4
		Soil samples (from 3 different locations)	3
		Stirring rod	1
		Wash bottle containing distilled or deionized water	1
		Waste container	1
		White household vinegar	4 mL

Lab	Title	Materials and Equipment	Qty
2	**Monitoring Microclimates** Use a weather/anemometer sensor to identify factors that affect measurements for reporting weather and climate information.	Mobile Data Collection System PASPORT Weather/Anemometer Sensor *Cardboard box, (20 cm)3 or larger* *Marking pen* *Scissors*	1 1 1 1 1
3	**Insolation and the Seasons** Use a stainless steel temperature sensor to measure the temperature of a solar panel positioned at different angles relative to the sun in order to determine how the earth's tilt and rotation around the sun is related to climate and the seasons.	Mobile Data Collection System PASPORT Stainless Steel Temperature Sensor *Black construction paper, 15 x 15 cm* *Cardboard, 15 x 15 cm* *Drinking straw* *Glue, bottle* *Protractor* *Scissors* Small Tripod Base and Rod *Tape* Three-fingered clamp	1 1 1 1 1 1 1 1 1 1 roll 1
4	**Investigating Specific Heat** Use fast-response temperature probes and stainless steel temperature sensors to determine and compare the specific heat of water to that of sand, as a model of land, and consider the effects of these differences on global weather and climate.	Data Collection System PASPORT Stainless Steel Temperature Sensor PASPORT Fast Response Temperature Sensor *Beaker, glass, 500-mL* *Beakers, glass, 250-mL* *Buret clamp* *Disposable insulated cup (2) and lid* *Heat lamp or 150 W incandescent lamp* *Hot plate* Mass balance or scale *Sand, 200 g* Small tripod base, and rod *Stirring rod* *Test tube, glass, 18 x 150-mm (large)* *Tongs* *Water*	1 2 2 1 2 2 2 1 1 1 per class 200 g 1 1 1 1 650 mL

Lab	Title	Materials and Equipment	Qty
5	**Water Treatment** Use pH, conductivity, and turbidity sensors to demonstrate how water treatment processes such as filtration, flocculation, and sedimentation improve water quality.	Data Collection System	1
		PASPORT Water Quality Sensor (or PASPORT pH and PASPORT Conductivity Sensors)	1
		PASPORT Turbidity Sensor	1
		Activated charcoal	2 g
		Balance	1 per class
		Beaker, 150-mL	4
		Beaker, 50-mL	1
		Beaker, large ("wastewater" container)	1
		Graduated cylinder, 100-mL	1
		Graduated pipet, 50-mL, and bulb	1
		Lint-free lab tissue	box
		Paper napkins, dinner, white, smooth	12
		Paper towels, white	4
		Soda bottle, empty, 500-mL	1
		Stirring rod	1
		Swimming pool water clarifier solution, 4%	2 to 4 mL
		Test tube, 18-mm OD or greater	1
		Wash bottle containing water	1
		Wastewater sample (made from coffee, soil, and kitty litter if the soil has a low clay content)	500 mL
		Water	300 mL
6	**Sunlight Intensity and Reflectivity** Use a light sensor, a fast-response temperature probe, and a stainless steel temperature probe to explore the concept that air temperatures near the earth's surface result largely from the interplay of the sun's incoming energy and the absorption, reflection, and radiation of that energy by materials on the earth's surface.	Mobile Data Collection System	1
		PASPORT Light Sensor	1
		PASPORT Fast Response Temperature Sensor	1
		PASPORT Stainless Steel Temperature Sensor	1
		Dark rock	500 g
		Dark sand	500 g
		High intensity incandescent lamp	1
		Large disposable plate	1
		Marking pen	1
		Mass balance	1 per class
		Paper	1 piece
		Rod and clamp	1
		Scissors	1
		Small cardboard box, (20 cm)3 or larger	1
		Tape	1 roll
		Three-finger clamp	1
		Tripod base and support rod	1
		White rock	500 g
		White sand	500 g

Lab	Title	Materials and Equipment	Qty
7	**Plate Tectonics** Use My World GIS™ to analyze evidence supporting the theory of plate tectonics by studying data of fossil and glacier deposits, elevation and bathymetry, seafloor age, and earthquake and volcano locations.	My World GIS software (installed on a computer) Project file: Plate Tectonics.m3vz	1 1
8	**Urbanization and Land Use** Use a weather sensor to examine physical and environmental factors that influence an area's weather.	Mobile Data Collection System PASPORT GPS Position Sensor PASPORT Weather/Anemometer Sensor My World GIS software (installed on a computer)	1 1 1 1
9	**Cellular Respiration and Carbon Cycle** Use a carbon dioxide sensor to compare the respiration of dormant bean sees with germinating bean seeds, and to observe the contribution of cellular respiration to the global carbon cycle.	Data Collection System PASPORT Carbon Dioxide Gas Sensor PASPORT Sensor Extension Cable *Dissecting microscope or magnifying glass* *Dry bean seeds* *Knife or scalpel* *Parafilm® for Erlenmeyer flask* *Sampling bottle or Erlenmeyer flask, 125-mL*	1 1 1 1 22 1 1 2
10	**Yeast Respiration** Use a dissolved oxygen sensor, a carbon dioxide sensor, and the EcoChamber™ to analyze aerobic and anaerobic respiration by yeast cells.	Data Collection System PASPORT Dissolved Oxygen Sensor PASPORT Carbon Dioxide Gas Sensor PASCO EcoChamber *Activated baker's yeast, 7-g packet* *Beaker, 1 L* *Graduated cylinder, 500-mL or 1-L* *Hot plate with magnetic stirrer and stir bar* *Magnetic stir plate with stir bar* *Microscope slide and cover slip* *Microscope with magnification to 400x* *Pipet, disposable* *Sugar* *Water*	1 1 1 1 1 1 1 1 1 1 1 1 100 g 1 L

Lab	Title	Materials and Equipment	Qty
11	**Photosynthesis and Primary Productivity** Use a dissolved oxygen sensor to determine the primary productivity of an aquatic plant.	Data Collection System	1
		PASPORT Dissolved Oxygen Sensor or PASPORT Water Quality Sensor	1
		Black cloth, opaque, 50 cm x 50 cm	1
		Dechlorinated tap water	1 L
		Elodea sp. plant	Several
		Lamp, 100 W or high-intensity	1
		Magnetic stirrer and stir bar	1
		Photosynthesis Tank	1
		Rubber stopper, #3 (included with Photosynthesis Tank)	1
		Alternative to the photosynthesis tank:	
		Erlenmeyer flask, 250-mL	1
		Large base and support rod	1
		Mineral oil	1
		Shallow pan or dish, large	1
		Three-finger clamp	1
12	**Photosynthesis and Cell Respiration in a Terrarium** Use an oxygen sensor, a carbon dioxide sensor, and a temperature sensor to demonstrate that a terrarium, as a closed system, is an excellent tool for conducting environmental studies and to design additional investigations on photosynthesis and cellular respiration.	Data Collection System	1
		PASPORT Oxygen Gas Sensor	1
		PASPORT Carbon Dioxide Gas Sensor	1
		PASPORT Temperature Sensor*	1
		PASPORT Sensor Extension Cable	1
		PASCO EcoChamber	1
		Fast-growing, small, potted plant	1
		Opaque cloth, about 1 m^2	1
		Strong incandescent or full-spectrum fluorescent light source	1
		USB hub (depending on data collection system)	1
13	**Weather in a Terrarium** Use a weather sensor and light sensor in a terrarium to conduct and design an investigation of weather, using this closed system to help identify independent variables, dependent variables, and controlled variables.	Data Collection System	1
		PASPORT Light Sensor	1
		PASPORT Weather Sensor	1
		PASPORT Sensor Extension Cable	2
		PASCO EcoChamber	1
		Fast-growing, small, potted plant	1
		Strong incandescent or full-spectrum fluorescent light source	1
14	**Ecological Niche: Coral Reefs** Use My World GIS to predict which regions of the world satisfy the basic requirements of temperature, salinity, and water depth for coral reef growth	Data Collection System	1
		My World GIS software (installed on a computer)	1
		Computer with access to the Internet	1
		Reference books containing information about coral reefs	Several
15	**Pollution and Harmful Algal Blooms** Use My World GIS software to investigate the life cycle, causes, and effects of an algal bloom.	My World GIS software (installed on a computer)	1
		Project file: Harmful Algal Blooms.m3vz	1

Lab	Title	Materials and Equipment	Qty
16	**Biodiversity and Native Species** Use the light sensor, temperature sensor, GPS position sensor, and My World GIS to collect and analyze field data in order to monitor local native species of plants and animals.	Mobile Data Collection System PASPORT GPS Position Sensor PASPORT Light Sensor PASPORT Stainless Steel Temperature Sensor PASPORT Sensor Extension Cable Computer with My World GIS installed *Colored tape* *Field guides of native plants and insects in your area* *Graph paper* *Pen, pencil, or colored pencils* *Pictures of common invasive species in your area* *Ruler* *Spreadsheet program such as Microsoft Excel®* *Tape measure*	1 1 1 1 1 1 1 Several 1 1 Several 1 1 1
17	**Biodiversity and Invasive Species** Use the light sensor, temperature sensor, GPS position sensor, and My World GIS to collect and analyze field data in order to monitor local invasive species of plants and animals	Mobile Data Collection System PASPORT GPS Position Sensor PASPORT Light Sensor PASPORT Stainless Steel Temperature Sensor PASPORT Sensor Extension Cable My World GIS software (installed on a computer) *Colored tape* *Field guides of native plants and insects in your area* *Graph paper* *Pen, pencil, or colored pencils* *Pictures of common invasive species in your area* *Ruler* *Spreadsheet program such as Microsoft Excel®* *Tape measure*	1 1 1 1 1 1 1 1 1 1 Several 1 1 1

Lab	Title	Materials and Equipment	Qty
18	**Modeling an Ecosystem** Use a variety of sensors to explore the use of terrariums as a closed system for environmental studies, designing ways to explore the interrelationships of biotic and abiotic structures in ecosystems.	Data Collection System Sensors (some of the sensors that can be used): PASPORT Oxygen Gas Sensor PASPORT Carbon Dioxide Sensor PASPORT Temperature Sensor* PASPORT pH Sensor PASPORT Conductivity Sensor PASPORT Weather Sensor PASPORT Sensor Extension Cable PASCO EcoZone™ System PASPORT Water Quality Colorimeter and sample vials (nitrate and ammonia recommended) *Compost or soil (quantity determined by student design of the experiment)* *Different types of living organisms* *Plant seeds or seedlings, or moss* *Pollution sources (depends on students' design):* *Detergent (10 mL liquid soap)* *Fertilizer (10 g)* *HCl or white vinegar (16.6 mL)* *Strong incandescent or full-spectrum fluorescent light source* USB hub (depending on data collection system) *Water, dechlorinated (quantity determined by student design of the experiment)*	1 or more 1 or more 1 Several Several 1 1 1 1
19	**Human Population Dynamics** Use My World GIS to examine the relationships between life expectancy, infant mortality rate, fertility rate, illiteracy rate, per capita income, and population growth.	My World GIS software (installed on a computer) Project file: Population Dynamics.m3vz *Spreadsheet program such as Microsoft Excel®*	1 1 1
20	**Survivorship and Mortality Curves: Cemetery Dynamics** Use a GPS position sensor to analyze data, obtained from a cemetery, for historical survivorship trends, including determining the life spans of people in the area and how these have changed over time.	Mobile Data Collection System PASPORT GPS Position Sensor My World GIS software (installed on a computer) Spreadsheet program installed on the computer *Blank data tables* *Map of the cemetery*	1 1 1 1 Several 1

Lab	Title	Materials and Equipment	Qty
21	**Energy Content of Food** Use a fast response temperature sensor to investigate and compare the energy content of four different food items: marshmallow, popcorn, peanut, and cashew.	Mobile Data Collection System PASPORT Fast Response Temperature Sensor *Aluminum pie pan* *Aluminum soda can* *Cardboard box, large* Electronic balance *Food samples: marshmallow, popcorn, peanuts, cashew* *Graduated cylinder, 100 mL* Large base and support rod *Marking pen* *One-hole rubber stopper, ~1 1/2" top diameter* *Paperclip, large* *Plastic straw* Rod and clamp *Tape* *Water* *Wooden matches (or starter wand)*	1 1 4 4 1 1 per class 1 each 1 1 1 4 5 1 1 1 roll 200 mL Several
22	**Global Resources and Energy Consumption** Use My World GIS to investigate the global energy resource economy by analyzing data to determine the global distribution and use of energy resources including fossil fuels, hydroelectricity, and renewable energy sources.	My World GIS software (installed on a computer) Project file: Global Resources and Energy Consumption.m3vz *Computer with an Internet connection*	1 1 1
23	**Wind Power – Where do we build?** Use My World GIS to study the feasibility of developing wind power in various cities in the United States.	My World GIS software (installed on a computer) Project file: Wind Power Development.m3vz *Computer with an Internet connection*	1 1 1

Lab	Title	Materials and Equipment	Qty
24	**Monitoring Water Quality** Use a water quality sensor, turbidity sensor, and weather/anemometer sensor to monitor the pH, dissolved oxygen content, conductivity, and turbidity of a natural body of water, determining how water quality changes in response to changes in environmental factors.	Mobile Data Collection System PASPORT Water Quality Sensor PASPORT Turbidity Sensor PASPORT Weather/Anemometer Sensor PASPORT GPS Position Sensor (optional) Sensor User Guides with calibration instructions and tables Chemical test kit (optional) *Duct tape, roll* *Long-handled sampling device* *Scissors* *Wading boots (optional)* *Wash bottle containing distilled or deionized water* *Wide-mouth sampling jar or small plastic bucket with a handle*	1 1 1 1 1 Several 1 1 1 1 1 pair 1 1
25	**Toxicology Using Yeast** Use a carbon dioxide gas sensor and a pH sensor to evaluate the role of pH in toxicity and the role of cell culture in toxicology studies.	Data Collection System PASPORT Carbon Dioxide Gas Sensor PASPORT pH Sensor PASPORT Sensor Extension Cable PASCO EcoChamber *Beaker, 100-mL (for vinegar)* *Beaker, glass, 2-L* *Erlenmeyer flask, 125-mL* *Graduated cylinder, 1-L or 500-mL* *Graduated cylinder, 25-mL or 10-mL* *Household bleach, half-strength* *Magnetic stir plate and stir bar* *Rapid-rise activated baker's yeast (7-g packet)* *Rubber stopper for Erlenmeyer flask* *Stirring rod* *Sugar* *Water* *White vinegar*	1 1 1 1 1 1 1 1 1 1 50 mL 1 1 1 1 100 g 1 L 50 mL

Lab	Title	Materials and Equipment	Qty
26	**Air Pollution and Acid Rain** Use a pH sensor to investigate chemical reactions important in the formation of acid rain to understand the relationship between man-made emissions, acid rain, and problems arising from acid rain.	Data Collection System PASPORT pH Sensor *1 M HCl* *1-hole rubber stopper for flask* *Beaker, 40-mL* *Erlenmeyer flask, 50-mL* *Flexible Teflon® tubing to fit glass tubing* *Glass tubing for rubber stopper* *Graduated cylinder, 50- or 100-mL* *Graduated pipet, 4-mL and pipet bulb* *Sodium bicarbonate* *Sodium bisulfite* *Sodium nitrite* *Wash bottle containing distilled or deionized water* *Water or deionized wate*	1 1 15 mL 1 1 1 20 cm 1 1 1 5 g 5 g 5 g 1 1 L
27	**Acid Deposition and Natural Water Bodies** Use My World GIS and student-collected data from the GLOBE project to discern patterns of acidic pH measurements, particularly in cities in the United States.	My World GIS software (installed on a computer) Project file: Acid Rain.m3vz	1 1

* Either the PASPORT Fast Response Temperature Sensor or the PASPORT Stainless Steel Temperature Sensor can be used for this experiment.

Calibration Materials

To calibrate various sensors, you will need the following:

pH Sensor

Item	Quantity	Experiment Where Used
Buffer solution, pH 4 Buffer solution, pH 7 or 10 Beaker, small Wash bottle with deionized or distilled water	25 mL 25 mL 3 1	1, 18, 25, 26

Dissolved Oxygen Sensor

Item	Quantity	Experiment Where Used
Clean electrode storage bottle Distilled water	1 5 mL	

Oxygen Gas Sensor

Item	Quantity	Experiment Where Used
Sampling Bottle (included with the sensor)	1	12, 18

Carbon Dioxide Gas Sensor

Item	Quantity	Experiment Where Used
Sampling Bottle (included with the sensor)	1	1, 10, 12, 18, 25

Turbidity Sensor

Item	Quantity	Experiment Where Used
100 NTU Standard	1	5, 24

Water Quality Colorimeter

Item	Quantity	Experiment Where Used
Calibration Ampule	1	18

Experiment by PASCO Equipment

This list shows the sensors and other PASCO equipment used in the lab activities.

Items Available from PASCO	Qty	Experiment Where Used
Data Collection System	1	1, 4, 5, 9, 10, 11, 12, 13, 14, 18[1], 25, 26
Mobile Data Collection System	1	2, 3, 6, 8, 16, 17, 20, 21, 24,
My World GIS software	1	7, 8, 14, 15, 17, 19, 20, 22, 23, 27
PASCO EcoChamber	1	10, 12, 13, 25,
PASCO EcoZone System	1	18
PASPORT Carbon Dioxide Gas Sensor	1	1, 10, 12, 18[1], 25
PASPORT Conductivity Sensor	1	1, 18[1]
PASPORT Fast Response Temperature Sensor	1	4, 6,
PASPORT GPS Position Sensor	1	8, 16, 17, 20, 24 (optional)
PASPORT Light Sensor	1	6, 13, 16, 17
PASPORT Oxygen Gas Sensor	1	12, 18[1]
PASPORT pH Sensor	1	1, 18[1], 25, 26
PASPORT Stainless Steel Temperature Sensor	2	4
PASPORT Stainless Steel Temperature Sensor	1	3, 6, 16, 17
PASPORT Temperature Sensor[2]	1	12, 18[1], 21
PASPORT Turbidity Sensor	1	5, 24
PASPORT Water Quality Colorimeter and sample vials	1	18[1]
PASPORT Water Quality Sensor	1	24
PASPORT Water Quality Sensor (or PASPORT pH and PASPORT Conductivity Sensors)	1	5
PASPORT Weather Sensor	1	13, 18[1]
PASPORT Weather/Anemometer Sensor	1	2, 8, 24

[1] The actual quantity of these items is determined by the student design of the experiment.

[2] Either the PASPORT Fast Response Temperature Sensor or the PASPORT Stainless Steel Temperature Sensor can be used for this experiment.

Normal Laboratory Safety Procedures

Overview

PASCO is concerned with your safety and because of that, we are providing a few guidelines and precautions to use when exploring the labs in our College Environmental Science guide. This is a list of general guidelines only; it is by no means all-inclusive or exhaustive. Of course, common sense and standard laboratory safety practices should be followed.

Regarding chemical safety, some of the substances and chemicals referred to in this manual are regulated under various safety laws (local, state, national, or international). Always read and comply with the safety information available for each substance or chemical to determine its proper storage, use and disposal.

Since handling and disposal procedures vary, our safety precautions and disposal comments are generic. Depending on your lab, instruct students on proper disposal methods. Each of the lab activities also has a Safety section for procedures necessary for that experiment.

General Lab Safety Procedures and Precautions

- Follow all standard laboratory procedures
- Absolutely no food or drink or chewing gum is allowed in the lab.
- Wear protective equipment (for example, safety glasses, gloves, apron) when appropriate.
- Do not touch your face with gloved hands. If you need to sneeze or scratch, take off your gloves, wash your hands, and then take care of the situation. Do not leave the lab with gloves on.
- Wash your hands after handling samples, glassware, and equipment.
- Know the safety features of your lab such as eye-wash stations, fire extinguisher, first-aid equipment or emergency phone use.
- Insure that loose hair and clothing are secure when in the lab.
- Handle glassware with care.
- Insure you have adequate clear space around your lab equipment before starting an experiment.
- Do not wear open-toe shoes or short pants in the laboratory.
- Allow heated objects and liquids to return to room temperature before moving.
- Never run or joke around in the laboratory.
- Do not perform unauthorized experiments.
- Students should work in teams of 2 or more in case of trouble and help is needed.

- Keep the work area neat and free from any unnecessary objects.

Water Related Safety Precautions and Procedures

- Keep water away from electrical outlets.
- Keep water away from all electronic equipment.

Chemical Related Safety Precautions and Procedures

- Consult the manufacturer's Material Safety Data Sheets (MSDS) for instructions on handling, storage, and disposing of chemicals. Your instructor should provide the MSDS sheets of the chemicals that you are using. Keep these instructions available in case of accidents.
- Many chemicals are hazardous to the environment and should not be disposed of down the drain. Always follow your instructor's instructions for disposing of chemicals.
- Sodium hydroxide, hydrochloric acid, and acetic acid are corrosive irritants. Avoid contact with the eyes and wash your hands after handling. In case of skin exposure, wash it off with plenty of water.
- Always add acids and bases to water, not the other way around, as the solutions may boil vigorously.
- Diluting acids and bases creates heat; be extra careful when handling freshly prepared solutions and glassware, as they may be very hot.
- Handle concentrated acids and bases in a fume hood; the fumes are caustic and toxic.
- Be sure that all acids and bases are neutralized before being disposed of down the drain.
- Wear eye protection, lab apron, and protective gloves when handling acids. Splash-proof goggles are recommended. Either latex or nitrile gloves are suitable. Use nitrile gloves if you have latex allergy.
- Read labels on all chemicals and pay particular attention to Hazard icons and safety warnings.
- When handling any bacterial species, follow aseptic techniques.
- Wash your hands before and after a laboratory session.
- If any solution comes in contact with skin or eyes, rinse immediately with a copious amount of running water for a minimum of 15 minutes.
- Follow the instructor's instructions for disposing of chemicals, handling substances.
- Check the label to verify it is the correct substance before using it.
- Never point the open end of a test tube containing a substance at yourself or others.
- Use a wafting motion when smelling chemicals
- Do not return unused chemicals to their original container.
- Keep flammable chemicals from open flame.

Dangerous or Harmful Substance Related Lab Safety Precautions

- When handling any bacterial species, follow aseptic techniques.
- Always flame inoculating loops and spreaders before setting them down on the lab bench.
- Pipetting suspension cultures can create an aerosol. Keep your nose and mouth away from the tip of the pipet to avoid inhaling any aerosol
- Use caution when working with acids.
- Use appropriate caution with the matches, burning splint and foods, and other hot materials.
- Be careful using a knife or scalpel.

Outdoor Safety Precautions

- Practice appropriate caution around water bodies, steep terrain, and harmful plants or animals.
- Treat plants, animals and the environment with respect.
- Inspect all equipment for damage (cracks, defects, etc.).
- Require students to use a buddy system and specify the procedure to use in case of trouble.

Other Safety Precautions

- If water is boiled for an experiment involving heat, make sure it is never left unattended. Remember, too, that the hot plate will stay hot well after it is unplugged or turned off.
- Any injury must be reported immediately to the instructor, an accident report has to be completed by the student or a witness.
- If you are suffering from any allergy, illness, or are taking any medication, you must inform the instructor. This information could be very important in an emergency.
- Try to avoid wearing contact lenses. If a solution spills in your eye, the presence of a contact lens makes first aid difficult and can result in permanent damage. Also, organic solvents tend to dissolve in soft contact lenses, causing eye irritation.

Additional Resources

- Flinn Scientific
- The Laboratory Safety Institute (LSI)
- National Science Education Leadership Association (NSELA)/Safe Science Series

Earth Systems and Resources

1. Determining Soil Quality

Objectives

Students explore the requirements and capacity of soil to support plant growth by examining the physical, chemical, and biological characteristics of different types of soil.

Procedural Overview

Students gain experience conducting the following procedures on three soil samples:

- Using the carbon dioxide (CO_2) gas sensor to determine the soil respiration rate
- Using pH and conductivity sensors to measure the soil pH, salinity, and buffering capacity
- Using a dissecting microscope and a light microscope to analyze the physical and biological characteristics of the soil samples

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and experiment	30 minutes
♦ Lab experiment	90 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Carbon dioxide gas sensor and sampling bottle
- pH sensor
- Conductivity sensor
- Sensor extension cable
- Stirring rod
- Beaker (4), 100-mL
- Beaker, 50-mL
- Graduated cylinder, 100-mL
- Microscope with magnification up to 400x
- Dissecting microscope
- Microscope slides and cover slips (3)
- Microwave oven (1 per class)
- Pipet, disposable
- Digging tool
- Soil samples (from 3 different locations)
- pH calibration standard solution, pH 4
- pH calibration standard solution, pH 7 or 10
- White household vinegar, 4 mL
- Distilled or deionized water, 300 mL
- Wash bottle containing distilled or deionized water
- Plastic bags (4), sealable, about 1-L
- Waste container
- Permanent marker
- Labeling tape

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- When organisms oxidize food for energy under aerobic conditions, oxygen gas (O_2) is consumed and carbon dioxide gas (CO_2) is released as a byproduct.
- Soil is a complex mixture of inorganic material, organic material, and living organisms, most of which require a microscope to be seen.
- Salts are ionic compounds composed of cations (positively charged ions) and anions (negative ions) so that the product is electrically neutral (without a net charge). The most common salt is sodium chloride (NaCl), also known as table salt.
- Most cells function best within a narrow range of acidity.
- The pH scale ranges from 0 through 14. A pH of 7 is neutral. The further below 7, the more acidic a solution is. The further above 7.0, the more alkaline it is.

Related Labs in This Guide

Labs conceptually related to this one include:

- Air Pollution and Acid Rain
- Cellular Respiration and the Carbon Cycle
- Monitoring Water Quality

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to your data collection system �(2.1)
- Calibrating a pH sensor �(3.6)
- Setting a conductivity sensor for a particular measurement range �(4.2)
- Monitoring live data without recording �(6.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)

- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple data runs in a graph �(7.1.3)
- Displaying data in a digits display �(7.3.1)
- Finding the values of a point on a graph �(9.1)
- Saving your experiment �(11.1)

Background

Soils are complex combinations of inorganic materials, organic materials, and living organisms. (*Organic* means carbon-based. *Inorganic* means not carbon-based.) Some combinations of materials yield soils that provide good support for plant growth. Others do not, or they only support certain types of plant growth.

Ideal soils for plant growth include the following characteristics:

- Being porous, to allow air and water to filter through them
- Being able to retain moisture
- Containing a substantial amount of humus (dead plant material)
- Having a pH in the neutral range from 6.0 to 7.5 and the ability to resist changes in pH
- Not containing too much salt or sodium
- Having a thriving population of decomposers

Decomposers, such as earthworms, ants, beetles, fungi, and bacteria, break down materials to the smallest building blocks that can be used by plants for growth.

Saline soils are high in salt content. Salt is a simple molecule essential to life, but it is quickly becoming a "silent killer" in the environment. In addition to common table salt (sodium chloride), other salts composed of various combinations of calcium, magnesium, potassium, sulfate, and nitrate, contribute to this dilemma. A high salt concentration results in movement of water from the root cells into the saline soil in an attempt to establish an osmotic equilibrium. The plant becomes stressed, wilts, and eventually dies.

The ions from dissolved salts flow in ground and surface water. Salt used to de-ice roadways is toxic to roadside vegetation. Ash water, a highly saline wastewater pollutant from power processing stations, is another contaminant. Saline soils might be found in areas where fertilizer is frequently added or the water table is high.

Sodic soils are those with an excess of sodium ions associated with clay particles. These soils are nonporous and become waterlogged. They cause stunting of plants due to poor water, air, and root penetration.

Although many plants thrive in slightly acidic soils, highly acidic soils may mobilize high levels of aluminum, manganese, nickel, and iron, which can be toxic to plants. In addition, these elements can interfere with the uptake of some essential nutrients, such as phosphorus, calcium, magnesium, and molybdenum.

Soils may become excessively acidic because of the addition of fertilizers, lack of buffers in the soil, addition of acidic water (for example, acid rain), and a number of other factors. Symptoms of acidic soil include stunting of plants, young leaves with deformities, yellowing of leaves, roots that are weak and stubby, and poor crop yields.

Alkaline soils usually have high salinity due to salts of sodium, magnesium, and calcium. Soils with a high pH (greater than 7.5) may hinder plant growth and cause yellowing, due to a lack of dissolved nutrients, such as iron.

Soils are a vital part of the ecosystem. Terrestrial plants comprise an important segment of primary productivity on which all living beings ultimately depend for food. Plants and decomposers are vital links in the global cycles of water, carbon, oxygen, nitrogen, sulfur, phosphorous, potassium, calcium, and other elements that are required for growth of living things. Being able to analyze soils and remedy poor soils are important skills for the good of humanity.

Pre-Lab Discussion and Experiment

Engage your students by telling them that they will be collecting a variety of soil samples to analyze and to determine how well they would support plant life. Tell them they will be using three sensors, a dissecting microscope, and a regular microscope to analyze physical, chemical, and biological characteristics of the soil samples.

Distribute clean, sealable plastic bags—three per student or group. Instruct students to 1) collect soil samples from their home or neighborhood, 2) label the source of each soil sample, 3) seal the bag to preserve moisture, and 4) record the soil information as directed in the Data Analysis section. Caution them to be sure they have permission to take soil samples and to avoid samples containing animal waste.

If necessary, review the correct operation of a dissecting and regular microscope.

Briefly present background on measuring salinity with a conductivity sensor. Help students recall that salts dissolve in water to become electrically charged ions. The conductivity sensor records the concentration of these ions in water. The conductivity sensor records data in microsiemens/cm (μS/cm). The higher the conductivity value is, the greater the concentration of salt ions.

Note: Since the range of salinity tolerated by plants is large compared to the variation between conductivity sensors, it is not necessary to calibrate the conductivity sensor.

Discuss the method for calibrating the pH sensor and why calibration is important. Remind students that there are slight differences between pH sensors. Since the range of tolerated pH is narrow for plants, it is important that the pH measurement is as accurate as possible. Calibration should reduce the variability in measurement between different sensors.

Point out that an important duty of agricultural outreach workers is to be sure their instruments have been calibrated properly.

If necessary, review the pH scale and the concepts of acidity, alkalinity, and neutrality.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. If you have access to some rich compost, include it as one of the samples to be analyzed, since it should provide excellent data for the biological investigations.
2. Consider the following schedule:
   - Part 1 can be assigned as pre-lab homework.
   - This lab can easily be split into two 50-minute sessions. Another way to accomplish the lab in less time is to assign groups to perform different parts of the lab on the same soil samples, sharing the data.
   - If you choose to have all groups do all parts of the lab, instruct students to do Parts 3 through 6 while they are collecting data for Part 2.
3. You may want to provide a copy of the user manual for the carbon dioxide gas, pH, and conductivity sensors.

Safety

Follow all standard laboratory procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Obtain samples (day before lab)

Strive for consistency in the collecting technique for each soil sample collected. Strive to collect samples of obviously different types.

1. Collect a soil sample by doing the following:
   a. Clean the digging device.
   b. Clear away leaves and any other contaminating debris.
   c. With the digging device, loosen the soil as deep as 8 centimeters.
   d. Place at least 200 mL (about 3/4 cup) of soil into a plastic bag.
   e. Seal the bag to preserve moisture.
   f. Label the sample (for instance:, “Vacant lot” or “Hiking trail”).
2. Collect two more soil samples using the same technique.

3. Why must you maintain the same technique when collecting the three different soil samples?

Using the same collecting technique minimizes variables you want to control so better comparisons can be made between samples.

4. In the Data Analysis section, complete the steps for recording soil information for all 3 samples.

You will set up and start "Part 2 – Soil respiration assessment." While you are collecting data for that part, you will complete Parts 3, 4, 5, and 6.

Part 2 – Soil respiration assessment

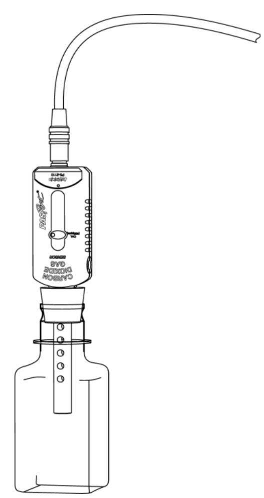
Set Up

5. Start a new experiment on the data collection system. �(1.2)

6. Connect the CO_2 gas sensor to the data collection system using a sensor extension cable. �(2.1)

7. Display a graph of CO_2 gas versus Time in seconds (s). �(7.1.1)

Soil respiration of Soil Sample 1



8. Using the 50-mL beaker, add approximately 50 mL (4 tablespoons) of soil from Soil Sample 1 to the sampling bottle.

9. Lower the CO_2 gas sensor into the bottle and cork it tightly using the attached stopper.

10. Why are you tightly corking the bottle?

We are creating a closed system. All the CO_2 gas that the soil may generate will be captured and measured.

11. Predict which soil sample will have the highest rate of cellular respiration as indicated by the rate of increase in CO_2? Why?

Answers will vary. However, generally, the sample that contains the most living organisms will be the sample with the highest rate of cellular respiration, and thus the highest rate of CO_2 generation.

Collect Data

12. Start recording data. �(6.2)

13. Adjust the scale of the graph to show all data. �(7.1.2)

Note: While recording this data, proceed to "Part 3 – Examine the physical characteristics of the soil" and complete that investigation.

14. After 600 seconds (10 minutes), stop recording data �(6.2) and save your experiment. �(11.1)

15. Find the value for the CO_2 gas concentration at 600 seconds, �(9.1) and record it in Table 2 in the Data Analysis section.

16. Carefully remove the stopper.

17. Vigorously shake the bottle upside down to empty all soil and excess CO_2 gas.

Soil Samples 2 and 3

Note: During the 600-second data recording periods for the second and third soil samples, prepare the soil samples for Part 4, Part 5, and Part 6. You can use the same soil sample preparations to conduct all three of these analyses. Take the readings for Parts 4 through 6 at convenient times (such as after beginning the 600-second CO_2 data recording) during Part 2.

18. For Soil Sample 2 and then for Soil Sample 3, repeat the steps of the "Soil respiration of Soil Sample 1" subsection.

Choose the Sample to Microwave

19. Identify the soil sample with the highest increase in CO_2 concentration. Place a 50-mL aliquot of this soil sample in a paper or plastic container and put it into a microwave oven.

20. Expose the sample to a high level of microwaves for 120 seconds.

21. What happens to the living organisms in the soil sample when you microwave it?

All living organisms in the soil sample will be killed by the microwaves.

22. For the microwaved sample, repeat the steps applied to the first sample ("Soil respiration of Soil Sample 1")

23. What important scientific process is being conducted in this step?

A negative control is being created with this process. This step shows the effect on CO_2 gas generation of removing all living organisms from the soil. This step also verifies that the increase in the CO_2 gas levels in the untreated soil were due to the presence of living microorganisms. This step helps establish the connection between the increase in CO_2 gas levels and cellular respiration.

Part 3 – Examine the physical characteristics of the soil

24. Place a small sample of soil (no larger than a penny) from each soil sample on a sheet of white paper (you can use the back of the previous page).

25. Spread the small amount of each of the soil samples into its own thin layer.

26. Compare the soil color, texture, structure, and apparent moisture level of each sample, and enter your observations in Table 1 in the Data Analysis section.

Note: You may need to update some of the information you entered when you initially collected the samples.

27. Sprinkle a small amount of each soil sample on a microscope slide and label the slides using a marker. Look at each slide under a dissecting microscope.

28. Enter new observations about soil composition in Table 1 in the Data Analysis section, considering the following:

a. Particle size and characteristics like sand, silt, or clay

b. Plant material such as root or leaf parts

c. Animal parts such as an insect leg or wing

29. Use the pipet to add a drop of water to the soil on each slide and cover each one with a cover slip.

30. Look at each slide using a microscope that magnifies the sample 400 times.

31. Enter new observations to Table 1 about the type of live organisms you observe.

32. In which sample did you find the most living organisms?

Answers will vary. However, the soil sample that is darkest and richest looking will probably contain the most living organisms.

Part 4 – Determine the soil salinity

Set Up

Preparing the soil

33. Remove any rocks and sticks. Crush Soil Sample 1 into a fine dust with the end of the handle of your digging tool or other suitable instrument.

34. Why do you need to pulverize the soil?

The soil needs to be pulverized to increase the surface area that is available, so a representative sample of the minerals in the soil dissolves when water is added.

35. Place 50 mL of Soil Sample 1 into a 100-mL beaker. Label the beaker "#1".

36. Add an equal volume of distilled water.

37. Mix the soil and water thoroughly with a stirring rod.

38. Allow the mixture to sit for at least 5 minutes.

39. Why are you adding water to the sample?

Conductivity measurements cannot be made with solids. Generally, water must be added to liberate the ions for measurement.

40. Repeat the steps for preparing the soil for the other two samples, rinsing the stirring rod after mixing each sample.

Measure the salinity

41. Connect the conductivity sensor to the data collection system �(2.1) and monitor live data without recording �(6.1) If necessary, open a digits display of conductivity. �(7.3.1)

42. Rinse the conductivity probe with distilled or deionized water.

Collect Data

43. Lower the conductivity probe into the soil-water mixture. Gently stir the solution with the probe during data collection.

44. Wait for the measurement to stabilize (as long as 30 seconds).

45. If necessary, adjust the sensitivity of the conductivity sensor. �(4.2)

46. Wait for the measurement to stabilize.

47. Enter the soil salinity value in Table 2 in the Data Analysis section.

48. Repeat the steps for measuring the salinity for the other two samples.

Part 5 – Determining the pH of the soil

Use the soil-water mixtures you prepared in Part 4 of the lab.

Set Up

49. Calibrate the pH sensor �(3.6)

50. Why are you calibrating the pH sensor?

A pH sensor needs to be calibrated when pH data is going to be compared with a standard or norm, or when pH data will be compared with pH data taken with another pH sensor. Small differences in electronics and sensors can be corrected with calibrated adjustments. Calibration is especially important with the pH sensor because plants have a narrow range of pH tolerance.

Collect Data

51. Rinse the pH probe with distilled or deionized water. Monitor live data without recording �(6.1) If necessary, open a digits display of pH. �(7.3.1)

52. Lower the pH probe into the soil-water mixture, and gently stir the solution with the probe during data collection.

53. Wait for the measurement to stabilize (as long as 30 seconds).

54. Enter the pH value in the "Initial Soil pH" column of Table 2 in the Data Analysis section.

55. Repeat the steps for collecting data for the other two samples.

Part 6 - Explore the buffering capacity of the soil

Set Up

In this buffering part of the lab, use the soil-water mixtures you prepared in the soil salinity and soil pH sections of the lab.

56. Prepare 40 mL of a 10% vinegar solution.

- **a.** Pour 4 mL of vinegar into a graduated cylinder.
- **b.** Fill the cylinder to 40 mL with distilled water to make a 10% vinegar solution.
- **c.** Pour the solution into a 100 mL beaker.

57. Rinse the pH probe with distilled or deionized water.

Collect Data

58. Lower the pH probe into the vinegar solution and gently stir the solution with the sensor during data collection.

59. Determine the pH of the vinegar solution and record it here: ________________.

60. What does the pH of the 10% vinegar solution indicate?

Even though the vinegar is diluted, it is still acidic and has a notably lower pH than any of the soil-water mixtures.

61. If a soil sample has a high buffering capacity, what will happen to the pH when you add the acid?

The pH will not decrease as much as for samples with less buffering capacity.

Determine the buffering capacity

62. Add 10 mL of the 10% white vinegar solution to soil-water mixture number 1 and mix thoroughly.

63. Rinse the pH probe with distilled water.

64. Lower the pH probe into the soil-water mixture and gently stir the solution with the probe during data collection.

65. Wait for the measurement to stabilize (as long as 30 seconds).

66. Enter the pH value in Table 2 in the Data Analysis section.

67. Repeat the steps of the subsection "Determine the buffering capacity" for the other two soil-water mixtures.

68. Save your experiment �(11.1) and clean up according to your instructor's instructions.

Data Analysis

Record soil information

1. Record detailed observations for each soil sample and its environment in Tables 1a, 1b, and 1c, identified by the label on the sample. These should include, where applicable:

- **a.** The appearance of the soil and soil composition, including conditions such as arid or humid; clay, sandy, loamy, or rocky
- **b.** The appearance and types of plants and other organisms in the area from which the soil was collected, for example shrubs, conifers, fungus
- **c.** What you hear, smell, touch, or taste, as well as what you see
- **d.** Animal tracks and the appearance of animals
- **e.** The terrain, holes in the ground, and the geological features of rocks
- **f.** The type of habitat, such as grassland or urban, including any nearby buildings and whether nearby roads are asphalt, cement, gravel, or dirt
- **g.** Anything unusual about the area, especially if it might be relevant to soil health, such as being next to an irrigated area, or a field with runoff from a roadway

Note: If the data is being collected during fall or winter months, it may not be possible to gather information such as yellowing of leaves or deformities on young leaves.

2. Use the back side of the paper to sketch any site details that might be helpful with your soil analysis. Sketch at least 10 square meters.

3. Record the site with a digital camera, if possible.

Note: A digital camera is a great source of objective data. Still, include a sketch as part of the recorded observations.

Table 1a: Detailed observations of Soil Sample 1

Location Description	Beside the road
Date and Time Collected	8/30/08, 11:00 a.m.
Air Temperature and Weather Conditions	30 °C, Fair, light breeze
Soil Color	Light brown
Soil Texture and Structure	Fine texture, clayey, hard, like hard pan
Soil Moisture	Very dry
Organisms Present	Some ants on the surface of the dirt, otherwise, none seen. We did not see more insects with the dissecting microscope, but we think we saw a few microorganisms with the 400x power microscope.
Detailed Observations	There were no plants growing in this soil. It was located next to a road and appeared to have been compacted by walkers.

Table 1b: Detailed observations of Soil Sample 2

Location Description	Field
Date and Time Collected	8/30/08, 11:15 a.m.
Air Temperature and Weather Conditions	30 °C, Fair, light breeze
Soil Color	Medium brown
Soil Texture and Structure	Mixture of fine texture and larger clumps of sand and humus
Soil Moisture	Slightly moist
Organisms Present	Some ants on the surface of the dirt, Some grubs, other small insects, and two earthworms in the dirt. Two butterflies flew by. We saw tiny insects with the dissecting microscope and lots of microorganisms in the 400x microscope.
Other Observations	The area was partly shaded by trees and shrubs.

Table 1c: Detailed observations of Soil Sample 3

Location Description	Compost pile
Date and Time Collected	8/30/08, 11:45 a.m.
Air Temperature and Weather Conditions	31 °C, Fair, light breeze
Soil Color	Dark brown/black
Soil Texture and Structure	Larger clumps of organic debris, very loose
Soil Moisture	Very moist
Organisms Present	Some small insects were in the compost. We saw other tiny insects with the dissecting microscope and lots of microorganisms with the 400x power.
Other Observations	We dug the compost out of the middle of the compost pile. On the top of the compost pile there were leaves and twigs.

Record measured results

4. Display the graphs for each of your data runs. �(7.1.3) Adjust the scale of the graph to show all data. �(7.1.2)

5. Make a sketch of each run of data for CO_2 concentration in parts per million versus Time. Label the overall graph, the scale of the y-axis, and the individual data runs.

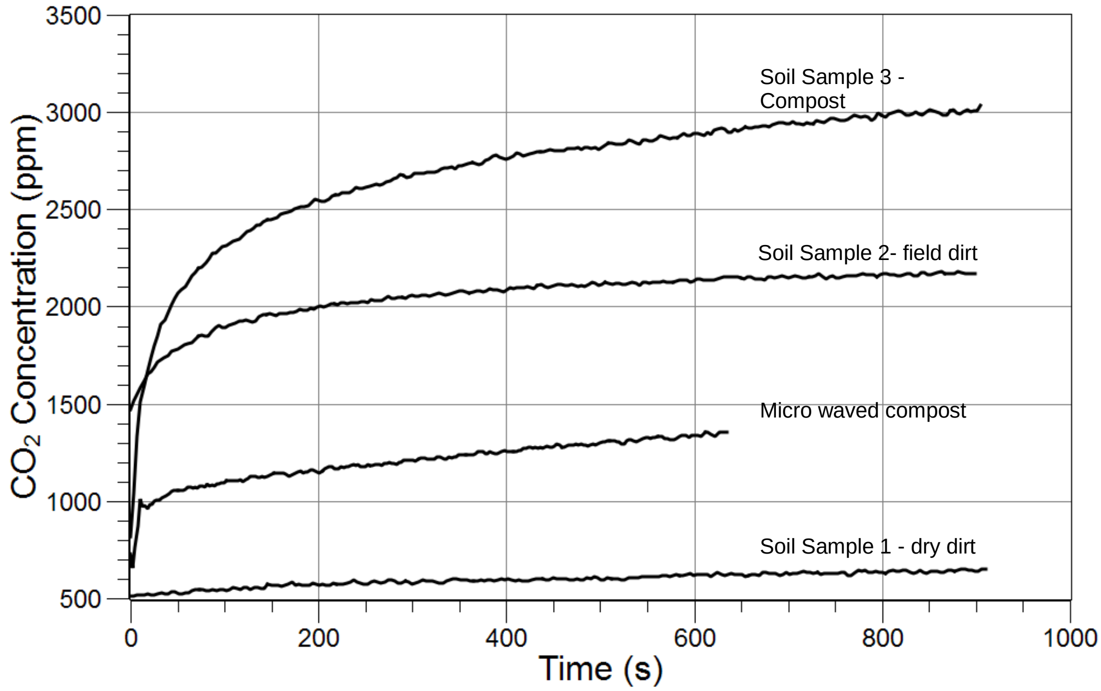


Table 2: Analysis of 3 soil samples

Soil Sample	Data Run	CO_2 Gas Generation (ppm)	Soil Salinity (conductivity) (µS/cm)	Initial Soil pH	Soil pH After Adding 10% Vinegar	Change in pH
1	1	610	65	5.9	5.3	-0.6
2	2	2180	121	6.1	5.9	-0.2
3	3	2900	44	6.6	6.4	-0.2
3	4	1200	45	6.6	6.3	-0.3

Analysis Questions

1. The rate of change of CO_2 gas concentration is indicative of the rate of change in cellular respiration. What kind of soil would you expect to produce CO_2 gas at a faster rate—dark, moist soil or dry, clayey soil? Why?

Moist, dark soil would be expected to produce CO_2 gas at a faster rate because it would be expected to contain more soil organisms. The soil would be high in humus and would contain three components essential to aerobic respiration by living organisms: water, food, and oxygen.

2. What were the effects of microwaving the soil? What happened to the rate of CO_2 gas increase after you microwaved the soil sample? Explain.

Microwaving the soil killed all the organisms in it. Therefore, the rate of respiration dropped to zero, as seen by the lack of increase in CO_2 gas concentration.

3. In which sample did you find the most soil organisms? Is this also the sample that had the highest rate of increase in CO_2 concentration? Discuss the relationship between respiration rate of soil organisms and changes in CO_2 gas concentration within the sample bottle.

Answers will vary depending on experimental results. However, the soil that apparently contained the most organisms should be the one for which the CO_2 gas concentration increased fastest.

4. Which of the three soil solutions had the highest conductivity? Explain why it might be higher than the other two samples. Recall the location of the sample.

Answers will vary. However, the student should include evidence from the collection site to explain why that soil had the highest conductivity. Answers should include mention of factors that might raise the salinity of the soil.

5. Which soil sample had the greatest buffering capacity? Did you see a relationship between buffering capacity and conductivity measurements? If so, explain why this relationship might exist.

Answers will vary. However, the student should include evidence from the change in pH after the acid was added to the soil-water mixture. Soil samples with higher buffering capacities should have higher conductivity readings, since calcium and magnesium salts are important contributors to the buffering capacity of soil.

In this example, soil samples 2 and 3 had the same buffering capacity. Sample 2, taken from a field, had the highest conductivity, indicating a high salt content that could contribute to buffering. Soil Sample 3 was taken from a compost pile. The organic material in compost increases the buffering capacity of soil.

6. Which of the soil samples would you predict would have the greatest capacity to support plant growth? Explain.

Answers will vary. However, students should support their answers in terms of a soil's texture, ability to retain moisture, pH, buffering capacity, salinity, humus content, and presence of decomposers.

In this example, Soil Samples 2 and 3 have most of the characteristics of soils that support plant growth: porous, retain moisture, contain humus, resist changes in pH, and have a thriving population of decomposers. Soil Sample 2 has a high salt content, which may limit its ability to support plant growth.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Based on your results, discuss the roles that soil plays in the carbon cycle.

The decomposers—macroscopic and microscopic organisms in the soil—break down the complex carbon-containing molecules in the soil, which they use as food. The decomposers digest this food in the process of cellular respiration to obtain chemical energy in the form of molecules like ATP, which they use to power their life processes. When cellular respiration occurs in the presence of oxygen gas, carbon dioxide gas is released as a byproduct. Thus, through aerobic cellular respiration by the decomposers, carbon is released from a solid form into a gas form, which can then be used by plants in the process of photosynthesis.

2. What effects do soils of high salinity have on plant growth? Why?

The high salt concentration results in a movement of water out of the root cells into the saline soil in an attempt to establish an osmotic equilibrium. The plant becomes stressed, wilts, and eventually dies.

3. Each plant type possesses an inherent tolerance level to salinity. In general, a crop should tolerate salinity levels up to 700 microsiemens per centimeter (μS/cm), without a decrease in yield; however, some plants tolerate even higher levels of salinity. If a soil contains more than this level of salt, what types of crops might be successfully grown in it?

Plants that grow in high salinity conditions include date palms, beets, kale, spinach, and asparagus.

4. It is best to avoid cultivation of highly saline and sodic (sodium-containing) soils because of the expense of reclaiming the soil. However, if it became imperative to salvage the land, how might you treat saline soil in order to harvest a crop with a high yield?

Cultural practices include growing salt-tolerant plants, planting trees to lower the water table, mulching to reduce evaporation, applying barnyard manure, applying chemical treatments (required prior to leaching saline-sodic or sodic soil to reduce the exchangeable sodium content with soluble calcium or gypsum), leaching with low-salt water, and by improving drainage by tilling through hardpan soil.

Leaching a highly saline acre of soil may require 48 acre-inches of water. This would mean about 27,152 gallons of relatively sodium-free water would be needed, since an acre-inch is defined as the volume of water required to cover 1 square acre of soil to a depth of 1 inch. To be successful, it may take multiple times leaching the soil to reduce accumulated salts.

5. What effects do very acidic or very alkaline soils have on plant growth? Why?

Symptoms of acidic soil include stunting of plants, young leaves with deformities, yellowing of leaves, roots that are weak and stubby instead of long (becoming more susceptible to drought), and poor crop yields. In legumes, highly acidic soils result in stem and petiole reddening, yellowing of older leaves, and a critical failure to produce root nodules (due to a decline of nitrogen-fixing bacteria). Highly acidic soils may mobilize high levels of aluminum, manganese, nickel, and iron, rendering the soil contaminated. In addition, these toxic elements interfere with the uptake of some essential nutrients, such as phosphorus, calcium, magnesium, and molybdenum.

Alkaline soils are usually soils with high salinity. Some alkaline soils cause movement of water from the root cells into the saline soil in an attempt to establish an osmotic equilibrium. The plant becomes stressed, wilts, and eventually dies. Some critical nutrients, such as iron, can become unavailable to plants in alkaline soils.

6. Each plant type grows best within a certain range of pH values. What are some plants that will grow well in relatively acidic soils (pH 5.0 to 5.5)? What are some plants that will grow well in relatively alkaline soils (pH 7.5 to pH 8)?

Some plants that grow well in relatively acid soils include blueberries, rhododendrons, strawberries, and potatoes.

Some plants that grow well in relatively alkaline soils include beans, barley, and alfalfa.

7. Describe methods that may be used to adjust the pH of soil.

The best way to raise the pH of soil (neutralize soil acidity) is to add lime to the soil. Lime products include dolomite, hydrated lime, ground limestone, and mixed lime.

To reduce the pH of soils (increase soil acidity) organic material such as peat moss, compost, manure, and sawdust can be added, increasing the soil microorganisms. Additionally, ground rock (elemental) sulfur can be carefully applied to lower soil pH.

8. Which of the three soil types would be more efficient at neutralizing acid rain? Explain.

Answers will vary, but students should choose the soil type that had the highest buffering capacity, since these buffering chemicals can neutralize acid.

9. List some possible remedies for the soil samples that seem to be less capable of supporting plant growth.

Answers will vary. However, they should include appropriate information from the answers above that apply to the particular characteristics of their soil samples.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. In which of the following do soil bacteria play an important role?

- **A.** The water cycle
- **B.** The carbon cycle
- **C.** The nitrogen cycle
- **D.** The phosphorous cycle
- **E. All of the above**

2. To which of the following characteristics of soil does humus *not* contribute?

- **A.** High water-holding capacity
- **B.** High nutrient-holding capacity
- **C. Mineralization**
- **D.** Aeration
- **E.** Water infiltration

3. Soils high in salinity cause plant damage because of which of the following?

- **A.** They are highly toxic to plants.
- **B.** They inhibit plant growth by preventing plant roots from taking in nutrients.
- **C.** They cause plants to wilt by creating osmotic pressure from roots to the soil.
- **D. Only B and C are true.**
- **E.** A, B, and C are true.

4. What can be altered as the result of change in soil pH?

- **A.** Growth of soil microorganisms
- **B.** Solubility of toxic substances in the soil
- **C.** Availability of mineral nutrients
- **D. All of the above**

5. Increase in soil acidity can cause which of the following?

- **A. Release of toxic metals such as Al, Fe, Mn, and Ni**
- **B.** Increase in alkalinity
- **C.** Release of calcium carbonate
- **D.** Increase in salts

6. Which of the following can make soil too acidic?

- **A.** Release of CO2 during soil respiration
- **B.** Release of calcium carbonate by parent rock
- **C.** Release of sulfur from burning of fossil fuels returning to the ground as acid rain
- **D. Answers A and C**

7. The addition of which of the following can raise the pH of acidic soils?

- **A.** Sulfur
- **B.** Salts
- **C.** Lime
- **D.** Compost or mulch
- **E. Either C or D**

Extended Inquiry Suggestions

Challenge students to try to remedy soil deficiencies as discussed in this experiment, and then to re-test their soil samples to see if improvements were made.

Have students research soil conservation efforts in your area Consider using the GPS Position Sensor to identify the locations for various soils. Then, create a spatial distribution of soil types in My World GIS™. See Biodiversity of Native Species for a description of how to set up spatial investigation in My World GIS.

2. Monitoring Microclimates

Objectives

This experiment leads students to 1) understand the distinction between microclimate and climate when collecting weather and climate information and 2) to identify factors that affect measurements for reporting weather and climate information. To do this, students:

- ♦ Determine the requirements of a weather station
- ♦ Determine the requirements of the sites where weather stations are located

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Making weather stations and determining sites for measurement.
- ♦ Collecting and analyzing data collected with a weather sensor.
- ♦ Analyzing data sets to understand factors that contribute to variations in data

Time Requirement

♦ Pre-lab discussion and experiment	50 minutes
♦ Preparation time	10 minutes
♦ Lab experiment	45 minutes, plus time to stop collecting data, if data collection extends to several hours.

Materials and Equipment

For each student or group:

- ♦ Mobile data collection system
- ♦ Weather/anemometer sensor[1]
- ♦ Cardboard box, 20 cm^3 or larger
- ♦ Scissors
- ♦ Marking pen

[1]Alternatively, use separate temperature, humidity-dew point, and barometric pressure sensors.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Because the earth turns daily on an axis that is tilted relative to the plane of the earth's yearly orbit around the sun, sunlight falls more intensely on different parts of the earth during the year.

- The difference in intensity of sunlight and the resulting warming of the earth's surface produces the seasonal variations in temperature.

Related Labs in This Guide

Labs conceptually related to this one include:

- Investigating Specific Heat
- Sunlight Intensity and Reflectivity

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Showing and hiding data runs in a graph �(7.1.7)
- Displaying data in a table �(7.2.1)
- Viewing statistics of data �(9.4)
- Saving your experiment �(11.1)

Background

Where does the data used by climatologists and weather forecasters originate? Until the arrival of satellite measurement capabilities, all data came from thousands of weather stations located across countrysides worldwide and on buoys scattered across the oceans. Today, data originating from both satellite observations and ground measurements are merged through complex computerized algorithms. These produce comprehensive results, for example, the low and high temperatures for a day for a particular area, the average temperature for a year in a given area, or the average global temperature for a year.

The features of a site for a weather station must be standardized across weather stations to minimize error introduced by particular aspects of the surrounding area. Inconsistencies can be caused by shade trees, heat reflected from buildings or parking lots, heat added from heating or air conditioning vents, proximity to a large body of water, the type of housing surrounding the weather sensors, and so on. The error introduced by these differences in microclimates can be considerable.

Pre-Lab Discussion and Experiment

Engage students with an explanation of weather stations, including Stevenson screens. Consider noting that Stevenson screens were invented by Thomas Stevenson (1817-1887), the father of author Robert Louis Stevenson.

Explain that Stevenson screens shield instruments against precipitation and direct heat radiation from outside sources, while still allowing air to circulate freely. The use of a standard screen allows temperatures to be compared accurately with those measured in earlier years and at different places.

Explain that the National Climatic Data Center (NDCD) currently collects data from more than 1000 weather stations throughout the United States as a basis for calculating climate data.

Arrange for a local meteorologist to speak to the class in person or by telephone conference.

1. Use the Internet to find and share photographs of weather stations and Stevenson screens. What do they look like? What are the characteristics of the sites and the surroundings?

Student could submit pictures or written descriptions, or both.

2. What questions will you ask the meteorologist when he speaks with the class?

Three possible questions: Where does the data come from for their weather forecasts? How is the data for weather forecasts collected? Where are the local weather stations located?

3. How does the daily weather differ from the climate?

Climate is an average of the weather over the course of the year. Any particular day can be outside of the normal for a particular climate.

Lab Preparation

These are the appropriate preparations prior to the lab.

Decide on a time period that students will collect data. The sample data shown with this lab is for data collected over a time period of 3 hours. This yielded a data set with multiple opportunities for discussion and comparison. However, data suitable for class comparisons could be collected over a period of as little as 10 minutes.

Note: The main focus of this lab is to compare data from multiple weather stations placed in different sites. For analyzing data from an individual station, it is more meaningful when data is collected for at least a few hours.

Instructor Tip: If you have your students collect data for only 10 to 20 minutes, you will not need to adjust the sampling rate of the sensor.

Consider ahead of time what will be safe and acceptable locations for students to place their weather stations and how much time they might be left unattended. When the collection period lasts for several hours, you may need to determine how to stop data recording and how to gather the equipment. (For instance, students can be asked to return later, or a class later in the day may assist with this part of the experiment.)

Ensure that the mobile data collection systems have fully charged batteries.

Provide students with a way to record the summary data from their weather station onto Table 2 so it is visible to the entire class. This will facilitate the sharing of class data and the calculation of class summary data.

Safety

Follow your normal outdoor class procedures.

Procedure with Inquiry

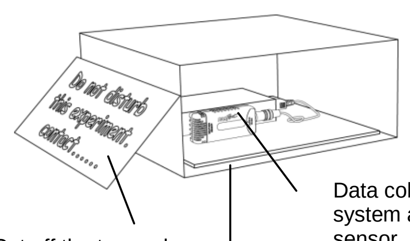
Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up

1. Using a cardboard box 20 cm by 20 cm or larger, cut the box so that it has no top or bottom, only the four connected sides.

2. Using the top or bottom cut from the cardboard box, make a sign that says, "Do not disturb this experiment. Contact [your instructor's name]."

Note: This step is necessary only if you are going to leave the weather station unattended.



3. Use the top or bottom cut from the cardboard box as a mat that you will set inside this "housing" for the weather station.

4. Find a location outside with unusual characteristics, especially one that is unlike what anyone else has chosen. Here are some examples:

- ♦ Well shaded by trees
- ♦ Close to a big parking lot
- ♦ Close to a pond or lake
- ♦ In the middle of a field
- ♦ Next to the vent of an air conditioner
- ♦ In a sheltered, sunny area on the south side of a building
- ♦ In a sheltered, shaded area on the north side of a building

5. Check with your instructor to be sure it is safe and otherwise acceptable to set up a weather station in the location you chose.

6. Start a new experiment on the data collection system. �(1.2)

7. Connect a sensor to your data collection system �(2.1)

Note: If you are going to collect data for longer than 20 minutes, set the sensor sampling rate to once per minute. �(5.1)

8. Display temperature data in a table on the data collection system. �(7.2.1)

9. Place the cardboard housing in the accepted location so that air can circulate through the two open ends and direct sunlight is least likely to shine on the equipment. (See the illustration above.)

10. Place the cardboard mat on the floor of the cardboard housing.

11. Place the data collection system and sensor on the mat.

12. Why are you protecting your weather sensor and other electronics from direct sunlight?

Shielding the weather sensor and other electronics from direct sunlight prevents damage to the equipment from the sun and eliminates the absorption of radiant energy from direct sunlight.

Collect Data

13. Collect data for the amount of time your instructor specifies.

Note: For the database of all data collected by the class, data collection for all weather stations should be for the same time period.

14. Start data recording. �(6.2)

15. Adjust the scale of the graph to show all data. �(7.1.2)

16. Record the following in Table 1 in the Data Analysis section:

- Starting time
- Primary physical characteristics of the site, especially anything that might affect temperature
- Prevailing weather conditions (such as cloudy, sunny, windy, or calm)

17. Will the maximum, minimum, and average temperatures of your site be higher or lower than the average temperature of all the sites? Why?

Answers will vary. For instance, temperature at a site near pavement might be higher than the average. Temperature on the north side of a building may be lower than average. The pavement holds and radiates more heat than other sites while the heat from the direct sun may be blocked on the north side of a building.

18. Stop data recording �(6.2) when instructed by your instructor to do so.

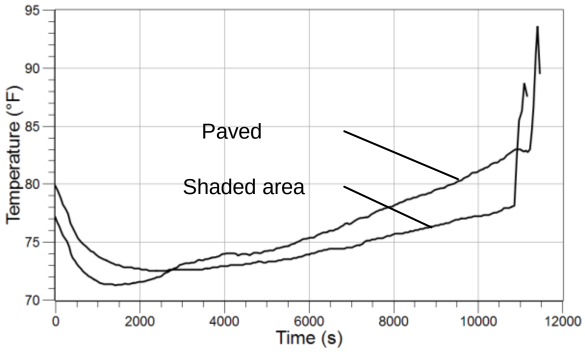
Note: For data collection lasting hours, make appropriate arrangements with other class instructors so you can stop the data recording at the specified time.

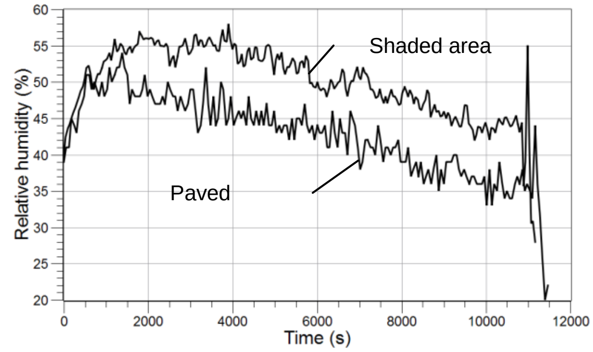
19. Record the time you stopped recording data in Table 1 of the Data Analysis section.

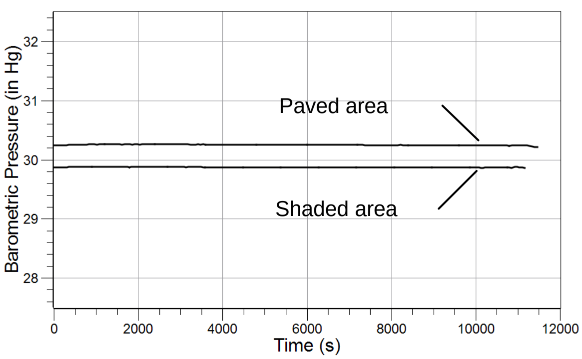
20. Save your experiment �(11.1) and clean up according to your instructor's instructions.

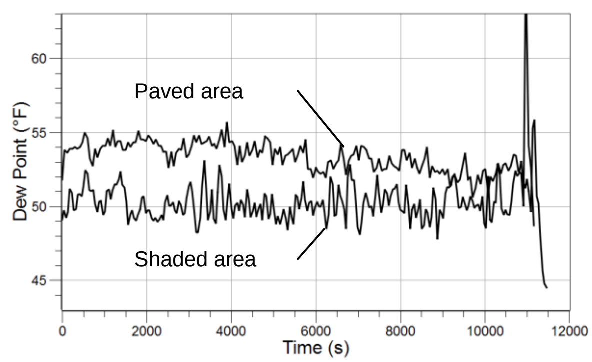
Sample Data

These graphs show a comparison of 4 weather parameters at 2 weather station locations: 1) a shaded area under trees and 2) a paved area near buildings.









Data Analysis

1. Open a graph display �(7.1.1) and display the temperature data on a graph of temperature (°C) versus time (s). �(7.1.7)

2. Adjust the scale of the graph to show all data. �(7.1.2)

3. Find the minimum, maximum, and mean values and record these values in Table 2. �(9.4)

4. Repeat this procedure for the barometric pressure, relative humidity, and dew point measurements. �(7.1.7)

5. Record your data for the individual weather station (from Table 2) on a table of class data your instructor has provided.

6. After every group has recorded its data on the class data table, complete Table 2.

Table 1: Weather station and data collection information

Date and time collection started	July 31, 2008 at 8:30 a.m.
Date and time collection ended	July 31, 2008 at 11:30 a.m.
Description of physical characteristics of the site, especially anything that might affect temperature	The weather station was placed on pavement in the parking lot on the south side of the building about 3 meters from the side of the building.
Prevailing weather conditions (such as cloudy, sunny, windy, or calm)	The prevailing conditions were sunny, clear sky, and calm wind.

Table 2: Individual and class weather station data

	Individual Weather Station			Average for All Class Stations		
	Minimum	Maximum	Mean	Minimum	Maximum	Mean
Temperature (°F)	71.38	83.4	76.2	71.2	78.1	75.6
Barometric Pressure (in Hg)	29.86	30.21	30.20	30.04	30.07	30.06
Relative Humidity (%)	33	54	43	37.5	56	46.5
Dew Point (°F)	44.49	53.17	50.20	47.55	54.44	51.80

Analysis Questions

1. How did your data compare with the class data?

Answers will vary. For this example, the minimum, maximum, and mean temperatures at the individual station were higher than those for the class. The average barometric pressure at this station was higher, which doesn't make sense, because the stations were located in close proximity. Perhaps this difference is due to a calibration issue with the different sensors. The humidity and the dew point at the individual station were lower than the class average.

2. Compare your actual statistics with your predictions.

Answers will vary, but students should be specific.

Synthesis Questions

Use available resources, and the following ideal characteristics for a climate monitoring station (according to the United States Climate Reference Network of the National Oceanic and Atmospheric Administration (NOAA)), to help you answer the following questions.

- Flat and horizontal ground
- Surrounded by a clear surface with a slope less than 1/3 (less than 19 degrees)
- Grass or other low vegetation ground cover, less than 10 centimeters high
- Sensors located at least 100 meters from artificial heating or reflecting surfaces, such as buildings, concrete surfaces, and parking lots
- Far from large bodies of water, except if it is representative of the area, and then located at least 100 meters away
- No shading when the sun elevation is greater than three degrees

1. How does the site you chose compare with the characteristics from the NOAA?

Answers will vary. For this example, the site did not match these specifications in any way.

2. Do your statistics or the average statistics from the class best describe the weather conditions in your area? Why?

Answers will vary. For this example, the class average is more representative because it includes data from multiple microclimates that represent the area. The individual station data was skewed higher for temperature and lower for humidity because the pavement absorbs and radiates more heat than other surface materials.

3. Which sites used in class would best contribute to the national climatology database? Why?

Answers will vary. A weather station situated in a manner that is closest to the NOAA specifications might be recommended.

4. Besides making sure sensors are calibrated and functioning properly, what site conditions should be monitored regularly to ensure collections of valid data?

Make sure the site is maintained properly. Check that the weather station is still level, that no trees or other shading have been introduced, that no buildings have been erected or paving has been added nearby. Check that the housing for the weather station is in good repair.

Multiple Choice Questions

1. Respectively, what are the short-term and long-term atmospheric conditions in a local area known as?

- **A.** Weather, patterns
- **B.** Climate, weather
- **C.** Weather, current
- **D.** Patterns, weather
- **E. Weather, climate**

2. What main environmental factors form the climate of an area?

- **A.** Average temperature
- **B.** Average precipitation
- **C.** Average humidity
- **D. A and B only**
- **E.** All of the above

3. Why do weather stations need to be level?

- **A.** The sensors do not work well if they are not level.
- **B.** They are more likely to fall over if they are not level.
- **C. Accurate precipitation data require collection chambers that are level.**

4. In order for a weather station site to provide useful and reliable data that represents the local climate and not a microclimate, what site characteristics must be satisfied?

- **A.** It is not near a pond or small lake.
- **B.** It does not have high vegetation growing in the surrounding area.
- **C.** I is not shaded.
- **D.** It is not close to buildings, paving, or artificial or reflected heat sources.
- **E. All of the above**

5. Which of the following apply to the calibration and regular maintenance of modern weather sensor equipment?

- **A.** It does not have to be done as often as in earlier times because of advances in technology
- **B. It has to be done more often than in previous times because of the tendency of electronic equipment to drift off calibrated settings over time.**
- **C.** It needs to be done as often today as in the 1800s when data was first being collected for climate studies.

Extended Inquiry Suggestions

Find out if there are official weather stations in your area. If so, visit and evaluate them according to NOAA's criteria for the placement of weather stations.

Have students do research on the locations of weather stations around the globe that provide data for global climate determinations. Have them report to the class on their findings.

Compare the daily weather to that of the local climate and explain the similarities/differences.

Consider adding GPS location to your data collection and importing into My World GIS. Once in My World investigate what led to regional geographic variation. Additionally, consider collecting data at different time of the year with different classes and compare the averages from one time of the year to the next.

3. Insolation and the Seasons

Objectives

Students determine how the earth's tilt and rotation around the sun is related to climate and the seasons. To do this they:

♦ Demonstrate the affect of changes in the angle of solar insolation on solar energy delivered to a given area.

♦ Connect changes tilt to seasonal temperature variations.

Procedural Overview

Students gain experience conducting the following procedures:

♦ Constructing a solar energy collection panel and aligning it relative to the sun

♦ Measuring the relative amount of solar energy captured by monitoring temperatures of the solar panel when positioned at different angles relative to the sun

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	75 minutes

Materials and Equipment

For each student or group:

♦ Mobile data collection system
♦ Stainless steel temperature sensor
♦ Small tripod base and rod
♦ Three-fingered clamp
♦ Protractor
♦ Scissors
♦ Cardboard, 15 x 15 cm
♦ Black construction paper, 15 x 15 cm
♦ Drinking straw
♦ Tape, roll
♦ Glue, bottle

Concepts Students Should Already Know

Students should be familiar with the following concepts:

♦ How sunlight varies during the year due to the earth's tilt as it orbits around the sun.

- ♦ The difference in sunlight intensity and the resulting differences in the warming of the earth's surface produce seasonal variations in temperature.

Related Labs in This Guide

Prerequisites:

- ♦ Sunlight Intensity and Reflectivity

Labs conceptually related to this one include:

- ♦ Investigating Specific Heat

Using Your Data Collection System

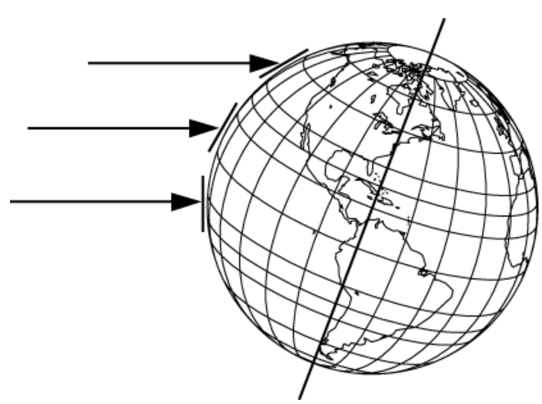
Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to your data collection system �(2.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data �(7)
- ♦ Saving your experiment �(11.1)

Background

Energy from the sun is by far the most important factor in our weather and climate. Solar radiation comprises more than 99.9% of the energy that warms the earth, drives the winds, and stirs the ocean currents. The solar energy that the earth receives is called insolation.

When the surface of the earth directly faces the sun at a 90-degree angle, insolation is highest. As the angle increases between the surface and the rays of sunlight, the same amount of energy is spread over a larger region and the insolation is reduced. This is known as the projection effect and is the reason why polar regions are much colder than equatorial regions. Therefore, the amount of insolation that a part of the earth receives during the day depends on the latitude at that part of the earth.



Earth spins daily around its axis (axis of rotation), which is tilted to approximately 23.5 degrees relative to its orbit around the sun. Thus, no matter the time of year, one part of the planet is always exposed to more direct insolation than another. As the earth orbits the sun, the amount of insolation will change at any particular location, causing the seasons to change. With its elliptical orbit, the distance from the earth to the sun varies by only 5 million miles, or about 3% of the average distance from the sun (the average distance from the sun is about 150 million miles) over the course of one year. The earth is closest to the sun (perihelion) around January 4th each year and furthest from the sun (aphelion) in early July.

At any point during the day, the amount of energy that a particular part of the earth receives changes due to the earth's rotation. One half of the earth receives sunlight, while the other half receives none. During rotation, the amount of sunlight reaching a specific location can vary due to terrain, latitude, and many other factors.

Pre-Lab Discussion and Experiment

Ask your students to consider why temperatures tend to be cooler in the winter and warmer in the summer. Explain that the earth is physically closer to the sun in January and farther from the sun in July. Point out that the tilt of the axis of rotation means that the northern hemisphere is tilted toward the sun during summer and that it is tilted away from the sun during winter.

Use a globe and a basketball (for the sun) to model and demonstrate the orbit of the earth around the sun.

A) Make sure the globe is tilted to about 23.5°. Place the basketball in the middle of a large table to model the sun. Put the globe in its perihelion position at the December solstice (closest to the sun with the North Pole tilted away from it). Point out that now the South Pole is pointed towards the sun.

Ask students the following questions:

1. Which factor, distance from the sun or tilt of the earth relative to the sun, would seem to be responsible for warm temperatures in the summertime?

The tilt of the earth on its axis relative to the sun is primarily responsible for warm temperatures in the summertime.

2. What time of the year is it (when the earth is closest to the sun and when the North Pole is pointed away from the sun)?

The time of the year is the December solstice, December 20 or 21, the shortest day of the year (winter solstice) in the northern hemisphere and the longest day of the year (summer solstice) in the southern hemisphere; the beginning of winter in the northern hemisphere, the beginning of summer in the southern hemisphere.

B) Model the orbit of the earth around the sun. Move the globe in a 90° clockwise arc around the basketball. Make sure the tilt and direction of the axis stay constant. Point out that now the North and South Poles are the same distance from the sun.

3. What time of the year is it?

The time of the year is the March equinox, March 20 or 21, the day when there are 12 hours of daylight and 12 hours of night in both the Northern and southern hemispheres; the beginning of spring in the northern hemisphere, the beginning of fall in the southern hemisphere.

C) Move the globe in another 90° arc around the sun to the aphelion position at the June solstice (furthest from the sun, with the North Pole tilted towards it). Make sure the tilt and direction of the axis stays constant. Point out that now the North Pole is pointed towards the sun.

4. What time of the year is it?

The time of the year is the June equinox, June 20 or 21, the longest day of the year in the northern hemisphere and the shortest day of the year in the southern hemisphere; the beginning of summer in the northern hemisphere, the beginning of winter in the southern hemisphere.

D) Move the globe in another 90° arc around the basketball, making sure that the tilt and direction of the axis stays constant. Point out the equivalent distance from the sun of the North and South Poles.

5. What time of the year is it?

The time of the year is the September equinox, September 22 or 23, the day when there are 12 hours of daylight and 12 hours of night in both the northern and southern hemispheres; this is the beginning of fall in the northern hemisphere, the beginning of spring in the southern hemisphere.

6. How does the angle of the sunlight reaching the earth's surface affect the temperature of that part of the earth.

Students should predict that the closer the angle of insolation is to 90°, the higher the concentration of energy that reaches the surface in a given amount of time. All other factors being equal, the higher the concentration of sunlight energy, the higher the temperature of the surface.

7. When do the warmest temperatures in summer and the coldest temperatures in winter usually occur?

The warmest temperatures in the summer and the coldest temperatures in the winter occur during the months after the solstices.

8. Why do the warmest temperatures in summer and the coldest temperatures in winter usually occur after the summer and winter solstices?

Although the greatest amount of insolation occurs at the summer solstice, the earth absorbs much of this energy, which is then radiated back into the atmosphere during the next two or three months. The cumulative effect of both the sun's energy and the heat energy radiating from the earth in the months after the summer solstice results in warmer temperatures after the date of the summer solstice.

Conversely, the least amount of insolation occurs at the winter solstice, but because the earth retains heat energy, much of which is subsequently radiated to the troposphere, it stays warmer. The coldest surface temperatures occur during the next two or three months as the radiated heat dissipates.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Acquire a globe and a basketball for the pre-lab discussion and experiment.

Instructor Tip: Although this lab is best done using the sun as the light source, a strong incandescent light source, such as a 150 W bulb, can also be used.

Safety

Add this important safety precaution to your normal laboratory procedures:

♦ Do not look directly at the sun.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

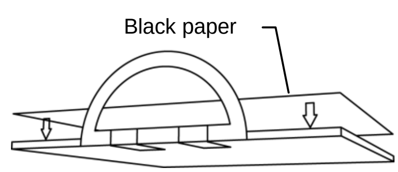
Part 1 – Make the solar panel and test it at 90° insolation

Set Up

1. Make a solar energy collection panel as follows:

  a. Glue a piece of black construction paper to the surface of the cardboard.

  b. Tape the protractor to it so it is perpendicular to the surface of the cardboard.



2. Tape the straw to the protractor so that it is perpendicular (90°) to the cardboard and the end of the straw is about 0.5 cm from the surface of the cardboard.

3. Tape the temperature sensor to the cardboard with its end near the center of the cardboard.

4. Take your solar panel, temperature sensor, data collection system, and rod stand outside. Find a sunny location sheltered from the wind.

5. Secure the solar panel using the tripod stand and 3-fingered clamp.

CAUTION: Do not look directly at the sun when performing the next step.

6. Arrange the angle of the surface of the cardboard so it is perpendicular (90°) to the sun and the straw is pointing at the sun.

Hint: When the surface of the cardboard is perpendicular to the sun, the light coming through the straw will be focused into a tight spot on the solar panel, and the shadow of the cardboard will be at its smallest size.

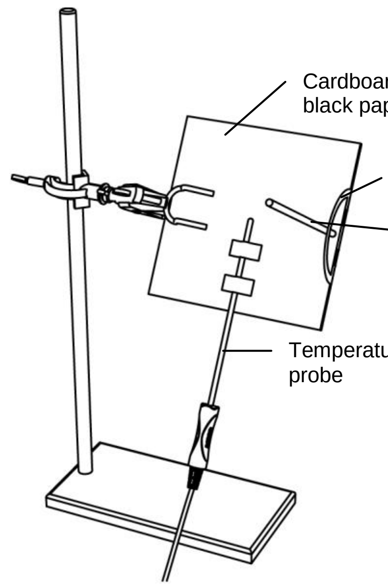
7. Start a new experiment on the data collection system. �(1.2)

8. Connect the temperature sensor to the data collection system. �(2.1)

9. Set up an appropriate display to view the data while it is being collected. �(7)

10. Why did you cover the surface of the cardboard with black paper?

The black paper absorbs more of the light energy than the plain cardboard. This energy is then radiated, so the temperature sensor can better detect differences in the amount of energy that has been absorbed at the various angles of insolation.



11. You will be testing three experimental situations with the cardboard positioned at:

- ♦ 90° relative to the light source
- ♦ 60° relative to the light source
- ♦ 30° relative to the light source

Will the position of the cardboard influence its temperature after 5 minutes at that position? Why?

The position of the cardboard influences how much the temperature will increase after 5 minutes because the sun's rays are most concentrated at the largest angle of insolation. The temperature will be highest when the angle of insolation is 90°.

Collect Data

12. Start data recording. �(6.2)

13. Record data for 5 minutes.

14. Write your data run number here _____________.

15. Stop data recording. �(6.2)

Part 2 – Test the solar panel at 60° insolation

Setup

16. Remove the solar panel and take it to a shaded location.

17. Remove the straw and tape it 30° from perpendicular on the protractor such that when the straw is perpendicular to the sun, the solar panel will be angled towards the horizon 30°, resulting in an angle of insolation of 60°.

18. Fan the solar panel to increase the rate of cooling. When it returns to approximately its original temperature, secure it to the tripod stand.

19. Align the solar panel as you did before. This will angle the solar panel towards the horizon 30° from the last setup, and it will thus receive insolation at 60°.

CAUTION: Do not look directly at the sun.

Collect Data

20. Start data recording. �(6.2)

21. Record data for 5 minutes.

22. Write your run number here _____________.

23. Stop data recording. �(6.2)

24. Remove the solar panel and take it to a shaded location.

Part 3 – Test the solar panel at 30° insolation

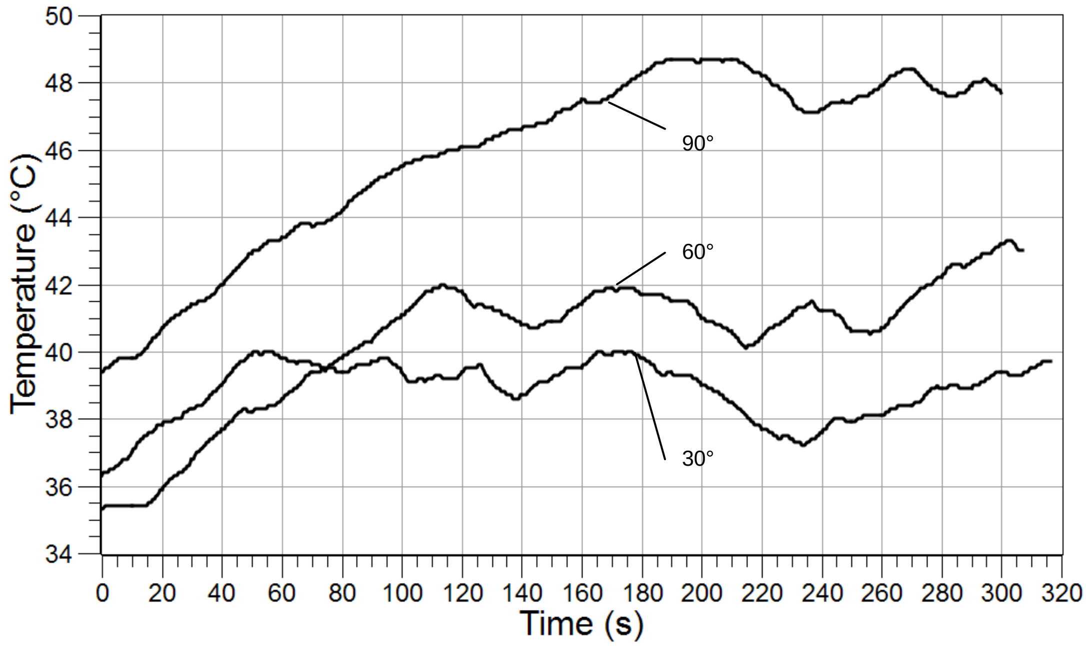
25. Repeat the procedure in Part 2 using a 60° tilt of the solar panel towards the horizon, and thus an angle of insolation of 30°.

26. Write your run number here_____________.

27. Save your file, �(11.1) and clean up according to your instructor's instructions.

Sample Data

Temperature of the solar panel at three angles of insolation.



Data Analysis

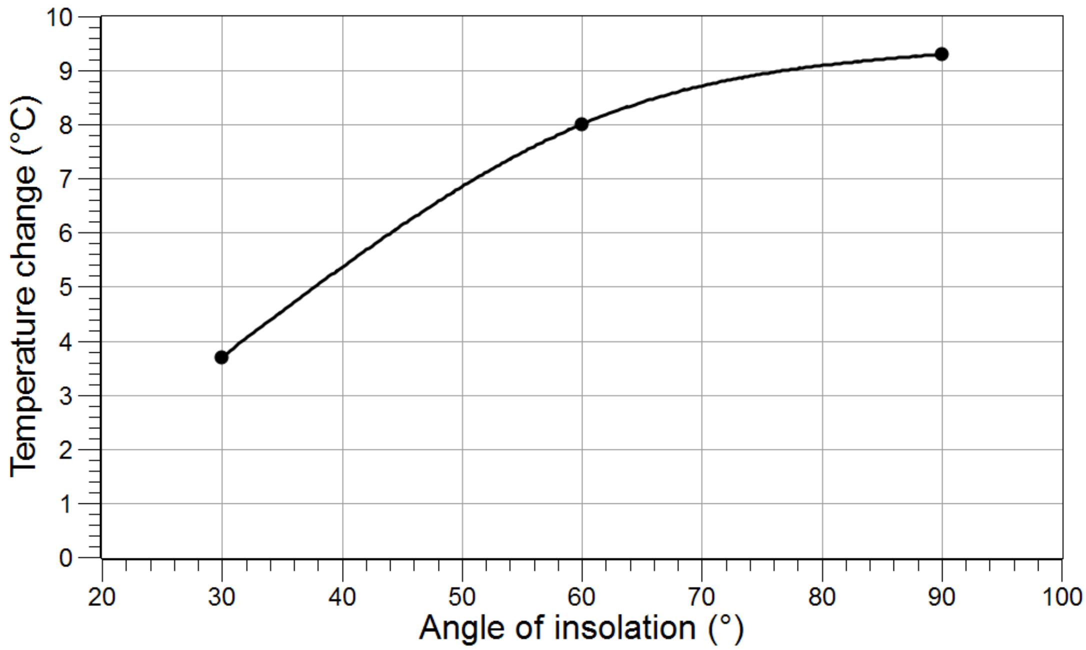
1. Find the minimum and maximum temperatures for the three data runs and calculate the change in temperature.

2. Enter these values in Table 1.

Table 1: Temperature comparison at different angles of insolation

Angle of Insolation	Minimum Temperature	Maximum Temperature	Δ Temperature
90°	39.4	48.7	9.3
60°	35.3	43.3	8.0
30°	36.3	40.0	3.7

3. Plot a graph of angle of insolation on the y-axis with change in temperature on the x-axis. Label the overall graph, the x-axis, the y-axis, and include units and scales on the axes.



Analysis Questions

1. Compare your results with your predictions.

Students should mention the specifics of their predictions and results.

2. What is the independent variable (the parameter you controlled) in this experiment?

The independent variable was the angle of insolation.

3. What is the dependent variable (the parameter that changed) in this experiment?

The dependent variable was the temperature of the solar panel.

4. What parameters did you try to hold constant in this experiment (controlled variables)?

The parameters held as constant as possible were time of exposure to the sun, initial temperature, type of solar energy collection device, time of day, location of data collection, air currents (wind) around the solar panel, and ambient air temperature.

5. Is the relationship between change in temperature and angle of insolation a linear one? Explain.

The relationship between the angle of insolation and temperature was not linear. The rate of change in temperature was slower when the angle of insolation changed from 90° to 60° than when it changed from 60° to 30°.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Using the results of this experiment and what you know about the motion of the earth around the sun as well as the tilt of the earth's rotational axis relative to its orbital plane, explain why seasons occur.

Seasons occur because of the tilt of the earth's axis of rotation. Although the earth has an elliptical orbit around the sun, such that the earth is closer to the sun by about 3% of the average diameter of its orbit at the perihelion (January 4), this variation in distance from the sun obviously does not cause the seasons. If it did, you would expect it to be summertime in both the northern hemisphere and the southern hemisphere in January.

The tilt of the earth's axis of rotation causes the North Pole to be pointed away from the sun in January and towards the sun in July. This relationship causes the angle of insolation to be greatest in the northern hemisphere about June 21, resulting in the greatest amount of energy being delivered to the northern hemisphere by the sun at that time. The opposite happens about Dec 21, when the North Pole is pointed away from the sun.

2. Why are seasons more pronounced the further you move away from the equator?

The seasons are more pronounced the further you move away from the equator because the changes in the angles of insolation are more extreme as you move towards the poles. Additionally, our data showed that the rate of decrease in insolation accelerates as the angle of insolation decreases.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. During wintertime in the northern hemisphere, the earth's North Pole is:

- **A.** Tilted towards the sun relative to the South Pole
- **B. Tilted away from the sun relative to the South Pole**
- **C.** The same distance from the sun relative to the South Pole

2. During summertime in the southern hemisphere, the earth's North Pole is:

- **A.** Tilted towards the sun relative to the South Pole
- **B. Tilted away from the sun relative to the South Pole**
- **C.** The same distance from the sun relative to the South Pole

3. At the spring and fall equinoxes, the earth's North Pole is:

- **A.** Tilted towards the sun relative to the South Pole
- **B.** Tilted away from the sun relative to the South Pole
- **C. The same distance from the sun relative to the South Pole**

4. The warm temperatures of summer in the northern hemisphere north of the tropics occur primarily because:

- **A.** The earth is closer to the sun
- **B.** The days are longer
- **C. The northern hemisphere is tilted towards the sun**
- **D.** Wind patterns change to bring warmer temperatures

5. The Tropic of Cancer and Tropic of Capricorn, respectively, are circles of latitude on the earth that mark the northernmost and southernmost latitudes at which the sun may be seen directly overhead (at the June solstice and December solstice, respectively). These circles of latitude are located at approximately

- **A.** 0° latitude
- **B. 23.5° latitude**
- **C.** 30.0° latitude
- **D.** 60.0° latitude
- **E.** 90.0° latitude

Extended Inquiry Suggestions

Challenge students to use available resources to conduct a comparison of latitude and change in minimum and maximum temperatures of various cities worldwide.

4. Investigating Specific Heat

Objectives

The high specific heat of water accounts for many characteristics of global weather and climate. In this experiment, students determine and compare the specific heat of water to that of sand, as a model of land. Students:

- Determine the relative heating and cooling rates of water versus sand.
- Determine the specific heat of sand and compare it to the specific heat of water.
- Consider the effects on global weather and climate of the different specific heats of water and land.

Procedural Overview

Students gain experience conducting the following procedures:

- Using two temperature probes, simultaneously measure the heating and cooling rates of water and sand, and then compare these rates.
- Using two temperature sensors, measure the initial temperatures of water and heated sand, the final temperature of the water-sand mixture, and then calculate the specific heat of the sand using the law of energy conservation.

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	75 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Stainless steel temperature sensors (2)
- Fast-response temperature probes (2)
- Beaker, glass, 500-mL
- Test tube, glass, 18 x 150-mm (large)
- Beakers (2), glass, 250-mL
- Sand, 200 g
- Heat lamp or 150 W incandescent lamp
- Small tripod base, and rod
- Buret clamp (2)
- Disposable insulated cup (2) and lid
- Water, 650 mL
- Tongs
- Stirring rod
- Hot plate
- Mass balance or scale (1 per class)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ No matter what happens in a closed system, the total amount of matter and energy remain the same.
- ♦ Thermal energy is transferred through a material by the collisions of atoms within the material. Over time, the thermal energy tends to spread out through a material and from one material to another if they are in contact. Thermal energy can also transfer by means of currents in air, water, or other fluids.
- ♦ The temperature of substances is directly related to the motion of the molecules of that substance. The more motion, the higher the temperature.
- ♦ How to use ratios and projections, including constant rates, in appropriate problems

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Sunlight Intensity and Reflectivity
- ♦ Insolation and the Seasons
- ♦ Monitoring Microclimates

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system � (1.2)
- ♦ Connecting multiple sensors to your data collection system � (2.2)
- ♦ Monitoring live data without recording � (6.1)
- ♦ Starting and stopping data recording � (6.2)
- ♦ Displaying data in a graph � (.1.1)
- ♦ Adjusting the scale of a graph � (7.1.2)
- ♦ Displaying two data runs in a graph � (1.3)
- ♦ Naming a data run � (8.2)
- ♦ Finding the values of a point in a graph � (9.1)
- ♦ Saving your experiment � (11.1)

Background

The specific heat of a substance (also known as specific heat capacity) determines how quickly the temperature of that material will rise or fall when it gains or loses heat energy. Specific heat is an intrinsic property of a substance and is dependent on its molecular structure and phase. The stronger the bonds (or intermolecular attractions) are, the higher the specific heat. The higher the specific heat, the more energy is necessary to raise the temperature of a substance and the more energy must be lost to decrease its temperature.

Liquid water has a type of intermolecular attraction (hydrogen bonding) that causes it to have a high specific heat. The relatively strong bond between the water molecules means more energy is needed to heat water up, and water is more efficient at retaining this captured heat.

Specific heat *c* refers to the amount of energy needed to raise the temperature of 1 gram of a substance 1 degree Celsius. This is expressed in units of joules per gram-degree Celsius (J/g·°C). The specific heat of water, 4.186 J/g·°C, is often represented as its own separate measure, the calorie.

Liquid water's specific heat is one of the highest of any substance. Therefore, liquid water requires more heat energy to increase its temperature than almost any other substance. Likewise, liquid water must lose more energy to decrease its temperature than almost any other substance.

The high specific heat of water is fundamentally involved in moderating global climate, global weather patterns, and local weather patterns. Without water's high specific heat, the global surface and air temperatures would fluctuate through a much larger range, making life on Earth impossible or severely reducing the types of organisms that could live on Earth.

The high specific heat of liquid water allows the oceans to function as huge energy sinks that can transfer large amounts of energy from one area to another, moderating the climates of all regions of the globe. The high specific heat of water also allows water to remain liquid across a large range of air temperatures, as well as to change in temperature slowly, providing a reliable habitat for aquatic organisms. The temperature of air above large bodies of water also stays within a narrower range, greatly moderating the climate above and near these bodies of water.

Conversely, the low specific heat of dry ground causes its temperature to increase more rapidly in response to heating from the sun, and to decrease more rapidly when the sun goes down. This heating or cooling result in the air above the ground being heated or cooled accordingly. In regions having land areas close to large bodies of water, this difference in the heating and cooling rates of land and water results in air movement (wind). As air over land is heated, it rises and cooler air from over the water moves in to take its place. This is called a sea breeze (also known as an onshore breeze), and the opposite, land breeze (also known as an offshore breeze), occurs at night when the water is warmer than the land.

Pre-Lab Discussion and Experiment

Introduction

Engage students by helping them to recall experiences when they were visiting an ocean beach or lake on a hot day and a cool night in the summer. Ask students to compare their perceptions of the temperature of the water versus the temperature of the sand or ground they walked on or the air temperature above the land. Students may recall running across a hot beach to reach the cool water on a hot, sunny day, or the silky warmth of the water compared to the cool air temperature during a moonlight swim.

Ask students the following questions.

1. How do these temperature differences occur, given the fact that the sun's energy is equally distributed on both areas throughout the day and equally absent at night?"

Record all ideas for student viewing. Tell students they will explore an intrinsic property of matter: specific heat, which results in these phenomena.

Instructor Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment.

Closed Systems

The learning goals of this experiment require that students understand the concept of conservation of energy in a closed system as well as the concept of transfer of thermal energy towards equilibrium. Test prior student knowledge to ensure that they understand these concepts.

2. Would you agree that boiling water has more energy in it than cold water? Where does this increased energy come from?

Boiling water has more energy in it than cold water. The energy comes from the heat source used to boil the water.

3. What happens to the energy in boiling water if we pour it into ice water?

The energy in the boiling water will melt the ice.

4. How can we measure this transfer of energy?

The energy transfer can be measured by measuring the final temperature of the water (the temperature of ice water and boiling water can be measured prior to pouring the boiling water into the ice water.

5. Would we get a different result if we did this in a closed container instead of an open one? Where would the energy go in each case, and what might be the difference in temperature?

The final temperature in a closed container would be higher than the temperature in an open container, since some heat energy will be lost to the surroundings in an open container. In the closed container, all the heat energy of the boiling water would be transferred to the ice water.

Note: If you think your students experience difficulty grasping these concepts, consider doing a demonstration. Ask students to predict the resulting temperature in the two instances before performing the demonstration.

Determining the Rate of Heating and Cooling

Students should be able to determine the rate of heating and cooling of water versus sand. If necessary, review the 2-point method of finding a rate, or review the procedure for finding the best-fit line and its slope using the data collection system.

If necessary, work through an example of the 2-point method for finding the rate, for example, finding the rate of temperature increase if the temperature rose from 20 °C to 30 °C over a period of 20 minutes. For example, [(30 °C – 20 °C)/ 20 min = 0.5 °C/min].

Students should know how to construct a ratio in order to compare the specific heat of water to that of land. If necessary, review ratios with your students. Ask students to find the ratio of boys to girls in the classroom as a simple test for prior knowledge. They can then calculate the fraction that represents the ratio of boys to girls.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. You will need some clean, dry sand for this experiment. This is readily available in bags in garden supply stores, aquarium supply stores, and construction supply stores.

Instructor Tip: To obtain more clear-cut data, the heating (lamp on) and cooling (lamp off) operations for sand and water in Part 1 can be extended from 5 minutes for each condition, as described in the procedure, to 15 minutes for each condition.

Safety

Follow all standard laboratory procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Rates of heating and cooling of water versus sand

Set Up

1. Start a new experiment on the data collection system. �(1.2)

2. Connect two fast-response temperature probes to your data collection system. �(2.2)

3. Display Temperature on the y-axis of a graph with Time on the x-axis. �(7.1.1)

4. Set up the graph display to show two data runs simultaneously. �(7.1.3)

5. Put 200 g of sand into a 250-mL beaker.

6. Put 200 g of water into another 250-mL beaker.

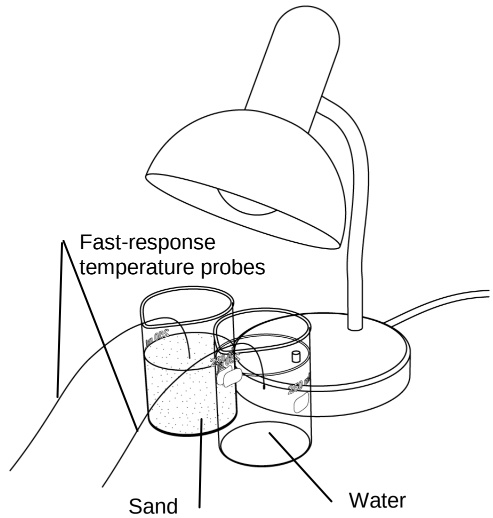
7. Place a fast-response temperature probe in each beaker as shown in the illustration.

Note: Each of the temperature sensors should be approximately one inch below the surface.

8. Place the heat lamp directly above the beakers so that both beakers receive the same amount of energy from the lamp.

9. Why is it important to heat both beakers equally?

It is important to heat both beakers equally so the water and the sand receive the same amount of energy from the light. Then the variable of heat added to the system will be equal for both materials.



Collect Data

10. Start data recording. �(6.2)

11. Adjust the scale of the graph to show all data. �(7.1.2)

12. Record data for 30 seconds.

13. Turn on the light and record data for an additional 5 minutes (300 seconds). *Do not stop recording data!*

14. How much faster do you think the temperature of the sand will increase than that of the water? How much faster will it decrease when the light is turned off? Give a specific rate comparison (such as twice as fast or twice as slow).

Students should specify a rate comparison, such as: "I think the temperature of the sand will increase two times as fast as that of the water, and it will decrease two times as fast as that of the water."

Note: While the data is recording for 5 minutes, you can begin setting up Part 2 of the procedure.

15. Turn the light off.

16. Continue recording data for 5 minutes.

17. Stop recording data. �(6.2)

18. Name the data runs "Sand" and "Water". �(8.2)

19. Save your experiment. �(11.1)

20. Complete the steps in the Data Analysis section for Part 1.

Part 2 – Determine the specific heat of sand

Set Up

21. How do you think the specific heat of sand will compare with the specific heat of water? Give a rate comparison (such as twice as fast or twice as slow).

Students should include a quantity in their predictions. For example, the specific heat of water will be 7 times higher than that of sand.

22. Fill the 500-mL beaker about 3/4 full with water.

23. Place the beaker on the hot plate, and turn it on to the highest setting.

24. Bring the water to a boil.

25. Set up the tripod base and rod while you wait for the water to boil. Fasten a buret clamp just above the beaker.

26. Measure the mass of the test tube: 20.9 g .

27. Fill the test tube half full with sand.

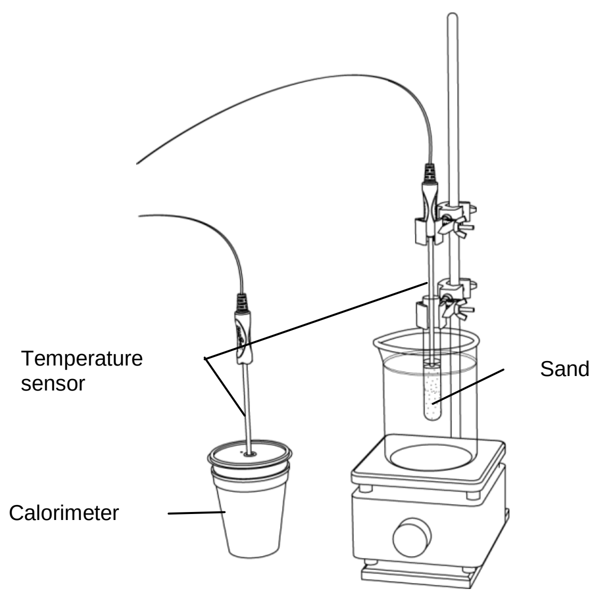
28. Measure the mass of the sand and the test tube: 40.7 g .

29. Calculate the mass of the sand alone and write the mass in Table 2 in the Data Analysis section.

30. Use the buret clamp to secure the test tube in the 500-mL beaker of boiling water. Make sure the sand in the test tube is below the water level.

31. Connect the two stainless steel temperature sensors to the data collection system. �(2.2)

32. Place one of the stainless steel temperature sensors into the middle of the test tube. Do not allow the sensor to touch the bottom or sides of the test tube.



33. Support the sensor with the second buret clamp.

34. Before making the calorimeter (by nesting two disposable insulated cups), make sure the lid has a hole in it that you can slide the stainless steel temperature sensor and stirring rod through.

35. Measure 70.0 g of room-temperature water.

36. Place the two disposable insulated cups together, and add the water into the top cup.

37. Use the other stainless steel temperature sensor to measure the temperature of the water in the insulated cup. �[6.1]

38. If necessary, open a graph display that shows Temperature on the y-axis and Time on the x-axis, �[7.1.1] and set up the graph display to show two data runs simultaneously. �[7.1.3]

Collect Data

39. Start recording data, �[6.2] and adjust the scale of the graph to show all data. �[7.1.2]

40. Record data for 600 seconds, then stop recording data.�[6.2]

41. Name the data run "Sand2". �[8.2]

42. Record the temperature of the sand in Table 2 in the Data Analysis section (T_{initial}).

43. Turn the hot plate off.

44. Use the same temperature sensor you used to measure the temperature of the water. Insert the temperature sensor through the hole in the lid (the lid is not on the disposable insulated cup yet).

45. Insert the stirring rod through the same hole and put the lid on the cup, making sure the thermometer is in contact with the water.

46. Start recording data, �[6.2] and adjust the scale of the graph to show all data. �[7.1.2]

47. Use tongs to remove the test tube and quickly pour the contents of the tube into the water in the calorimeter.

48. Immediately cover the disposable insulated cup with the lid, making sure the temperature sensor doesn't touch the side or bottom of the cup. Stir the water and sand mixture.

49. Why did you pour the sand into the water?

Hint: The specific heat of water is a known constant: 4.186 J/g °C.

Because the specific heat of water is a known constant, it is possible to calculate the total amount of energy added to the water from the change in the water temperature. Because the amount of heat lost by the sand equals the amount of heat absorbed by the water, you can find the unknown quantity: the specific heat of sand.

Although students may not know this answer yet, they should know it by the end of the lab and should be expected to complete the answer at that point. Tell students that if they do not know the answer to this question, return to it later when they do.

50. Continue stirring the water and sand mixture.

51. Record data until the temperature starts to level off, and then stop recording data. �(6.2) (This will take about 1 minute.)

52. Name the data run "Calorimeter". �(8.2)

53. Save your experiment. �(11.1)

54. How did the initial temperature of the water and sand added to the insulated cup compare to the final temperature of the water-sand mixture? Where did the heat energy of the sand go when you put it into the water?

The initial temperature of the sand was higher than the initial temperature of the water, but when the two were combined, their temperatures became equal (the sand lost heat energy and the water gained heat energy).

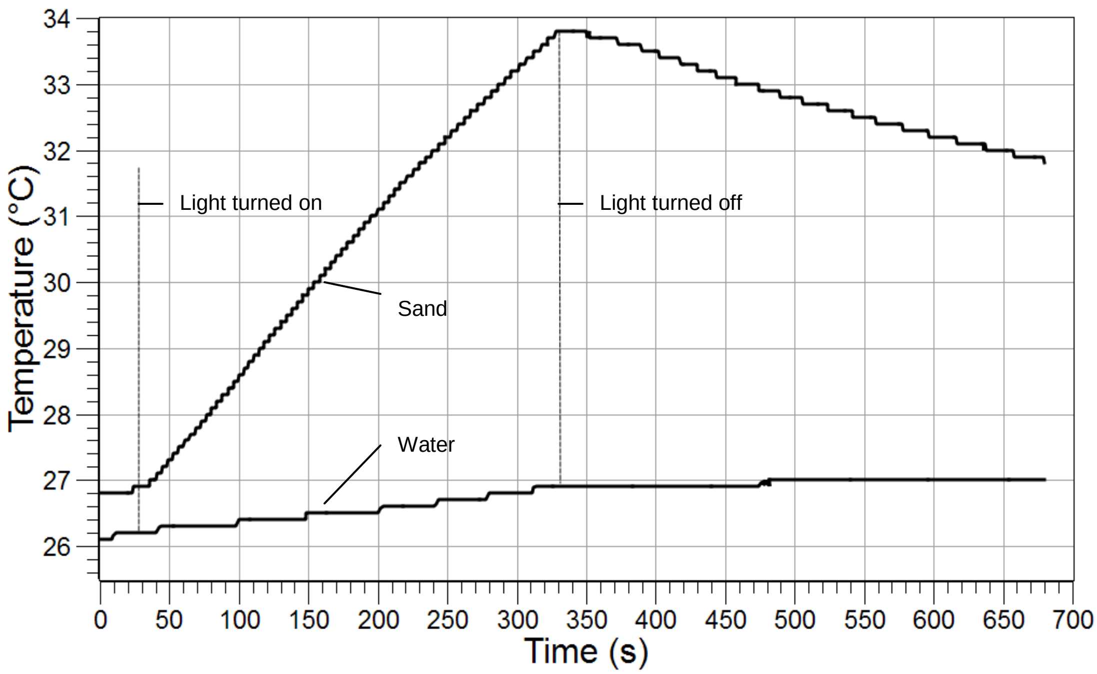
55. What was the purpose of using an insulated cup and lid rather than simply using a beaker?

The insulated cup reduces the amount of heat lost to the surrounding environment, helping to create a closed system.

Data Analysis

Part 1 – Heating and cooling of water versus sand

1. Sketch your two data runs, "sand" and "water," on the graph. Label both data runs, label the axes with units and a scale, and indicate when the light was turned on and turned off.



2. Use the graph tools to determine the temperature data points specified in the Table 1. �(9.1)

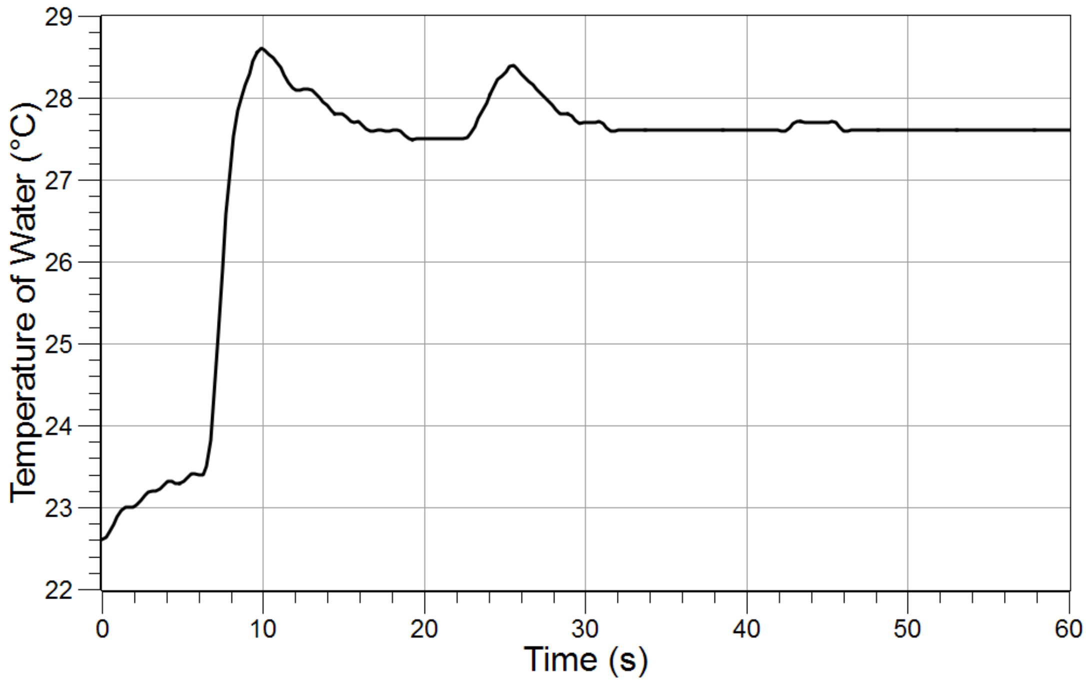
3. Complete the calculations for Table 1.

Table 1: Rates of heating and cooling of water and sand

	$T_{initial}$ (°C)	$T_{max,light\ on}$ (°C)	$\Delta T_{heating}$ (°C)	$Rate_{heating}$ (°C/s)	T_{final} (°C)	$\Delta T_{cooling}$ (°C)	$Rate_{cooling}$ (°C/s)
Water	26.1	26.9	0.9	0.003	27.0	0.1	0.0003
Sand	26.8	33.8	16.10	0.018	31.9	1.9	0.0060

Part 2 – Determine the Specific Heat of Sand

4. Sketch the graph of the third data run of Temperature versus Time for the water-sand mixture. Be sure to label the x-axis and y-axis regarding parameter and units of measurement as well as the data runs.



5. Find the initial and final temperatures of the data run and enter them in Table 2. �(9.1) (The initial temperature of the sand should have been entered earlier).

6. Complete the calculations for Table 2.

Hint: Determine the amount of heat gained by the water (Q) using the mass of the water (m), the specific heat of the water (c), and the change in temperature of the water (ΔT.) This relationship is described by the equation: $Q = mc\Delta T$.

Table 2: Determining the specific heat of sand

Material	Mass m (g)	T_{initial} (°C)	T_{final} (°C)	ΔT (°C)	Q (J)	Specific Heat c (J/g °C)
Water	70.0	22.6	27.6	4.0	1172	4.186
Sand	19.8	78.4	27.6	50.8	1172	1.2

Analysis Questions

1. Calculate the ratio of the sand's rate of temperature increase to the rate of the water's temperature increase during the heating condition.

Answers will vary slightly from those in the example where the ratio of the rate of increase in temperature of sand to water is 0.018:0.003 or 6:1.

2. Calculate the ratio of the sand's rate of decrease to the rate of the water's temperature increase during the cooling condition.

Answers will vary slightly from those in the example where the ratio of the rate of decrease in temperature of sand to water is 0.006:0.0003 or 20:1.

3. How much faster did sand heat up and cool down compared to water? How does your prediction regarding the relative rates of heating and cooling compare with the results? Give a quantitative comparison.

Answers will vary. Students should compare their predictions to their answers. Using this example, students should state that they found that sand heated up 6 times faster and cooled down 20 times faster than water. Then they should compare those rates to the ones they predicted.

4. In Part 1 of this exploration, what was the independent variable and the dependent variable, and what factors did you hold constant?

The independent variable was the type of substance: sand or water. The dependent variable was the temperature of the substance. The factors held constant included the amount of energy added to the system, the mass of the substance being tested, the type of container holding the substance, the time of measurement, and the measurement technique.

5. Compare your results for Part 2 with your prediction, using specific quantities.

Answers will vary, but students should make a quantitative comparison. For example, students could say that they predicted that water has a specific heat that was 7 times that of sand, based on the comparative rates of heating and cooling of sand and water. In the example data for Part 2, students found that the specific heat of water was about 3.5 times greater than that of the sand.

6. What is the relationship between the specific heat of a substance and the rate of temperature change when the energy content of the environment around it changes?

The higher a substance's specific heat, the slower it changes in temperature when the energy content of its environment changes.

7. What characteristics of water account for its high specific heat?

Water's strong intermolecular bonds, especially the hydrogen bonds, account for its high specific heat.

8. In this experiment, what does *Q* represent? Why was *Q* the same for the water and the sand?

Q represents the amount of energy transferred from the sand to the water when the two were combined. In this experiment, *Q* was calculated from the change in temperature of the water, water's specific heat, and the mass of the water. To find the specific heat of sand, we assumed that all of the energy given up by the sand was transferred to the water. Therefore, by experimental design (using the calorimeter), *Q* was the same for the water and the sand.

9. List some important sources of experimental error that might occur in this experiment.

In Part 1, the amount of energy added to each system might not be exactly the same. In Parts 1 and 2, an unknown amount of energy was lost to the environment, because we did not truly have closed systems. Also, there may have been calibration differences between the temperature sensors.

Synthesis Questions

Use available resources to help you answer the following questions.

In the following questions, assume that the data you obtained for sand represents data for land in general.

1. How could you modify the experiment to be more confident in this assumption?

Additional substances found on land, such as dry soils of different types, gravel, and vegetation, could be analyzed to determine their specific heat. A mean of these values could be compared with the specific heat of water.

2. Explain how the proximity to a large body of water influences weather. Provide an example.

Because of the high specific heat of water, proximity to a large body of water moderates the weather. The range of daily temperatures near the water is less than the range that occurs inland. Additionally, weather conditions near the coast can be foggy, whereas inland there will be no fog. For example, the weather can be foggy and cool in San Francisco, California, while simultaneously 100 miles inland, the weather can be sunny and hot.

Conversely, in the winter, the temperature in San Francisco can be cool, whereas the temperature 100 miles inland can be below freezing. On a day in July, the maximum temperature in San Francisco was 18 °C (65 °F), while the maximum temperature in Sacramento, in interior California at about the same latitude and elevation, was 38 °C (101 °F)

3. Explain how the proximity to a large body of water influences climate. Provide an example.

Because of the high specific heat of water, proximity to a large body of water moderates the climate. Compared to areas inland, the average summer temperatures are cooler and the average winter temperatures are warmer near the water. For example, the average temperatures in Brisbane, on the coast of Australia, in January and July, respectively, are 25 °C (77 °F) and 14 °C (58 °F). Those for Alice Springs, in the interior of Australia at the approximately the same latitude and elevation are 34 °C (93 °F) and 12 °C (53 °F), respectively.

In another example, farmers along the coast of California do not have to be concerned about crop damage due to frost, whereas in the central valley of California, frost is common during the winter.

4. Explain how a large land mass influences weather. Provide and example.

Because of the low specific capacity of land, a large land mass causes daily highs in temperature in the summer to be higher inland relative to that on the coast or over the ocean. For example, on a day in July, the maximum temperature in Vancouver, Canada (on the Pacific coast) was 23 °C (73 °F), whereas for Winnipeg, Canada, which is about the same latitude and elevation in interior Canada, the maximum temperature was 28 °C (82 °F).

5. Explain how a large land mass influences climate. Provide and example.

Because of the low specific capacity of land, a large land mass causes the average summer daytime temperature to be higher and the average winter daytime temperature to be lower than for smaller land masses at the same latitude. For example, the average temperatures in February and July for Manchester, England are

3 °C (37 °F) and 16 °C (60 °F), respectively. In contrast, those for Novosibirsk in the interior part of the Russian Federation at approximately the same latitude and elevation are –20 °C (–4 °F) and 19 °C (67 °F), respectively.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. In Part 2 of this experiment, to complete your calculations you relied on the assumption that all of the heat energy in the heated sand was transferred to the water in the insulated cup until the temperatures of the sand and water were equal. Thus, you were counting on

- **A.** The laws of motion.
- **B. The first law of thermodynamics (energy conservation).**
- **C.** The second law of thermodynamics (entropy).
- **D.** The third law of thermodynamics (entropy reduces as temperature lowers but is always present).
- **E.** The law of gravity.

2. All of the following influence global air circulation EXCEPT

- **A.** Uneven heating of the earth's surface.
- **B.** Rotation of the earth on its axis.
- **C.** The difference in specific heat of water compared to that of land.
- **D.** Seasonal changes in temperature and precipitation.
- **E. The position of Earth's moon relative to Earth.**

3. Compared to a substance with a low specific heat, a substance that has a high specific heat

- A. **Requires more heat per gram to be added to it to cause an increase in temperature.**
- **B.** Requires less heat per gram to be added to it to cause an increase in temperature.
- **C.** Requires the same amount of heat per gram to be added to it to cause an increase in temperature.
- **D.** Has a larger mass.
- **E.** None of these is true.

4. Water has a high specific heat because

- **A.** It changes from a solid to a liquid phase at a relatively high temperature.
- **B. It has intermolecular hydrogen bonds.**
- **C.** It boils at 100 °C.
- **D.** It freezes at 0 °C.

5. The high specific heat of water compared to that of land results in

- **A.** The small range of temperatures in the oceans compared to that on land.
- **B.** Coastal climates that have smaller ranges of temperature compared to those of inland areas.
- **C.** The ability of large fresh water bodies to stay in liquid phase when air temperatures drop below 0 °C.
- **D.** **All of these are true.**

Extended Inquiry Suggestions

Ask students to conduct an Internet search to find the specific heat of various substances. Find the specific heat of common building materials. Challenge students to relate these specific heats to the phenomenon of the urban heat island effect found in cities. What would be the affect on city temperature of including a lot of foliage in a city (Remember that plants contain a lot of water and also transpire).

The specific heat of room-temperature air (about 23 °C, 40% relative humidity, 200 meters above sea level) is about 1 J/g °C. Challenge students to design an experiment to test the affect of humidity on the heat capacity of air. Ask them to state their hypothesis and then test the hypothesis.

5. Water Treatment

Objectives

Students demonstrate how water treatment processes such as filtration, flocculation, and sedimentation improve water quality.

Procedural Overview

Students will gain experience conducting the following procedures:

- Evaluating water treatment processes using direct observation and by measuring conductivity, pH, and turbidity.
- Using test results to design, build, test, and evaluate a water treatment process.

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and experiment	45 minutes
♦ Lab experiment	90 minutes or two, 45-minute sessions

Materials and Equipment

For each student or group:

- Data collection system
- Water quality sensor (or pH and conductivity sensors)
- Turbidity sensor
- Beaker (4), 150-mL
- Beaker, 50-mL
- Beaker, large ("wastewater" container)
- Test tube, 18-mm OD or greater
- Graduated pipet, 50-mL, and bulb
- Graduated cylinder, 100-mL
- Transfer pipet, 2 mL
- Stirring rod
- Balance (1 per class)
- Buffer solution pH 4, 25 mL
- Buffer solution pH 10, 25 mL
- Soda bottle (2), empty, 500-mL
- Paper napkins (12), dinner, white, smooth
- Paper towels(4), white
- "Wastewater" sample, 500 mL[1]
- Swimming pool water clarifier solution, 4%, 2 to 4 mL
- Wash bottle containing water
- Activated charcoal, 2 g
- Water, 300 mL
- Lint-free lab tissue

[1]To formulate using tap water, soil with a high clay content or crushed kitty litter, and coffee, refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Renewable and non-renewable resources
- ♦ Measuring conductivity
- ♦ Measuring pH
- ♦ Measuring turbidity

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Monitoring Water Quality
- ♦ Determining Soil Quality

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting multiple sensors to the data collection system �(2.2)
- ♦ Calibrating a pH sensor �(3.6)
- ♦ Calibrating a turbidity sensor �(3.7)
- ♦ Monitoring live data without recording. �(6.1)
- ♦ Displaying data in a digits display �(7.3.1)

Background

There are several steps in the water treatment process common to both drinking water and wastewater treatment. Among these processes are coagulation, flocculation, and filtration.

Filtration technology is abundant and can be used to remove nearly any impurity from water. However, using only filtration devices is not cost effective, so usually filtration is combined with other water treatment methods.

Both types of water treatment—for drinking water and for wastewater—start by passing the water through a screen to remove larger objects. Then, a coagulant is added to the water. Salts of aluminum (alum) or water-soluble organic polyelectrolytes are often used as coagulants. Coagulants cause suspended particles to form clumps. Next, these clumps aggregate into larger clumps, or flocs. These flocs are dense enough to settle out of the water in a process called sedimentation. The water is then filtered through a variety of media of varying porosities, including activated carbon, sand, and gravel. Filtration works by trapping impurities in the spaces between the granules of the media and allowing the water to flow through it.

While the water looks clean at this point, several precautions must be taken to eliminate viruses or bacteria in the water that can cause disease. Three of the most common ways to disinfect water include: 1) treatment with chlorine, 2) bubbling with ozone, or 3) exposure to ultraviolet light. More advanced (and expensive) filtration methods use membranes—for example, reverse osmosis and micropore filtration—for special purposes.

The United States Environmental Protection Agency (EPA) publishes the Primary and Secondary Drinking Water Standards on the Internet. These specify the maximum level of contaminants in the United States for drinking water supplied by municipal water treatment facilities and are good references to have on hand.

The United States standards for the water quality of natural bodies of water that support aquatic organisms are also specified by the United States EPA in their Red Book and Gold Book. These are also available on the Internet. Treated wastewater must ensure that these standards are maintained when wastewater is discharged back into the ecosystem.

Pre-Lab Discussion and Experiment

Many students have not thought carefully about how the water they drink and the water they put into the sewer system is processed. Discuss water usage and waste in the home and community by asking the following questions:

1. How does water get into the home?

The water that is pumped into residences has to meet water quality standards. A better term for what we usually just call "water" is "drinking water." This is what comes out of the faucet, spigot, and garden hose. Although drinking water is also used for things like bathing, cooking, and car washing, the idea remains the same: it is safe to drink and contains no offensive taste, odors or color.

In order to provide homes with drinking water, communities have developed water treatment plants to ensure the water is safe. Water comes into the home via a distribution network that includes a watershed, a collection point (such as a reservoir, tower, or tank), and the water treatment facility. From there, water is piped to businesses and homes served by the water treatment facility.

2. Where does it come from?

Water that is ultimately fed into the home can come from a variety of sources. Raw, untreated water is obtained from the large bodies of water, like lakes and rivers, of a local or distant watershed.

3. How, generally, does it leave the residence?

Answers will vary based on your location and local water and sewage treatment facilities.

Bring in water samples from various sources and discuss whether treatment is necessary to improve quality. Help build students' understanding of humans' interactions with the water cycle and their effects on the environment by asking the following questions:

4. How does proximity to industries and to areas affected by the presence of people alter water quality?

Industries that introduce pollutants into the water or air have the potential to adversely affect water quality. Also, the way people use the land can affect water quality. For example, when rain hits the land or the structures, such as roads and parking lots, that people build, the rainwater picks up substances such as pesticides, fertilizers, and car fluids that have leaked and brings them as part of the runoff into a creek, lake, or other body of water.

5. What can be done to prevent water pollution from industries?

One of the following will have to occur: industry has to stop operations, trap and dispose of pollutants before they are introduced to the environment, or treat water to remove the pollutants.

Engage students and prepare them for a successful lab experiment by doing a demonstration and asking them to predict the outcome. You can turn this into a contest.

Tell students you will analyze the local tap water for its pH, conductivity, and turbidity. Have them write down their predictions regarding these parameters. Tell them that these predictions will be used to determine the winner of your contest.

Demonstrate how to properly calibrate the pH and turbidity sensors and then test the pH, turbidity, and conductivity of the local tap water.

Note: The conductivity sensor does not need calibrating because the possible calibration error is small compared to the magnitude of conductivity being measured.

Note: Model the correct method for handling the cuvettes of the turbidity sensor.

Note: Highlight the need to submerge the conductivity sensor so the holes on the end of the sensor are submerged, and emphasize the need to wash the sensor with water between measurements.

Note: Emphasize the need to rinse containers between trials.

Discuss the results with students. Try to relate these to what you know about the source of the water or the water treatment procedures in your area. For example, if your local water is taken from a valley river or well, it is likely to have higher levels of dissolved solids, and thus higher levels of conductivity, than water that is taken from a river flowing through a mountain. (This is because the water in the well or river valley has been exposed to more runoff from the watershed or for more time to minerals in the ground.)

Turbidity will be low or not measurable because water treatment facilities are required to remove suspended solids for sanitation reasons. So even if your water source is turbid, the water delivered from your tap will not be turbid.

The pH will be in the neutral zone because water treatment facilities are required to adjust the pH to neutral. That is because pH that is too acidic or basic is corrosive to water pipes. So even if your area has acidic water, the pH will be adjusted by the water treatment facility so the water flowing through the pipes has a pH in the neutral zone.

Have students find the total numerical value of the difference between their guesses and your measurements, with the winner being the students with the lowest difference for each of the three parameters.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Purchase dinner napkins, paper towels, swimming pool water clarifier, and activated charcoal at local stores.

- Swimming pool water clarifier is widely available at hardware/home improvement stores.
- Activated charcoal is widely available at health food stores as loose powder or in 250-mg capsules. Both forms work well, but the capsules take longer and are messier to use, because a total of 8 capsules for each group will have to be opened.

Note: Activated charcoal can get messy if students are careless with it. Have plenty of paper towels and soap handy.

2. Consider having students bring in empty 500-mL disposable plastic bottles. Otherwise, save them yourself or find a source of them.

3. Prepare the "wastewater" sample (about 500 mL are required per group): Fill a large container (for example 2 to 3 gallons) with water, and add the following:

- Two to three handfuls of potting soil (Make sure the soil has a high clay or silt content. If not, add some crushed kitty litter.) Strive for a turbidity of about 400 NTU.
- Coffee or instant coffee granules. Add enough until you can detect a coffee odor.

4. Prepare the 4% solution of swimming pool water clarifier: Mix 4 mL of clarifier solution with 96 mL of water. This will create enough for approximately 50 groups.

Safety

Follow all standard laboratory procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Determining effects of different water treatment processes

Set Up

1. Stir the "wastewater" sample to uniformly mix it.

2. Pour 100 mL of the well-mixed "wastewater" sample into each of four 150-mL beakers.

3. Label the beakers as follows:

- ♦ Beaker 1, "#1 Untreated"
- ♦ Beaker 2, "#2 Activated Charcoal"
- ♦ Beaker 3, "#3 Sedimentation"
- ♦ Beaker 4, "#4 Coagulation"

4. Set Beaker 3 aside for at least 30 minutes. Enter the starting time: __________

5. Put 2 mL of the 4% swimming pool clarifier solution in Beaker 4 and use the stirring rod to stir vigorously.

6. Note any changes in appearance and record these in Table 1 in the Data Analysis section.

7. Periodically during the next 30 minutes, slowly stir this solution.

Note: Swimming pool clarifier solution contains coagulating agents similar to those used in municipal water treatment facilities.

8. Start a new experiment on the data collection system. �(1.2)

9. Connect a water quality sensor (or pH and conductivity sensors) and a turbidity sensor to the data collection system. �(2.2)

10. Display pH, conductivity, and turbidity in a digits display. �(7.3.1)

11. Use pH 4 and pH 10 buffer solutions to calibrate the pH sensor. �(3.6)

12. Calibrate the turbidity sensor. �(3.7)

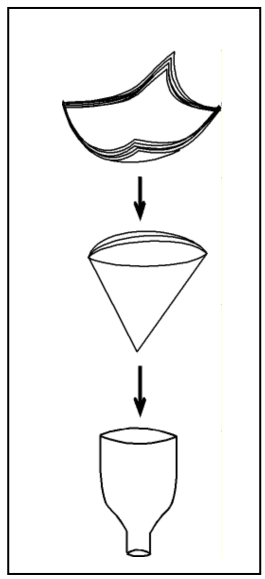
Note: It is not necessary to calibrate the conductivity sensor for this experiment.

13. Prepare a paper membrane filter as follows:

a. Cut off the top half of a 500-mL soda bottle to use as a funnel.

b. Fold a paper towel in half, and then fold it in half again. Separate the layers to make a funnel-shaped filter.

c. Stack 3 paper napkins together, and shape them into a shallow bowl. Tuck these into the paper funnel, and push the entire paper membrane construction into the funnel, forming a bowl to hold the filtrant.



14. Prepare an activated charcoal–paper membrane filter as follows:

a. Make another paper membrane filter as described in the previous step.

b. Measure and add 1 gram of activated charcoal to 100 mL of tap water and stir.

c. Pour this slurry into the filter.

d. After that aliquot has been filtered, slowly pour another 100 mL of tap water into the filter.

e. You should now have a paper membrane filter covered with a layer of activated charcoal. If the water filtering through it is not clear, filter an additional 100 mL of tap water.

Note: This step ensures that the activated carbon becomes fixed inside the filter and is not leaking into the filtrate.

Note: Activated charcoal is specially prepared so that it is extremely porous and can thus trap and remove molecules from water, especially large organic molecules such as those responsible for odors and colors. The activated charcoal must also be filtered out of the water.

15. Which water treatment method do you think will have the greatest effect on the following?

Odor ____________________________

Color ____________________________

pH ______________________________

Conductivity ____________________

Turbidity ________________________

16. Which water treatment method do you think will have the least effect on the following?

Odor ___________________________

Color ___________________________

pH ______________________________

Conductivity ____________________

Turbidity _______________________

Collect Data – Untreated waste water

17. Examine the untreated "wastewater" sample (Beaker 1). Note its odor, color, and general appearance, and record these in the Table 1 in the Data Analysis section.

18. Monitor live data without recording. �(6.1)

19. Determine the pH, conductivity, and turbidity, and record them in Table 1.

Collect Data – Paper membrane filtration

20. Now test the effect of filtration on the untreated wastewater sample.

a. Slowly pour the untreated sample into the paper filter, being careful to keep the liquid contained inside the paper napkin "bowl".

b. Collect the filtrate in the 50-mL beaker.

21. Determine the odor, color, and general appearance of the filtrate, and record these in Table 1.

22. Transfer the filtrate to a large test tube.

23. Determine the pH, conductivity, and turbidity, and record them in Table 1.

24. Rinse the beakers and test tube.

Collect Data – Activated charcoal-paper membrane filtration

25. Using the activated charcoal–paper membrane filter you prepared earlier, filter 100 mL of the "wastewater" from Beaker 2 into the graduated cylinder.

26. Discard the first 30 mL of filtrate. Collect the remaining filtrate in the 50-mL beaker.

27. Note the odor, color, and general appearance of the filtrate, and record these in Table 1.

28. Transfer the filtrate to the large test tube.

29. Determine the pH, conductivity, and turbidity, and record them in Table 1.

30. Rinse the beakers, graduated cylinder, and test tube.

31. What effects did adding activated charcoal to the paper membrane filtration have on the results of the filtration?

In our sample, the water had less of an odor and it appeared cleaner. The conductivity dropped significantly, so the charcoal was effective at removing dissolved solids.

Collect Data – Coagulation plus paper membrane filtration

32. Observe the coagulated sample (Beaker 4). Compare it with an untreated sample and record your observations here:

Students should see that the coagulated sample is cloudier than the untreated sample. They may see flecks of white floc on the surface. When they swirl the water, they will see coagulated clumps moving in the water.

33. Determine the pH, conductivity, and turbidity and record the data in Table 1 (in the row labeled "Coagulation").

34. Prepare another paper membrane filter as described previously.

35. Filter the coagulated sample using this paper membrane filter.

36. Note the odor, color, and general appearance of the filtrate, and record these in Table 1.

37. Transfer the filtrate to the large test tube.

38. Determine the pH, conductivity, and turbidity, and record them in Table 1.

39. Rinse the beakers and test tube.

Collect Data – Sedimentation

40. From Beaker 3, carefully pipet a 30-mL sample from the top of the solution, being careful not to disturb the solution.

41. Place the sample in the test tube.

42. Note the odor, color, and general appearance of the sample, and record these in Table 1.

43. Determine the pH, conductivity, and turbidity, and record them in Table 1.

44. Rinse the beakers and test tube.

Part 2 – Designing and testing a water treatment system

Set Up

45. Design a water treatment procedure using the techniques presented in Part 1 of this experiment.

46. Record the water treatment steps in your design and explain why you chose this design. Refer to your test results in Part 1.

Designs will vary, but students should include at least 2 treatments and have good reasons for their process design that are based on the data they collected in Part 1. An example of an effective design is as follows:

1) Add a coagulating agent to the sample.

2) Allow coagulation to proceed for 30 minutes.

3) Prepare an activated charcoal-coated paper membrane filter.

4) Filter the coagulated sample.

Given this example, an explanation might be as follows:

I ruled out using sedimentation because it is too slow for the amount of time I have to test my system. I reasoned that if I add a coagulating agent, the suspended solids will clump. The activated charcoal forms a more non-porous surface on the paper filter, as shown when it allowed water to filter at a slower rate. So by using the activated charcoal-coated paper membrane filter, I can have more effective removal of suspended solids as well as better removal of odor and color.

Collect Data

47. Treat 100 mL of the "wastewater" using the system you designed.

48. Note the odor, color, and general appearance of the sample, and record these in Table 2.

49. Transfer the filtrate to the large test tube.

50. Determine the pH, conductivity, and turbidity, and record them in Table 2.

51. Clean up according to your instructor's instructions.

Data Analysis

Table 1: Water treatment process results

Water Treatment Type	pH	Conductivity (µS/cm)	Turbidity (NTU)	Odor	Appearance (Color, Transparency, Other Observations)
Untreated "wastewater"	6.4	449	357	noticeable coffee odor	brown, turbid, organic material floating on top
Paper membrane filtration	6.7	448	348	noticeable coffee odor	brown, a little less turbid, no large pieces of organic material
Activated charcoal + paper membrane filtration	6.6	217	173	coffee odor very slight or absent	clearer than untreated, less color
Coagulation	6.5	414	700	noticeable coffee odor	extremely turbid, cloudy
Coagulation + paper membrane filtration	6.6	460	300	noticeable coffee odor	clearer than untreated, but not as clear as activated charcoal filtered
Sedimentation	6.4	401	409	noticeable coffee odor	looked a lot like the untreated water, but had more large insoluble pieces sitting on the bottom

1. Compare the data obtained from your designed water treatment system with the data collected in Part 1 and complete the "Best Individual Test System" row in Table 2.

2. Share the data from your designed water treatment system with those collected by classmates and then complete the "Best Designed System in the Class" row in Table 2.

Table 2: Results of the designed water filtration systems

Water Treatment Data Set	pH	Conductivity (µS/cm)	Turbidity (NTU)	Odor	Appearance (Color, Transparency, Other Observations
My designed treatment system	6.6	235	15	Not detectable	clear, slight tint of brown
Best individual test system (from Part 1)	6.6	217	103	Very slight	somewhat turbid, slight tint of brown
Best designed system in the class					

Analysis Questions

1. Compare your predictions with your results. Which result surprised you the most?

Answers will vary, but students should include reference to their test results.

2. What was the effect of filtration using a paper membrane?

Membrane filtration using paper filters removed only the large, medium, and somewhat small suspended material.

3. What was the effect of treatment with the activated charcoal and membrane filtration?

Membrane filtration through a layer of activated charcoal worked the best of all the treatments, but it was also the slowest. Most of the coffee odor was removed as was some of the color. Additionally, some of the conductivity and turbidity was removed.

4. What was the effect of treatment with a coagulating agent? What was the effect of coagulation and paper membrane filtration?

Treatment with a coagulating agent caused the solution to become cloudy and even more turbid than before. Conductivity and pH did not seem to be affected much.

After filtering, the filtrate was somewhat clearer than the untreated sample, but not as clear as the activated charcoal–paper membrane filtered sample. There did not seem to be a reduction in the odor.

5. What was the effect of treatment with sedimentation?

Sedimentation for 30 minutes had a limited effect, with only the largest pieces settling out. If the water was filtered first before the sedimentation step and then allowed to sit for a day, the results would probably improve.

6. What quality of water is measured with the conductivity sensor?

Conductivity is a measurement of the ability to conduct electricity. In water, it is a measure of the concentration of ions and can be roughly related to total dissolved solids (TDS) measurement, which is much more cumbersome to perform. Total dissolved solids (mg/L) can be estimated from its conductivity (μS/cm) by dividing the conductivity measurement by 2.

7. Which treatment method worked best for odors?

The treatment that worked best for odors was filtration through the activated charcoal–paper membrane.

8. Which treatment method worked best for removing turbidity? Which was least effective?

The treatment that worked best for removing turbidity was filtration through the activated charcoal–paper membrane. Sedimentation was the least effective treatment.

9. What was the effect of the various treatments on pH?

In this example, all of the treatments raised the pH slightly.

10. Compare the results obtained with your custom-designed filtration process to those you got with the individual filter media. Be sure to make comparisons regarding the rate of filtration. (Why might this be important?)

An example: My custom-designed filtration process worked better than any of the individual processes alone. Most notably, the filtrate was much clearer than for any of the other processes. However, I noticed that my designed filtration technique was slow, much like the activated charcoal–paper membrane filtration process. This is important because water treatment facilities have to treat huge amounts of water in a short period of time. Some way would have to be found to speed up this process if it were to be used on a large scale.

11. Based on your results and those of your classmates, which combination of treatments produced the best results? Explain, using your data to support.

The best combination is likely to include coagulation and filtration through an activated charcoal filter. Student data should be included in the answer.

12. **How did your class's best design measure up to the United States Environmental Protection Agency's Drinking Water Standards? Describe one way you might improve your system or the evaluation of your system.**

The United States Environmental Protection Agency's Drinking Water Standards specify the following maximum contamination levels for the parameters you measured:

- pH: 6.5 to 8.5
- Conductivity: total dissolved solids, 500 mg/L (which corresponds to a conductivity of approximately 1000 μS/cm)
- Turbidity: 1 NTU
- Odor: 3 threshold odor number (a threshold odor number is defined as the greatest number of dilutions of a sample with "odor-free" water yielding a definitely perceptible odor)

For this example, the designed system met the requirements for pH and conductivity, it was close to meeting the requirement for turbidity, but it was not determined whether the odor requirement was met. To improve the testing procedure, an evaluation test for odor that includes determining the threshold odor number should be included.

Synthesis Questions

Use available resources to help you answer the following questions.

1. **What are some differences between water treatment for human consumption compared with wastewater treatment for discharge into the environment?**

Water treated for human consumption has to be disinfected. For this purpose, chlorine or a chemical that chlorinates is added to drinking water. Chlorine may not be added to wastewater unless coliform bacteria persist after the treatment process.

Water that is being treated for human consumption cannot be turbid, but some turbidity is allowed for wastewater.

Wastewater may be held in holding tanks and treated with decomposers, such as certain types of bacteria.

Wastewater undergoes more sedimentation treatment, with the sediment (sludge) being hauled to landfills or being used for some purpose.

Wastewater may be filtered through organic filters like a natural estuary.

Odors are not monitored for wastewater.

2. **What treatment methods would you include if you had to design a wastewater treatment system that resulted in drinking water? Explain.**

Students should incorporate the data they collected in this experiment into their reasoning. Answers should also demonstrate that students have read about and understand water treatment processes.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **The main purpose of sewage treatment is to:**

   A. Kill pathogenic bacteria and reduce odor

   B. **Remove biodegradable materials from the water and to kill pathogenic bacteria**

   C. Kill pathogenic bacteria and remove plant nutrients

   D. Kill pathogenic bacteria, remove biodegradable materials, and make the water safe for human use

   E. None of the above

2. **The main purpose of drinking water treatment is to:**

   A. Kill pathogenic bacteria and reduce odor

   B. Remove biodegradable materials from the water and kill pathogenic bacteria

   C. Kill pathogenic bacteria and remove plant nutrients

   D. **Kill pathogenic bacteria, remove biodegradable materials, and make the water safe for human use**

   E. None of the above

3. **What factor is NOT generally included in treating water for human use?**

   A. Cost effectiveness

   B. Killing microorganisms

   C. Removing suspended solids

   D. **Removing dissolved solids**

   E. A and C

Extended Inquiry Suggestions

Take a field trip to a local water treatment facility.

Invite an outreach person from a local water treatment facility to come to your classroom or interact via conference call to answer questions regarding the methodologies used for local water treatment as well as to discuss career opportunities in water treatment.

Have students research some current challenges in water treatment, such as how to economically remove salts from ocean or irrigation water, whether or not to add fluoride to drinking water, or what to do about new water contaminants, such as low levels of prescription drugs and pesticides, that are not removed by current methods.

Have students research global initiatives that seek to provide people in developing nations with safe, clean water systems. Use search terms such as water treatment, developing countries, and new technology to find information about treatment systems that have been recently designed to help worldwide purification of water. Discuss simple water treatment procedures and civil engineering strategies that can improve water quality and how these might be implemented.

6. Sunlight Intensity and Reflectivity

Objectives

Students explore the concept that air temperatures near the earth's surface result largely from the interplay of the sun's incoming energy and the absorption, reflection, and radiation of that energy by materials on the earth's surface. In the process, students:

- Analyze the laboratory evidence showing the differences in reflectivity of various earth materials
- Explain the effect of the earth's reflectivity on surface temperatures

Procedural Overview

Students gain experience conducting the following procedures:

- Using light and temperature sensors to measure the reflectivity (albedo) of various earth materials
- Using light and temperature sensors to measure air temperature and sunlight intensity throughout the day

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	90 minutes (or two 45-minute sessions)[1]

[1]If you (rather than your students) collect the data for part 2, the lab will require one 45-minute session.

Materials and Equipment

For each student or group:

- Mobile data collection system
- Light sensor
- Fast-response temperature probe
- Stainless steel temperature sensor
- Mass balance (1 per class)
- High intensity incandescent lamp
- Large disposable plate
- Tripod base and support rod
- Three-finger clamp
- Rod and clamp
- White sand[1], 500 g
- Dark sand[1], 500 g
- White rock[1], 500 g
- Dark rock[1], 500 g
- Small cardboard box, $(20\text{ cm})^3$ or larger
- Tape
- Paper and marking pen
- Scissors

[1]Such as that found at an aquarium supply store

Concepts Students Should Already Know

Students should be familiar with the following concepts:

♦ Energy transformation

♦ Light and other electromagnetic waves can warm objects

♦ Thermal energy transfer

Related Labs in This Guide

Labs conceptually related to this one include:

♦ Insolation and the Seasons

♦ Investigating Specific Heat

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

♦ Stating a new experiment on the data collection system �(1.2)

♦ Connecting multiple sensors to the data collection system �(2.2)

♦ Selecting a measurement range on a light sensor �(4.3)

♦ Changing the sample rate �(5.1)

♦ Starting and stopping data recording �(6.2)

♦ Displaying data �(7)

♦ Adjusting the scale of a graph �(7.1.2)

♦ Selecting data points in a graph �(7.1.4)

♦ Displaying multiple variables on the y-axis of a graph �(7.1.10)

♦ Displaying multiple graphs simultaneously �(7.1.11)

♦ Naming a data run �(8.2)

♦ Finding the values of points in a graph �(9.1)

- Viewing statistics of data �(9.4)

- Saving your experiment �(11.1)

Background

The air temperature near the earth's surface depends primarily on two things: the amount of energy provided by the sun and the amount of energy the earth is radiating. When these two factors are added together, the total energy is greatest shortly after the time of greatest sunlight intensity. On a sunny day, the greatest intensity of sunlight occurs around mid-day. However, the hottest part of the day typically occurs from one to several hours later.

The amount of heat the earth’s surface can absorb and subsequently radiate depends on the composition of the materials comprising the surface. Dark, rough materials absorb greater amounts of incoming solar radiation and therefore radiate more energy. Conversely, light colored, smooth materials reflect greater amounts of solar radiation and as a result have less energy to radiate. The reflectivity of a surface is its *albedo*. The higher the albedo, the more light is reflected and the less energy is absorbed.

Pre-Lab Discussion and Experiment

Show students maps of global temperatures.

Instructor Tip: Use the following keywords in an Internet search engine to find suitable Web sites: IRI Global Climatological Temperature.

Then show students illustrations from a textbook of angles of incoming solar radiation (insolation) relative to the earth’s surface. Discuss with students the reasons why the highest global temperatures correspond to the greatest angle of insolation.

Ask students to sketch a graph of their prediction of the light intensity from the sun starting at sunrise and ending at sunset.

On the same graph, have them sketch their prediction of the graph of air temperatures versus time of day.

Ask students:

1. What time of day do you expect the intensity of insolation to be the greatest?

Correct answers will include mention of the time of day when the sun has reached the greatest angle of insolation, about noon. You may choose to leave this question unresolved until after the lab experiment.

2. What time of day do you expect the air temperature to be the highest?

Students may say that the highest air temperature will occur at the same time that the insolation angle is the greatest, that is, about noon. However, due to the additive effect of earth’s reflectivity, the highest air temperature will generally occur later in the day (particularly on a sunny day with light winds), usually about 3 or 4 p.m. You may choose to leave this question unresolved until after completing the lab experiment.

3. Make a list of the materials you will be using in the order you predict will be the least reflective material to the most reflective.

Students should rank the materials they have to work with in the lab from least to most reflective. For this experiment: dark rock, dark sand, white rock, white sand.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Purchase the rock and sand. These can be purchased from any store that sells aquarium supplies.
2. Arrange to have students collect their equipment stations and stop data recording in the late afternoon or evening. Alternatively, you can place the equipment stations and collect the data for this part.

Instructor Tip: The experiment in Part 2 is best performed on a sunny day with little or no wind.

Safety

Add this important safety precaution to your normal laboratory procedures:

♦ Do not look directly at the sun.

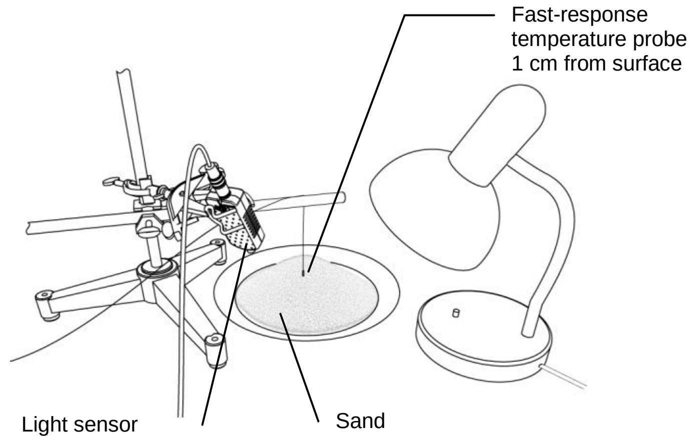
Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Measuring reflection and radiation of sand and rock

Set Up

1. Put 500 g of white sand in a large plate.
2. Start a new experiment on the data collection system. �(1.2)
3. Connect a light sensor and a fast-response temperature probe to the data collection system. �(2.2)



4. Set up appropriate displays to view the data as it is being collected. �(7)

5. Place the lamp on one side of the plate so it will shine down into it at about a 60° angle.

6. Mount the light sensor on the tripod base and rod stand, using the three-finger clamp. Position it on the other side of the plate, directly opposite the light and angled at approximately the same angle as the light source towards the plate.

7. Set up the fast-response temperature probe so it hangs about 1 cm above the surface of the sand.

8. Which material do you predict will have the greatest albedo? Which the least?

Predictions will vary, and all predictions should be accepted. The lightest-colored materials generally have the greatest albedo, while the darkest-colored ones have the least.

9. Which material do you predict will absorb the most heat from the light energy?

Predictions will vary, and all predictions should be accepted. The darkest-colored materials absorb the most heat from the light energy.

10. Which material do you predict will radiate the most heat after the light is turned off?

Predictions will vary, and all predictions should be accepted. The darkest-colored materials will radiate the most heat after the light is turned off.

11. Are you measuring direct light or reflected light?

Reflected light is being measured in this experiment.

Collect Data

12. Turn on the light.

13. After 30 seconds, start data recording. �(6.2)

14. After 60 seconds, turn the light off. *Do not stop recording data.*

15. Record data for an additional 180 seconds.

16. Stop data recording. �(6.2)

17. Put the sand back into the container.

18. Name your data run. �(8.2)

19. Save your experiment with an appropriate file name. �(11.1)

20. Repeat this procedure for the remaining materials: dark sand, white rock, and dark rock.

Note: Exercise care to keep the positions of the light, plate, temperature sensor, and light sensor constant throughout the testing of the four materials.

Part 2 – Measuring sunlight intensity and the earth's reflectivity

Set Up

21. Make an outdoor equipment station: Cut two holes in the bottom of a small cardboard box such that a light sensor will be held snuggly in one and a stainless steel temperature sensor will be held snuggly in the other.

22. Make sure your data collection system is fully charged.

23. Connect the sensors and change the sample rate to 1 sample per minute. �(5.1)

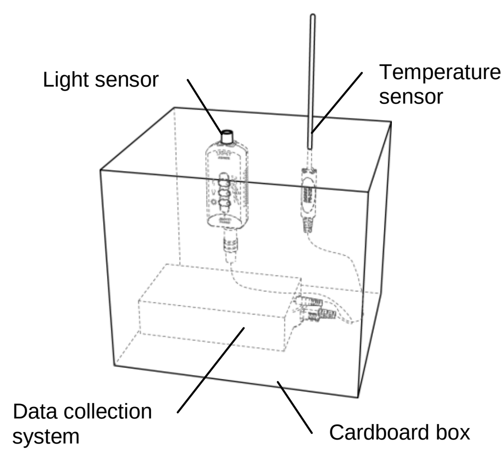
24. Set up appropriate displays to visualize the data. �(7)

25. Select the widest range on the light sensor. �(4.3)

26. Make a portable experiment station

a. Turn the box upside down

b. Thread the light and temperature sensors through the holes until they fit securely, and point straight up in the air. Use tape if necessary to help secure them.



27. Make a sign that says: DO NOT DISTURB! EXPERIMENT IN PROGRESS. CONTACT: [YOUR NAME]. THIS EXPERIMENT IS BEING CONDUCTED FROM [DATE] [TIME] TO [DATE] [TIME].

28. Carry the portable experiment station, sign, and tape outside. Find a location with the following characteristics:

- It is a safe place to leave the experiment station;
- It will receive full sun all day with no shading;
- It is not near (within 5 meters) a building or on pavement;
- The box will not get wet from sprinklers.

29. What time of day do you predict the intensity of insolation will be the greatest?

Predictions will vary, and all predictions should be accepted. On a sunny day, the greatest intensity of insolation is around noon. If the day is partly cloudy, the pattern is less predictable.

30. What time of day do you predict the air temperature will be the greatest?

Predictions will vary, and all predictions should be accepted. On a sunny day, the highest temperature generally occurs between 3 and 4 p.m. If the day is partly cloudy, the pattern is less predictable.

Collect Data

31. Start data recording. �(6.2) Record your starting time in Table 2.

32. Carefully enclose the data collection system inside the box using tape to hold the flaps closed.

33. Place the box in the test location. Make sure the sensors are still pointing straight up.

34. Record data until late afternoon or evening. Then, stop data recording �(6.2), save your experiment �(11.1), and clean up according to your instructor's instructions.

Data Analysis

Part 1 – Measuring reflection and radiation of sand and rock

1. Display two graphs simultaneously. On one graph, display Light intensity on the y-axis with Time on the x-axis. On the second graph, display Temperature (°C) on the y-axis with Time on the x-axis. �(7.1.11)

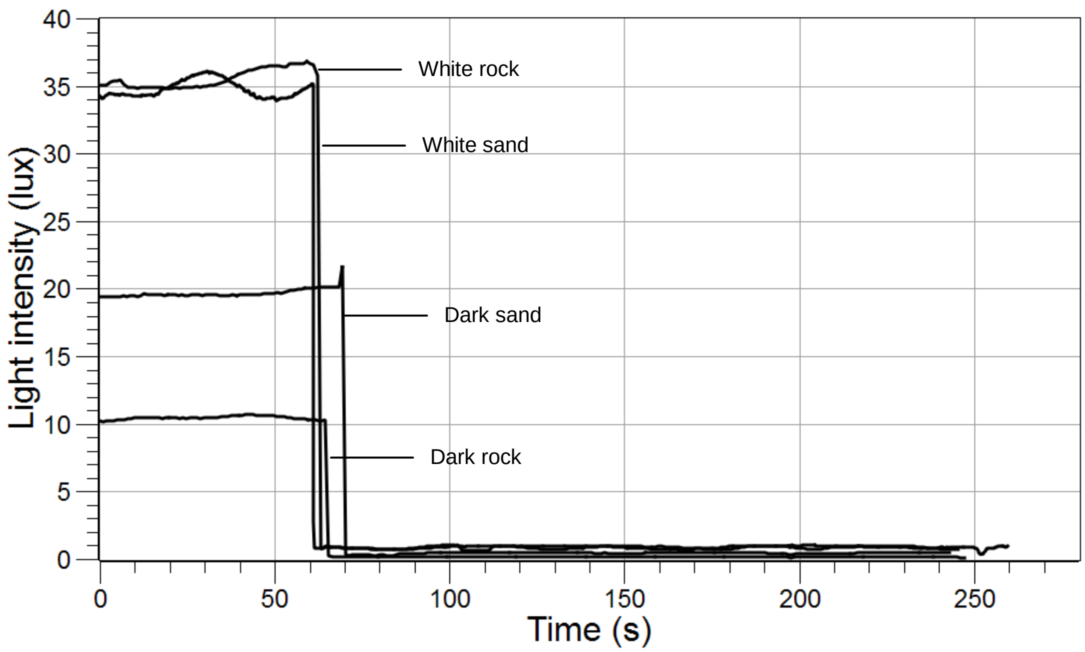
2. Adjust the scale of the graphs to show all data. �(7.1.2)

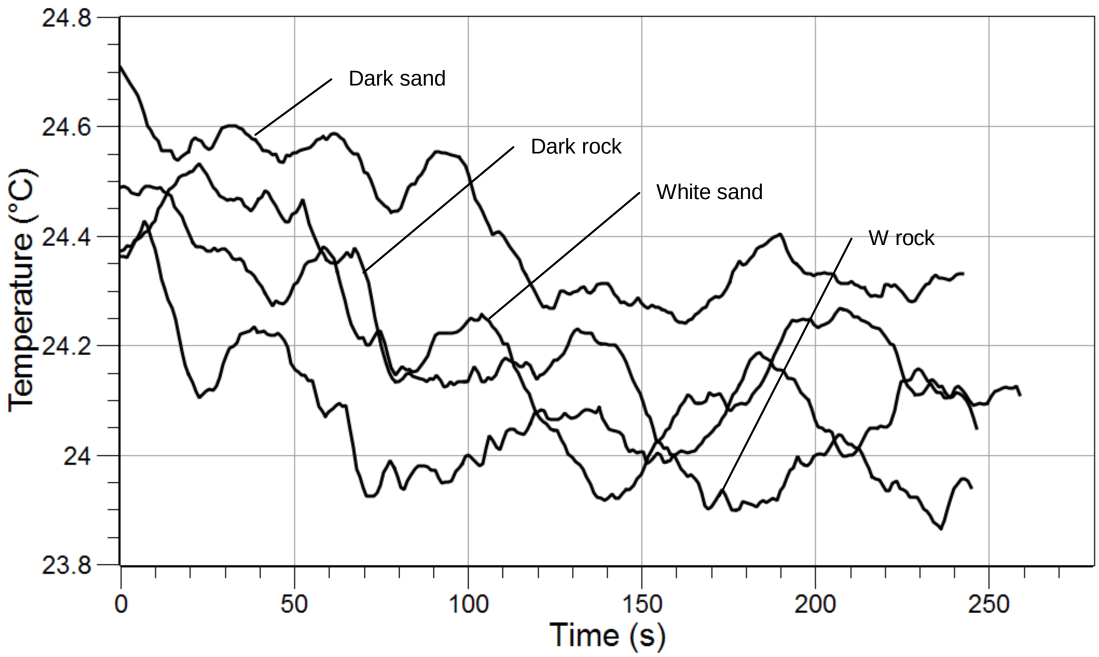
3. View the statistics for each graph, �(9.4) select the appropriate data points on each data run, �(7.1.4) and record the mean values that are called for in Table 1.

Table 1: Reflection and radiation of sand and rock

Material	Mean Reflected Light Intensity (lux)	Mean Air Temperature (Light Off) (°C)
White Sand	36.06	24.2
Dark Sand	5.95	24.4
White Rock	9.68	24.0
Dark Rock	2.87	24.2

4. Sketch parameter (light intensity, temperature) versus time graphs of your data for the four experimental conditions. Label your four runs, the overall graphs, the x-axes, and the y-axes. Including units and scales on the axes.





Part 2 – Measuring sunlight intensity and the earth's reflectivity

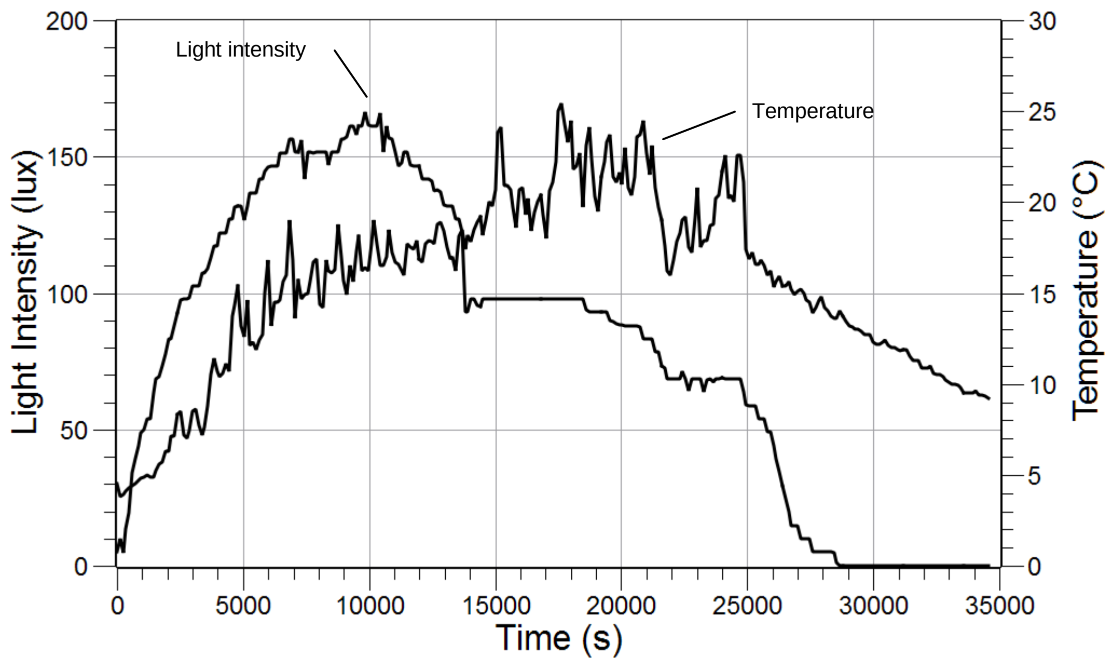
5. Display both Light intensity and Temperature (°C) on the y-axis of a graph with Time on the x-axis. �(7.1.10)

6. Find the coordinate values for the maximum temperature and light intensity on the graph, �(9.1) and complete Table 2.

Table 2: Reflection and radiation of sand and rock

	Start Time	Greatest Value	Seconds from Start When Maximum Occurred	Time of Day
Light Intensity (lux)	10:00 a.m.	166	10,000	12:45 p.m.
Temperature (°C)	10:00 a.m.	25.4	17,804	2:55 p.m.

7. Sketch a parameter versus time graph of your data for the two experimental variables. Use a key to differentiate your two variables. Label the overall graph, the x-axis, the y-axis, and include units on your axes.



Analysis Questions

Part 1 – Measuring reflection and radiation of sand and rock

1. Compare your predictions with your results.

Students should be specific regarding their predictions and comparisons with results.

2. What were the dependent variables in this experiment? The independent variable?

The dependent variables were the temperature of the air just above the material and the light intensity. The one independent variable was light energy.

3. Why were you careful to leave the same amount of space between each material and the light sensor, temperature sensor, and light source for each data collection?

It was important to control these variables to ensure that the same amount of light energy was applied to each trial, the same angle of incidence of light was used, and the same conditions for recording temperature were preserved.

4. Which characteristics of the materials make them good reflectors?

The materials that were good reflectors were light in color and smoother in texture.

5. What is the relationship between the magnitude of the albedo of the material and the final air temperature?

The higher the albedo, the lower the final air temperature is.

6. What happens to the light that is not reflected? What happens to this energy? How might this occurrence affect daily temperatures on the earth's surface?

The light that is not being reflected is absorbed by the earth materials. Some of this energy is then radiated back into the air as heat energy. For the earth, this means that earth materials absorb sunlight and then radiate some of this energy as heat into the air later in the day, so the ground temperatures stay warm longer after the sun goes down. Deserts and beaches with light colored sand would have higher temperature fluctuations over a 24-hour period than those with dark-colored sand.

Part 2 – Measuring sunlight intensity and the earth's reflectivity

7. Does your data support your predictions? Explain

Students should give specific details regarding what they predicted and how that relates to what they measured.

8. Explain how the warmest temperature of the day could be in the late afternoon when the sun's greatest intensity is earlier in the day.

During the time of day when the sun's light is most intense, the earth's surface materials are absorbing some of this energy, depending upon their albedo. As this absorbed energy is radiated from the surface of the earth, it warms the air molecules at the surface. This heat is added to the air near the surface, raising the air temperature after the sun's intensity begins to reduce.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Discuss what happens to the energy in sunlight when it strikes surfaces that have a high albedo.

When sunlight strikes surfaces with a high albedo, most of it reflects back into the atmosphere. The material it strikes absorbs little energy, so there is less energy to be converted to heat. Thus, less heat subsequently radiates to the air molecules.

2. Discuss what happens to the energy in sunlight when it strikes surfaces that have a low albedo.

When sunlight strikes surfaces with a low albedo, most of it is absorbed by the material, and much of this energy is converted into heat. Some of this heat energy is radiated to the air molecules near the surface.

3. Explain how the warmest temperature of the year could be after the date when the sun's greatest intensity occurs.

The warmest day of the year is often after the date of the sun's greatest intensity because the earth absorbs the sun's energy and continues to radiate it to air molecules. This heat accumulates in the atmosphere, and over time, weather conditions can move this heat to a surface location where temperatures rise to their maximum summer temperatures.

4. What type of material would you use to make a solar heater for a swimming pool? Why?

You would want to use black material because it absorbs the most sunlight energy, which can be transferred to the water.

5. What type of material would you use to make summer curtains for your home windows? Why?

You would want light-colored material with a smooth texture, because these characteristics of materials cause them to have a high albedo. The curtains would reflect much of the sunlight to the outside.

6. You want to build a new home using energy efficient passive solar technology. Since you live in Columbus, Ohio, you want your house to be cool in the summer and warm in the winter. Answer the following questions:

a. At latitudes above the Tropic of Cancer and below the Tropic of Capricorn, how does the angle of the sun change with the seasons? How would you use the difference to help you with the design of your new home?

At mid-day in the summer, the sun is more directly overhead. As fall and winter approach, it sinks lower towards the horizon. You would orient your home so windows face the south to catch the winter sun, and you would design the roof to overhang all the windows of the house to shade them from the summer sun.

b. What are two ways to enhance solar absorption in the winter?

Ways to enhance solar absorption in the winter are to have large windows on the south side of the house and dark-colored flooring next to these windows. Shade trees should be deciduous.

c. What are two ways to reduce solar absorption in the summer?

Two ways to reduce solar absorption in the summer are to have a light-colored roof with ample overhangs and to plant shade trees on the east, south, and west sides of the house.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which factor relates to the reflective nature of a surface?

- **A.** Light intensity
- **B. Albedo**
- **C.** Absorption
- **D.** Angle of incident
- **E.** Temperature

2. Compared with a material with a high albedo, a material with a low albedo:

- **A.** Radiates more heat
- **B.** Radiates less heat
- **C.** Reflects more light
- **D.** Reflects less light
- **E. Both A and D**
- **F.** Both B and C

Extended Inquiry Suggestions

Challenge students to predict the reflectivity and measure additional earth materials, and compare the results with those from this lab experiment.

Challenge students to measure sunlight intensity and air temperature for several days exhibiting different weather characteristics, such as seasonal differences, cloudiness, and windiness. Have them compare the results with this lab experiment.

7. Plate Tectonics

Objectives

Explore the theories and evidence that lead to our current understanding of the crustal movement of plates and the drift of the continents. To understand this concept, students:

- Explore the evidence used by Alfred Wegener when he proposed the theory of continental drift.
- Consider the evidence from fossils, glacial deposits, earthquake distribution and depth, distribution of volcanoes, and seafloor age for seafloor spreading.
- Use the evidence for plate tectonics to recognize the different types of plate boundaries.

Procedural Overview

Students gain experience conducting the following procedures:

- Evaluating the fossil evidence for continental drift
- Considering glacial striation and deposits
- Modeling earthquake depths in relation to convergent plate boundaries
- Comparing volcano distribution to convergent boundaries
- Relating earthquake distribution to transform boundaries

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and experiment	10 minutes
♦ Lab experiment	Two 50-minute lab sessions

Materials and Equipment

For each student or group:

- Computer with My World GIS™ software installed
- Computer with access to the Internet
- Project file: Plate Tectonics.m3vz

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Divergent and convergent plate boundaries
- ♦ Fossils as evidence for time frame in geologic history
- ♦ Geologic time periods
- ♦ Glacial deposits and striations as evidence for historical climates
- ♦ Volcanoes and earthquakes

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Earthquake Epicenters and Tsunami
- ♦ Physical Features of the Ocean Floor
- ♦ Seafloor Spreading and Plate Tectonics

Using My World GIS

Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

- ♦ Opening a project file �(12.1.1)
- ♦ Hiding or showing a layer �(12.2.4)
- ♦ Using the Zoom In or Zoom Out Tools �(12.4.3)
- ♦ Using the Zoom To All Tool �(12.4.5)
- ♦ Using the Link Tool �(12.4.10)
- ♦ Using the Create Horizontal Transect Tool �(12.4.9)

Background

Plate tectonics is a relatively new scientific concept, introduced some 40 years ago, but it has revolutionized our understanding of the dynamic planet on which we live. The theory unified the study of the earth by drawing together many branches of the earth sciences, from paleontology (the study of fossils) to seismology (the study of earthquakes). It provides explanations to questions that scientists have speculated about for centuries, such as why earthquakes and volcanic eruptions occur in very specific areas around the world, and how and why mountain ranges like the Alps and Himalayas formed.

The theory of plate tectonics states that the earth's lithosphere is fragmented into a dozen or more large and small plates that are moving relative to one another as they ride atop the hotter, more mobile asthenosphere. Before the advent of plate tectonics, however, some people already believed that the present-day continents were the fragmented pieces of pre-existing larger landmasses ("supercontinents").

Continental drift

The belief that continents have not always been fixed in their present positions was suspected long before the 20th century. This notion was first suggested as early as 1596 by the Dutch map maker Abraham Ortelius in his work *Thesaurus Geographicus*. Ortelius suggested that the Americas were "torn away from Europe and Africa by earthquakes and floods" and went on to say, "The vestiges of the rupture reveal themselves, if someone brings forward a map of the world and considers carefully the coasts of the three [continents]." Ortelius' idea surfaced again in the 19th century.

Pangaea

However, it was not until 1912 that the idea of moving continents was seriously considered a full-blown scientific theory—called Continental Drift—introduced in two articles published by a 32-year-old German meteorologist named Alfred Lothar Wegener. He contended that around 200 million years ago Pangaea began to split apart. Alexander Du Toit, Professor of Geology at Johannesburg University and one of Wegener's staunchest supporters, proposed that Pangaea first broke into two large continental landmasses, Laurasia in the northern hemisphere and Gondwanaland in the southern hemisphere. Laurasia and Gondwanaland then continued to break apart into the various smaller continents that exist today.

Fossil evidence

Wegener was also intrigued by the occurrences of unusual geologic structures and plant and animal fossils found on the matching coastlines of South America and Africa, which are now widely separated by the Atlantic Ocean. He reasoned that it was physically impossible for most of these organisms to have swum or been transported across the vast oceans. To him, the presence of identical fossil species along the coastal parts of Africa and South America was the most compelling evidence that Laurasia and Gondwanaland were once joined.

In Wegener's mind, the drifting of continents after the break-up of Pangaea explained not only the matching fossil occurrences but also the evidence of dramatic climate changes on some continents. For example, the discovery of fossils of tropical plants (in the form of coal deposits) in Antarctica led to the conclusion that this frozen land previously must have been situated closer to the equator in a more temperate climate where lush, swampy vegetation could grow. Other mismatches of geology and climate included distinctive fossil ferns (Glossopteris) discovered in what are now polar regions and the occurrence of glacial deposits in present day arid Africa, such as the Vaal River valley of South Africa.

Skepticism about plate tectonics and continental drift

The theory of continental drift would become the spark that ignited a new way of viewing the earth. However, at the time Wegener introduced his theory, the scientific community firmly believed the continents and oceans to be permanent features on the earth's surface. Not surprisingly, his proposal was not well received, even though it seemed to agree with the scientific information available at the time.

Wegener's theory of continental drift was hotly debated on and off for decades following Wegener's death before it was largely dismissed. However, beginning in the 1950s, a wealth of new evidence emerged to revive the debate about Wegener's provocative ideas and their implications. Much of the evidence centered on establishing the existence of large masses of land, called tectonic plates, and describing the mechanism of their motion.

Seafloor spreading

In 1960, an American geologist named Harry Hess proposed an idea to explain the mechanism for plate motion. His theory, called seafloor spreading, explained how new oceanic crust is created when magma rises to the surface along mid-ocean ridges, cools, and spreads out, leaving old oceanic crust furthest away from the ridge and new oceanic crust closest to the ridge. This provided the driving force to plate movement that was not accounted for in Wegener's theory of continental drift.

By 1968, the combination of seafloor spreading and continental drift helped to formulate a new theory called the theory of plate tectonics. According to the theory of plate tectonics, the lithosphere is broken into large segments called plates. These plates "float" on the convection currents within the mantle and continuously move and change shape and size.

Pre-Lab Discussion and Experiment

Remind students that there is no one reason for the occurrence of plate tectonics. It is an event that happens as a result of intricate and highly interconnected geologic processes.

Ask students to brainstorm their ideas or assign the following question for homework:

Are volcanoes and earthquakes distributed geographically according to a pattern or is their distribution random?

Instructor Tip: If done in class, accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment.

Instructor Tip: There is a large amount of data contained in this project file that can be overwhelming to students. Encourage students to take their time.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Be sure students have access to the My World GIS program from their computers.

2. Make the project file, Plate Tectonics.m3vz, available to students.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

Set Up

1. Open the Plate Tectonics project file (Plate Tectonics.m3vz). �(12.1.1) The following layers are in the Layer List:

- ***Linked Images*** – contains plate boundary and other relevant images. These images are represented by link flags on the map and are anchored to specific points.
- ***Fossil Distribution*** –displays the locations of several plant and animal fossils. It is a point layer adapted from fossil distribution data showing location (provided by the University of North Dakota).
- ***Glacial Deposits*** – displays filled areas representing the locations and distribution of glacial deposits.
- ***Earthquakes medium m4.0-5.9 (2001-03)*** – displays records from 2001 to 2003 that represent earthquakes of medium intensity (magnitude 4.0-5.9).
- ***Plate Boundary Types*** – displays polyline representations of the three types of plate boundaries.
- ***Volcanoes*** – displays all volcanoes worldwide, which can be classified by elevation.
- ***Continents*** – displays an outline of all world countries.
- ***Lines of Latitude and Longitude*** – display parallels of latitude and meridians of longitude.
- ***Sea-floor age (m.y.)*** – displays the age of the spreading seafloor, represented by color, in millions of years.
- ***Elevation & Bathymetry*** – displays elevation (height of land above mean sea level) and bathymetry (depth of the ocean floor below mean sea level) in a 1-degree grid for the entire surface of the earth.

Data Analysis

Part 1– Early evidence of plate movement

As early as 1596, geographers and cartographers like Abraham Ortelius noticed the similarities between some coastlines. Ortelius suggested that the Americas were "torn away from Europe and Africa... by earthquakes and floods."

In 1912, Alfred Wegener proposed that the continents had drifted apart over the past 300 million years from a single super-continent.

1. Use the Zoom In Tool �(12.4.3) to take a closer look at the eastern coastline of South America and the western coastline of Africa. What visual evidence do you see in the map you are viewing that supports Ortelius' statement?

Most students should recognize that the shapes of the eastern coast of South America and the western coast of Africa appear to fit together like puzzle pieces.

2. To get a look at another pair of coastlines to confirm the evidence, zoom out from the southern hemisphere and zoom in to the northern hemisphere in the area of the northern Atlantic. �(12.4.3) What additional visual evidence do you see that supports Wegener's statement?

Students should see evidence of the western coast of Greenland and the eastern island coast of Canada fitting together.

3. A third view from another perspective is accomplished by changing the map view by using the Map View pull down menu above the map. Change the map view to Stereographic. Do any other fits support the theory of continental drift in this projection?

Answers will vary. Students can discuss western Australia and eastern Antarctica, the rift between Africa and Saudi Arabia, the fit of northern Australia to Papua New Guinea, and the fit of the islands of Indonesia to other countries.

4. Change the map view back to Geographic.

5. What additional kinds of evidence support Wegener's hypothesis?

In the early 1900s, scientists knew that many examples of the same fossilized plants and animals had been found in pairs of land masses that were now across oceans from each other. Examples were known from South America and Africa, North America and Europe and Madagascar and India.

Part 2 – Fossil distribution

6. Show the Fossil Distribution layer. �(12.2.4) Select the radio button next to Glossopteris. �(12.3.2)

7. Use the Link Tool to learn more about Glossopteris. �(12.4.10)

a. When did Glossopteris plants first appear in the fossil record? When did they go extinct?

They arose during the Permian, and they went extinct during the Triassic.

b. On which continents have Glossopteris fossils been found?

They have been found in Asian (specifically India), South America, Africa, Australia and Antarctica.

c. Why is Glossopteris considered an important fossil?

The rapid appearance, expansion, and relatively quick extinction of this group, as well as the large number of species, has made the group very important to understanding paleobiogeography. Their fossils also help explain the connectedness of the land forms where their fossils are found.

d. Is there a mechanism you can think of that could have moved Glossopteris seeds from one continent to another?

Students may refer to water-borne transport mechanisms or wind-borne mechanisms.

8. Select the Cynognathus radio button in the Fossil Distribution layer, �(12.3.2) then use the Link Tool to learn more about Cynognathus. �(12.4.10)

a. Does the information in this article regarding the locations where Cynognathus fossils were found confirm the locations plotted on the map?

Yes. The Fossil Distribution layer shows fossils found in South America and Africa. The article confirms this.

b. What does the term Cynognathus mean?

The word means “dog jaw”.

c. Does Cynognathus have any body feature that could have enabled it to move from one continent to another?

This animal had strong legs and could travel overland if the continents were connected, but it could not swim far since it lacks swimming adaptations such as webbed feet or streamlined body.

9. Select the Lystrosaurus radio button in the Fossil Distribution layer, �(12.3.2) then use the Link Tool to learn more about Lystrosaurus. �(12.4.10)

a. What new information is presented in this article regarding the locations where Lystrosaurus fossils have been found?

Lystrosaurus fossils have been found in Antarctica, India, and Africa. In recent decades it has been found in Russia, China, and Mongolia.

b. Is there a mechanism or body feature you can think of that could have allowed Lystrosaurus to move from one continent to another?

Like Cynognathus, Lystrosaurus lacks swimming adaptations, even though the article says it probably was an aquatic feeder like a hippopotamus. With its strong legs, it could have walked to migrate, which means the landforms would have had to have been connected.

10. Select the Mesosaurus radio button in the Fossil Distribution layer, �(12.3.2)then use the Link Tool to learn more about Mesosaurus. �(12.4.10)

a. How old are the rock formations that the African and South American Mesosaurus fossils were found in?

The rocks are from the Permian Age, 280 - 248 MYA

b. Is there a mechanism you can think of that could have allowed Mesosaurus to move from one continent to another?

This animal's body is perfectly adapted to swimming, so it could have swum across waterways.

Part 3 – Glacial evidence

11. Wegener also considered evidence from glacial deposits from the Pennsylvanian period. Scientists understood the conditions under which glaciers and ice sheets form.

a. What conditions do you think are required for glaciers and ice sheets to form?

Extended periods of colder-than-usual weather where the summers are not warm enough to melt all of last season's snowpack. This pattern needs to repeat for many years to form a glacier or ice sheet.

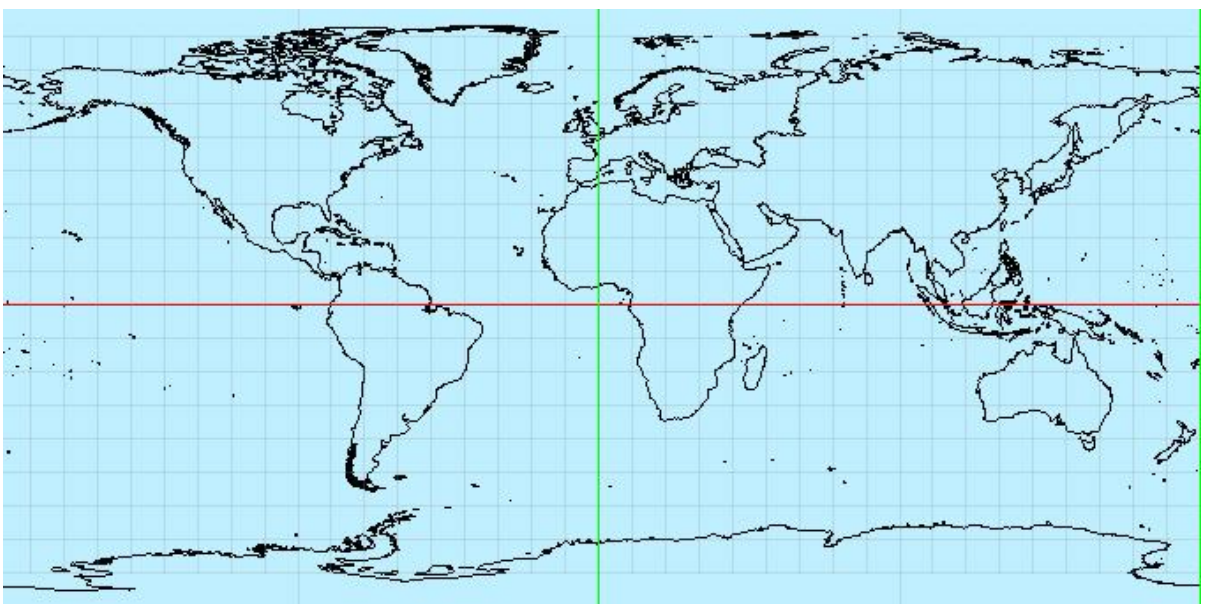
b. In which geographic regions do these conditions exist today?

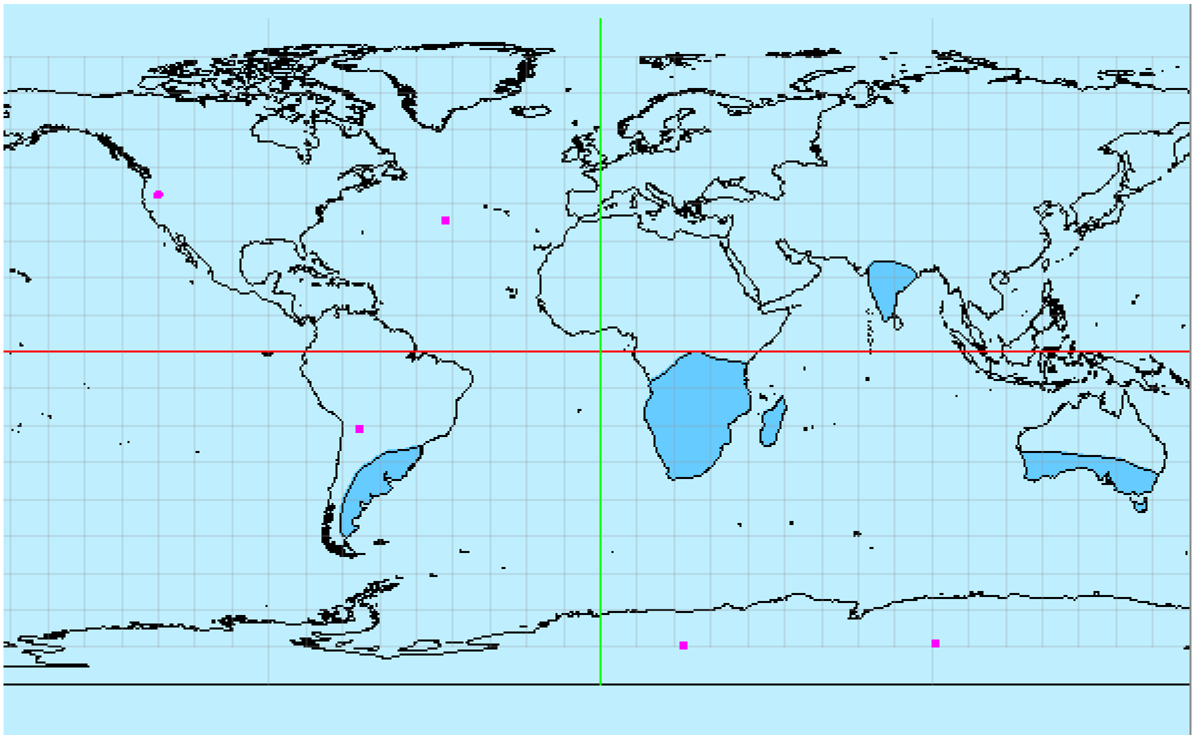
High latitudes and high elevations worldwide.

12. Hide the Fossil Distribution layer and show the Linked Images layer, �(122.4) then select the Link Tool. �(12.4.10)

13. Open the link to Pangaea on Antarctica. The window that opens shows a series of maps. Study the position of the continents during the Permian period.

Based on the position of the continents during the Permian, where would you predict continental glaciers would be found? Mark the locations or regions on the map below.





14. Show the Glacial Deposits layer. �(12.2.4)

Note: The data that are plotted in blue on the map are glacial deposits. Additional data in the form of glacial striations provide further evidence of the location of continents during the Permian period.

15. Compare your predictions to the data shown on the map. What are the similarities and differences between your predictions and the actual data?

Answers will vary, but students should be comparing the glacial deposits to the location of the landmass during the Permian.

16. Consider the climate in the locations where the glacial deposits shown on the map were found. Is it likely that glaciers could form in those regions today?

These locations are not likely to accumulate glaciers today. The locations are either tropical or temperate, and today, even our polar zones are not as cold as they used to be.

17. What does this suggest about the position of the continents?

Students could conclude that the continents have shifted position or that the climate has changed in those locations.

18. Hide all of the layers except Continents, Elevation & Bathymetry, and Lines of Latitude and Longitude. �(12.2.4)

Part 4 – Divergent Plate Boundaries

19. Show the Plate Boundary Types layer. �(12.2.4)

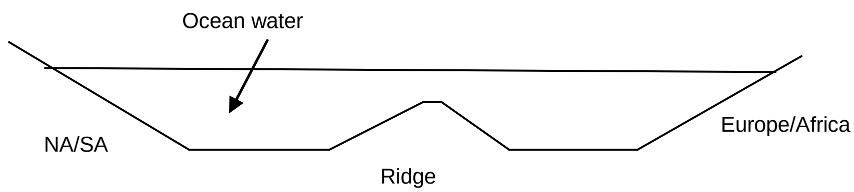
20. Select the Zoom In Tool �(12.4.3) and zoom into the Atlantic Ocean.

21. The plate boundary that runs roughly down the middle of the Atlantic Ocean is known as the Mid-Atlantic Ridge. Describe the shape of the Mid-Atlantic Ridge relative to the coastlines of Europe, North America, South America and Africa.

The location of the Mid-Atlantic Ridge roughly mirrors the coastlines on either side of the Atlantic Ocean.

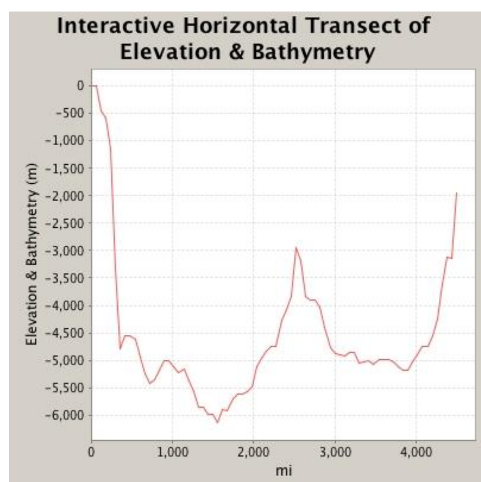
22. If you were to hand-draw a horizontal transect (cross-section) across the boundary from Florida to Africa (at a constant latitude), what would it look like? Draw your answer in the space below.

Answer:



23. Select the Create Horizontal Transect Tool, and click OK in the dialogue box that opens. �(12.4.9)

24. Create a transect across Florida from west to east, staying at a constant latitude until you reach Africa. Compare the profile to your drawing above. What is the elevated area between 2000 and 3000 miles?



The Mid-Atlantic Ridge.

25. Would the statement, "The Atlantic Ocean from Florida to Africa gets progressively deeper away from the coastlines and reaches a maximum depth in the middle of the ocean" be accurate? Why or why not?

It would not be accurate because the midpoint between the two shorelines is also the location of the Mid-Ocean Ridge, which is a mountain range. So the depth of the ocean above this ridge is shallower than the areas to the east and west of the ridge.

26. Close the profile window. Hide the Plate Boundary Types and Elevation & Bathymetry layers and show the Sea-Floor Age layer. �(12.2.4)

27. Describe the pattern of ages from the Mid-Atlantic Ridge toward North America and toward northern Africa.

According to the color scale below the map, the oldest material is located next to North America and next to northern Africa. From both locations, as you move toward the center of the ocean, the seafloor gets progressively younger. It is the youngest right under the Mid-Ocean Ridge.

28. Select the Young sea-floor 5 m. y. radio button. Around what type of plate boundary is this very young seafloor found? Name one ocean floor feature where there is an abundance of young seafloor.

Young seafloor is found all along the divergent boundaries in the seafloor. There is an abundance of young seafloor at the Mid-Ocean Ridge.

29. Select the Old sea-floor 170-180 m. y. radio button. �(12.3.2) Where is this very old seafloor found?

The old seafloor is found near the continental margins, which will correspond with subduction zones.

30. Hide the Sea-floor age (m.y.) layer and show the Earthquakes Medium m4.0-5.9 (2001-03) and Plate Boundary Types layers. �(12.2.4) This dataset shows the epicenters of over 28,000 earthquakes around the world, and the points are color coded according to the depth of the focus. Toggle between the pre-selected depths to verify the depths of the earthquakes around the Mid-Atlantic Ridge.

31. Describe the distribution of earthquakes in the Atlantic Ocean basin. Be sure to discuss the relationship between earthquakes and the Mid-Atlantic Ridge.

The earthquakes are very shallow along the Mid-Atlantic Ridge. They are at or less than 10 km in depth.

32. Hide the Earthquake layer and show the Volcanoes layer. �(12.2.4) What does the distribution of volcanoes along the Mid-Atlantic Ridge tell you about the type of plate boundary associated with the Mid-Atlantic Ridge?

There are surprisingly few volcanoes along the Mid-Atlantic Ridge, and most of the seafloor volcanoes are not anywhere near the Ridge. This tells us that the Mid-Atlantic ridge is not associated with the common types of volcanoes and must be a non-explosive type of plate boundary.

33. Based on the evidence you have seen including: seafloor profile, seafloor age, earthquake and volcano distribution, what type of plate motion do you think is associated with the Mid-Atlantic Ridge?

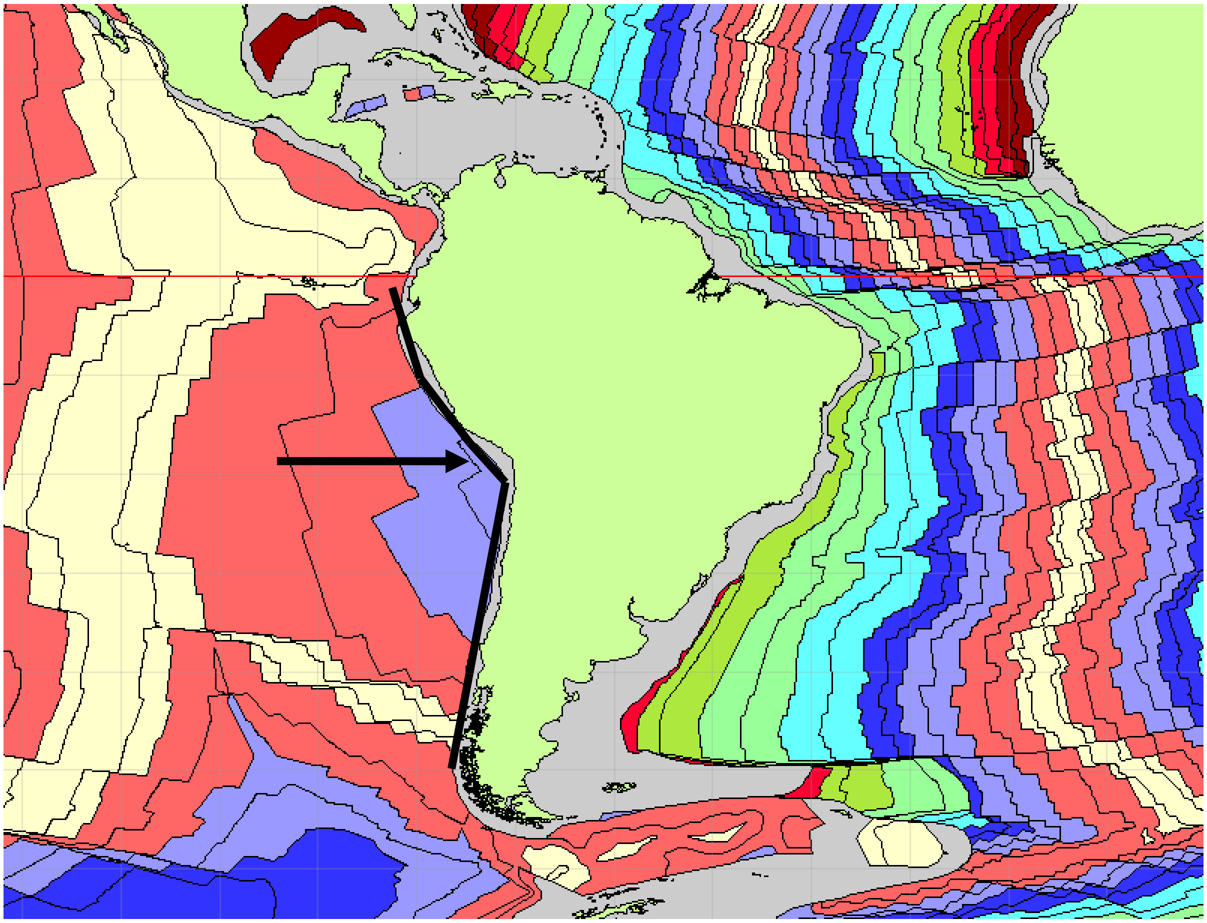
The young age of the rock indicates that the seafloor is newly created at the Ridge. The lack of volcanism indicates that the creation of new rock must be something like gentle but regular expulsion of low viscosity basalt. This would indicate that the type of plate motion associated with this area is that of a divergent plate.

Part 5 – Convergent Plate Boundaries

34. Hide all of the layers except Latitude & Longitude and Continents. �(12.2.4) Use the Zoom To All tool to zoom out to the full extent. �(12.4.5)

35. Use the Zoom In tool �(12.4.3) to show South America and the eastern Pacific ocean.

36. Show the Sea-floor age (m.y.) layer �(12.2.4) and hide all data selections. �(12.3.2) In the picture below, draw a convergent plate boundary where you think it would be located based on the age of the seafloor. Draw arrows on your boundary to show the direction of plate motion.



37. Hide the Sea-Floor Age layer show the Elevation & Bathymetry layer. �(12.2.4) Is the ocean depth pattern west of the coast of South America consistent with the location of the convergent boundary that you drew on the map above? Use the Pointer Tool if necessary to verify the ocean depth in several areas. �(12.4.6)

Answers will vary, but students should see the pattern going in opposite directions.

38. Show the Earthquakes medium m4.0-5.9 layer. �(12.2.4)

a. What are the depths of the earthquakes close to the western coast of South America?

Very shallow - around 10 km deep

b. What happens to the depth of the earthquakes with increasing distance to the east from the western coastline of South America?

The depth of earthquakes gradually deepens from 100 - 400 km, and finally on the very eastern edge of the zone, some are 700--800 km deep.

39. Show the Volcanoes layer and the Linked Images layer. �(12.2.4) Select the Link tool �(12.4.10) and open the convergent boundary diagram image in South America. Is the location of volcanoes close to the coastline consistent with the location of volcanoes shown in the diagram?

Yes; it looks like the volcanoes are on the continent, just inland of the coast.

40. Based on the evidence you have seen including seafloor age, bathymetry, and earthquake and volcano distribution, what type of plate motion do you think is associated with the western coast of South America? Explain your answer.

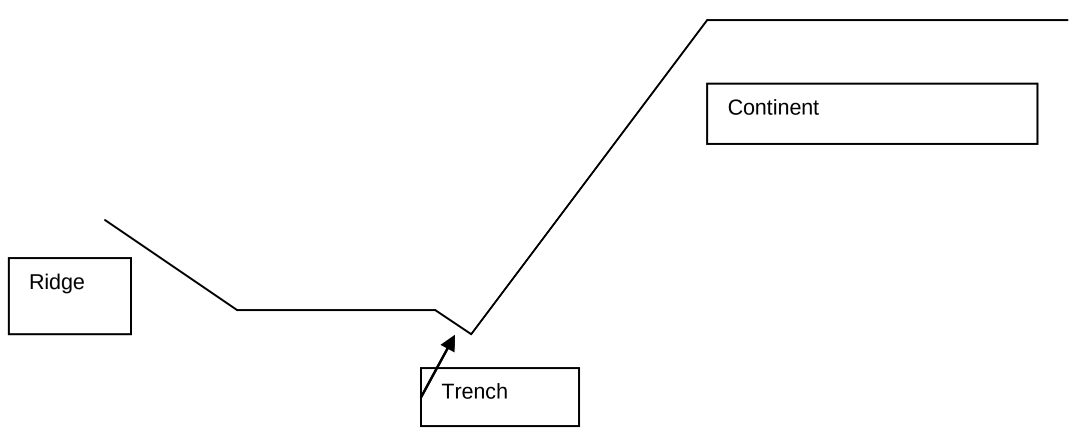
The seafloor is oldest where it meets the continent. The land is riddled with earthquakes and volcanoes, and the seafloor plate subducts . This is a convergent boundary.

41. To **further confirm that this is a convergent boundary, let's consider the location of an oceanic trench. Review the convergent boundary image using the link tool and locate the area marked "trench."** �(12.4.10) **Close this window after you have answered the following question.** What is the relationship between the position of the trench and the convergent plate boundary?

A trench will form on the side of the boundary associated with the subducting plate. When two plates of differing densities come together at a convergent plate boundary, the more dense plate (oceanic crust) subducts under the less dense (usually continental) plate to form a trench.

42. If you were to draw a horizontal transect across the convergent zone what would it look like? Draw your answer in the space below.

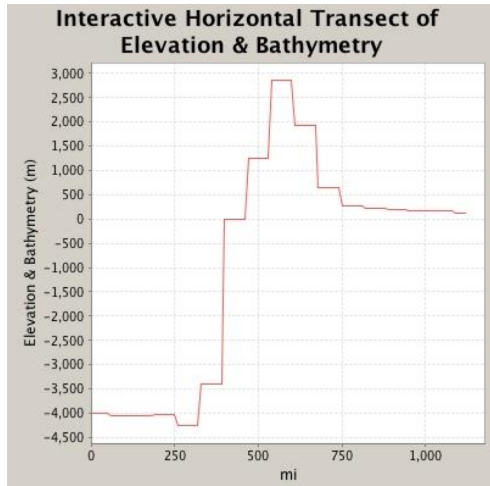
A horizontal transect will show a deep V-shaped trench before the continental crust begins to rise.



43. Select the Create Horizontal Transect Tool, �(12.4.11) and change the sample size from 60 to 10 to increase the resolution of the profile, then click OK.

Draw the profile from just west of the earthquakes surrounding the convergent plate boundary near South America to just east of the deepest earthquakes staying parallel to the equator.

44. Describe how the profile fits with your prediction from above. Then use the graph to answer the following questions.



Student answers will vary as to whether their predictions were verified. Students may be surprised at the elevation increase of the continent.

a. What is the elevation decrease from sea level to the deepest part of the trench?

From sea level, the trench falls to 4,000 m.

b. What is the elevation increase from sea level to the highest part of the mountains on the continent?

From sea level, the mountains rise to nearly 3,000 m.

c. Which has the greatest change in elevation: the rise on the continent or the depth of the trench?

The depth of the trench has a greater change in elevation than the rise of a mountain on a continent.

Part 6 – Transform Plate Boundaries

45. Close the horizontal transect window. Hide the Volcanoes and Earthquakes medium m4.0-5.9 layers. �(12.2.4) Use the Zoom To All tool to zoom out to the full extent. �(12.4. 5)

46. Zoom in to the west coast of the United States. �(12.4.3) Focus on the region around Oregon and Washington.

47. Select the Link Tool and open the Transform Plate Boundary image located in North America. �(12.4.10)

48. With the image open, focus on the region around the Mendocino Fracture Zone, and predict the following:

a. What pattern will earthquakes have around a transform plate boundary (many or few, clustered or widely spread)?

Earthquakes around transform plate boundaries will be uniformly clustered on either side of the boundary (but not both).

b. Would you expect the earthquakes to be deep or relatively shallow?

Earthquakes will be relatively shallow.

c. Will there be volcanoes present?

There will be no volcanoes at transform plate boundaries.

49. Check your predictions. Show the Earthquakes medium m4.0-5.9 (2001-03) layer. �(12.2.4) Was your prediction about the pattern of earthquakes around a transform fault correct? Explain why the earthquakes occur at the depths they do.

Student answers will vary as to whether their predictions were verified. The earthquakes occur at these depths because this is where the crust is fracturing.

50. Show the Volcanoes layer �(12.2.4) and describe how your prediction fits with your observation. What do you notice about the location of the volcanoes? Do you think that the plate activity that takes place at a transform boundary creates volcanoes? Explain your answer.

Student answers will vary as to whether their predictions were verified. Volcanoes found near transform plate boundaries are usually the result of other plate boundary activity (usually at divergent plate boundaries).

Analysis Questions

1. Describe one of the early evidences that led to the theory of plate tectonics.

Some of the first evidences that led to the theory of plate tectonics were both visual and archaeological in nature. Coastlines of Africa and South America look very clearly like they once fit together.

2. Explain why ocean trenches are close to continents and not in the middle of oceans.

Ocean trenches are close to continents and not in the middle of the oceans because of the nature of convergent plate boundaries. Oceanic plates are denser than continental plates. When the two plates approach each other, the oceanic plate subducts beneath the continental plate, causing the trench to form. When two plates of equal density meet, such as two oceanic plates or two continental plates, neither will subduct but will rather cause the building of very large mountain ranges, such as the Himalayas.

3. What is occurring in the ocean region between North America and Europe?

A divergent plate boundary exists in the ocean region between North America and Europe. At this boundary, the North American and Eurasian plates are moving away from each other, causing an upwelling of magma from the rift created in the ocean floor. This material cools and forms new ocean floor.

4. How does the distribution of prehistoric fossils provide evidence for the theory of continental drift?

Evidence of fossils on continents that are now separated by thousands of miles of ocean suggests that the continents were once close enough together for species to migrate freely. Fossil deposits provide evidence for the theory of continental drift in that these fossils exist where the continents were closest to each other. Species migrated over these continents while they were still very closely connected (keeping in mind that the movement of the plates to their present-day location took hundreds of millions of years).

5. Does it make sense that these fossils are distributed in such different environments? Why or why not?

It makes logical sense that these fossils would be distributed in very different environments. The environments that these fossils are currently found in vary greatly because of millions of years of geologic and ecological evolution. Millions of years ago, especially due to the fact that Pangaea existed in much the same zone, the climate of all areas was mostly the same, varying only slightly in temperature, terrain, et cetera.

6. How does the evidence for glacial movement provide evidence for the theory of continental drift? How does this evidence correlate to fossil distribution?

Glacial sediments and striations suggest that a supercontinent existed at one point. These striations indicated glacial flow toward the poles and away from the equator, suggesting that the continents had once been contiguous. Fossil deposits and distribution across the continents suggest the same.

7. Glaciers no longer exist in the locations shown on the map. Why do you think these glaciers disappeared?

These glaciers were formed in a relatively stable environment when the continents were close together. The climate was not nearly as warm as it is today. As the continents began to drift apart, and as time progressed, the temperatures in the area surrounding each glacier gradually increased. Notice that these glaciers are located in places that are now among some of the hottest and most humid in the world.

8. Describe the plate motion at each of the following boundaries

a. Transform

The lateral movement of plates.

b. Convergent

Two plates moving toward each other; one plate subducts under another.

c. Divergent

Two plates moving away from each other.

9. How does the distribution of seismic activity define the type of plate boundary present?

Seismic activity is seen in very distinct spots depending upon the boundary at which it takes place. Seismic activity at a transform plate boundary will be scattered on either side of the boundary. At a divergent plate boundary, seismic activity will be most prevalent at the oceanic rift. Convergent plate seismic activity will be heaviest on the side at which the subduction occurs.

10. Why are volcanoes not common at a transform plate boundary?

Volcanoes are not common at transform plate boundaries because of the lateral movement of the plates. This movement does not cause the upwelling of magma, nor does it disturb either plate enough to form a volcanic mountain.

11. What trend does the earthquake distribution at a transform plate boundary follow?

Earthquake distribution at a transform plate boundary is seen on both sides of the plate boundary.

12. What geographic formations are found at divergent plate boundaries?

Ridges are found at divergent plate boundaries.

13. Describe the difference in seafloor age at a convergent and divergent plate boundary, and explain why there is a difference.

Seafloor age at a convergent plate boundary is older than that at a divergent plate boundary. Divergent plate boundaries cause rifts in the ocean floor that result in the upwelling of magma. This magma cools to form new oceanic crust, while the older material moves outward from the rift. Eventually, two plates, consisting of older lithospheric material, will converge to form mountain ranges and oceanic trenches.

14. What geographic formations are found at a convergent plate boundary?

Mountain ranges and oceanic trenches are found at a convergent plate boundary.

15. What trends are evident in volcano and earthquake distribution?

Earthquakes are seen only on the side of the boundary that subducts, while volcanoes are seen several hundred miles in on the side that does not subduct.

16. Why do you think deeper earthquakes occur further inland at convergent boundaries?

Pressure caused by the melting of the oceanic plate into the asthenosphere causes a magma pool to form under the continental plate, putting additional pressure on the area. In some of these areas, eruptions may occur.

Synthesis Questions

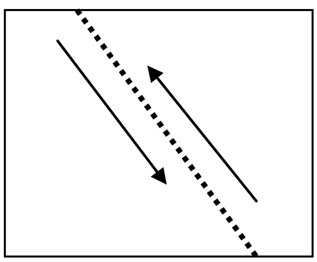
Use available resources to help you answer the following questions.

1. Compare and contrast the distribution of earthquakes associated with divergent, convergent and transform plate boundaries.

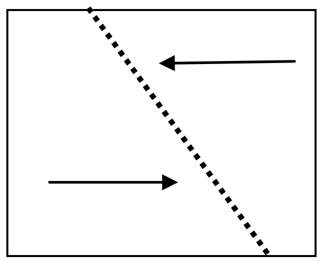
Earthquakes are associated with all three forms of plate boundaries. Earthquakes are shallow closer to the boundary and deeper farther from the boundary. Earthquakes occur on the overriding plate at a convergent boundary and right along the plate boundary in divergent and transform boundaries. Finally, earthquakes are more abundantly widespread along convergent boundaries and can happen well in from the boundary, as is the case in Europe and Asia.

2. Draw a diagram showing the relative direction of plate motion for each of the three types of plate boundaries.

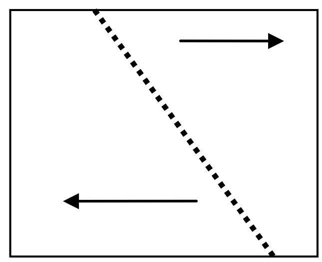
The transform boundary should show arrows pointed in opposite directions on either side of the boundary. Divergent boundaries should show arrows pointing away from the boundary in opposite directions, and convergent boundaries should show arrows pointing toward one another on either side of the boundary.



Transform Fault



Convergent Fault



Divergent Fault

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. What type of plate boundary would you expect to produce the most volcanoes?

- **A.** Convergent
- **B.** **Divergent**
- **C.** Transform
- **D.** Both A and C
- **E.** All of the above create an equal number of volcanoes.

2. What type of plate boundary tends to produce shallow and deep earthquakes?

- **A.** **Convergent**
- **B.** Divergent
- **C.** Transform
- **D.** Both A and B
- **E.** Both B and C

3. What evidence is there to support the theory of plate tectonics?

- **A.** Fossil evidence
- **B.** Glacial deposits
- **C.** Geographic evidence
- **D.** **All of the above**
- **E.** None of the above

4. The San Andreas Fault forms the boundary between the

- **A.** Pacific Plate and Juan de Fuca Plate.
- **B.** **North American Plate and Pacific Plate.**
- **C.** Nazca Plate and South American Plate.
- **D.** Pacific Plate and Cocos Plate.
- **E.** European Plate and Arabian plate.

5. Continental drift is primarily caused by

- **A.** **Convection.**
- **B.** Gravity.
- **C.** Advection.
- **D.** Friction.
- **E.** All of the above.

Extended Inquiry Suggestions

Students may want to explore the maps that have been drawn to represent the position of the continents over time. There are many good sources for these maps, including geology textbooks. By finding and printing maps from different periods in Earth's history and discussing how the continents moved to be in those positions, students gain in the ability to predict how the continents may look in the future. Construct a sequence of maps for every 200 million years and project into the future for the next 200 million years. Post a timeline around the classroom and correlate the maps to the timeline for a visual continuum.

8. Urbanization and Land Use

Objectives

Examine physical and environmental factors that influence an area's microclimates. Students gain experience with weather data by:

- Locating position by satellite and GPS.
- Coordinating weather data with GPS data to investigate the different temperatures that arise in a locality due to various physical and environmental differences.

Procedural Overview

Student gain experience conducting the following procedures:

- Mapping a walking trail around their school grounds using GPS
- Gathering weather data along the route
- Importing the data into My World GIS over an aerial photo
- Visually representing the data and spotting trends as influenced by the physical terrain and environmental conditions

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	45 minutes

Materials and Equipment

For each student or group:

- Mobile data collection system
- GPS position sensor
- Weather/Anemometer sensor
- Computer with My World GIS™ installed

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Weather, such as wind, atmospheric pressure, humidity, and so on
- How weather elements help to influence the local and global weather

Related Labs in this Guide

Labs conceptually related to this one include:

♦ Insolation and the Seasons

♦ Monitoring Microclimates

♦ Sunlight Intensity and Reflectivity

♦ Weather in a Terrarium

Using Your Data Collection System and My World GIS

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

♦ Starting a new experiment on the data collection system �(1.2)

♦ Connecting sensors to the data collection system �(2.1)

♦ Starting and stopping data recording �(6.2)

♦ Exporting data for use in mapping software �(11.3)

♦ Launching My World GIS software �(12.1)

♦ Importing a new data file into the data library �(12.1.2)

♦ Importing a data file or map from the Internet �(12.1.3)

♦ Adding a layer to the layer list �(12.2.1)

♦ Editing the appearance of a layer �(12.2.5)

♦ Changing the parameter shown in the Fill Color �(12.3.5)

♦ Using the Zoom to Active Layer Tool �(12.4.4)

♦ Using the Pointer Tool �(12.4.6)

Background

Temperature Variability

Often we turn to the local news for weather forecasts. Usually, we want to know if it is going to be rainy, sunny, or cloudy. In addition, we like to plan our clothing according to the high temperature for the day. The meteorologist gives the high and low air temperatures for the day, but temperature can vary depending on the environment, even in the same city, even in the same front yard!

In fact, scientists have used remote sensing to measure extreme temperature variations found in urban areas. In an aerial view of Sacramento, photographic images compared side-by-side to infrared (IR) or thermal images show temperature differences of as much as 50 degrees Fahrenheit (28 degrees Celsius) between the lightest and darkest areas in the photograph (EPA). The hot areas tend to be over rooftops and roads, while the cooler areas tend to be over water or land covered with vegetative surfaces.

How Land Use Affects Temperatures

Land use has a profound impact on surface temperatures. Microclimates that are warmer than surrounding areas, called heat islands, are formed in urban areas. Natural surfaces, such as water, soil, and vegetation actually moderate climate because of their higher moisture content. Water has a very high specific heat, which means it is capable of absorbing a great deal of added heat while showing only a minimal change in temperature. Whether a natural surface is composed of mostly exposed soil or plant matter, all natural surfaces absorb heat more effectively than urban surfaces such as pavement and concrete. Urban surfaces tend to be more reflective and have lower specific heat capacities. Additionally, tall buildings can radiate heat. Therefore, air trapped between tall structures tends to be both warmed and restricted from being easily flushed out by wind.

By measuring temperature variations over a small area, such as your school campus, you can identify general trends relating to land use and urbanization. These observations can then be used to make suggestions for possible actions to be taken by a campus or city to moderate its own microclimate.

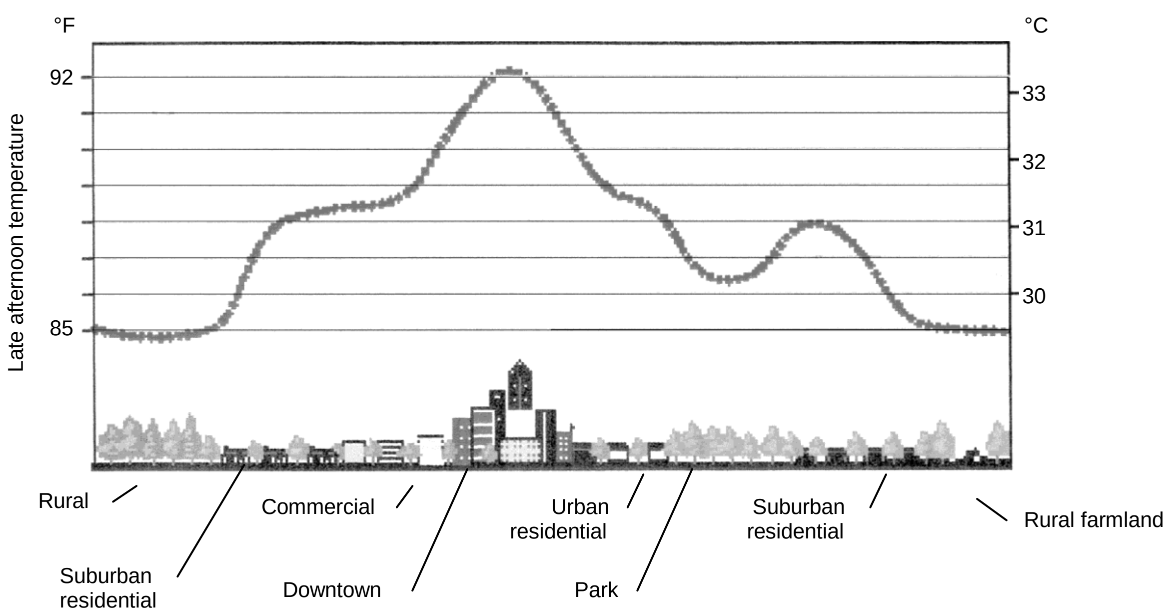


Image courtesy of U.S. EPA

Temperature profile of an urban heat island

Pre-Lab Discussion and Experiment

1. How does proximity to water affect air temperature?

Air temperatures near water vary over a more narrow range, being cooler in the summer and warmer in the winter, than air temperatures over land, other factors being equal.

2. How does the air temperature over grass compare to that of asphalt?

Other factors being equal, in warm, sunny weather, air temperatures over grass will be cooler than those over asphalt. In cold weather, air temperatures over grass may be warmer than those over asphalt.

3. How does air temperature in the shade compare to air temperature in direct sunlight?

Air temperatures in the shade will be cooler than in direct sunlight.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

♦ Be sure students can access the My World GIS program from their computers.

Note: Plan to supervise students while they are outside the classroom. Students should not need to leave campus to collect data.

Safety

Add these important safety precautions to your normal outdoor procedures:

♦ Do not leave campus to collect data.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up

1. Start a new experiment on the data collection system. �(1.2)

2. Connect the weather/anemometer sensor and GPS position sensor into the data collection system. �(2.1)

Collect Data

3. Start recording continuous data. �(6.2)

4. Walk around the designated area for approximately 15 minutes, pausing for at least 30 seconds in each specific area where you wish to gather the most accurate temperature data. Be sure to measure temperature over a variety of land surfaces (asphalt, pavement, concrete, grass, near water, near trees, and so on). Pay close attention to your surroundings as you move from surface to surface. Is the grass wet or dry, and so on.

5. Stop recording data and return to the classroom. �(6.2)

Sample Data

The data represented on the aerial photograph above were collected at a park in Roseville, California. These data are similar to data that your students will collect. Two parameters have been assigned two separate attributes in My World GIS as follows: wind speed (size) and temperature (color). On a warm, sunny day, students might see, as is illustrated in this example, higher temperatures in areas that are made of concrete or asphalt and are sheltered from wind, lower temperatures and wind speeds under trees, and lower temperatures with higher wind speeds in open, grassy areas.

Data Analysis

1. Export your data from the data collection system to a USB flash drive for use in the My World GIS mapping software �(11.3)

2. Launch My World GIS �(12.1) and import the data file into the Data Library. �(12.1.2) The layer should also be automatically added to the Layer List.

3. Add the USGS Digital Ortho-Quadrangles WMS map to the map below the imported data set.

4. Highlight the imported data layer, and click the Zoom to Active Layer Tool. �(12.4.4) This centers the map on the weather data.

5. Use My World GIS to manipulate your data into revealing trends about the weather in the areas from which you collected the data, either by editing the layer's appearance (for two or more parameters) �(12.2.5) or changing the fill color (one parameter). �(12.3.5)

6. Use the Pointer Tool to identify the trends in your data. �(12.4.6)

Analysis Questions

1. Which area showed the highest average temperature? Explain why.

Answers will vary. However, in general, the highest average temperatures tend to be found over or next to urban surfaces, such as asphalt, pavement, and concrete. Higher temperatures are also found close to tall buildings.

2. Which area showed the lowest average temperature? Explain why.

Answers will vary; however, in general, the lowest average temperatures tend to be found over natural surfaces, such as water, grass, trees, and so on.

3. Did any spots have a higher or lower temperature than you expected? Can you explain this?

Answers will vary based on student data. Some shady areas might still show fairly high temperatures that are not much different from adjacent areas. This could be a result of a combination of factors. Primarily, in this case, shady areas are blocked from wind by trees. The shading from the sun causes the temperature to fall slightly, but the area is still warm due to a lack of wind. This is especially true if the shaded area is adjacent to an asphalt area, which will radiate large amounts of heat into nearby areas.

4. How did wind speed affect the recorded temperature? Were any other measurements or structures a factor?

Answers will vary depending on student data. Students should see temperatures decrease as wind speeds increase. Temperatures around large structures where winds would be blocked by trees, building, and so on, might still be cool, depending upon the amount of shade in the area.

5. How did the humidity change over the course of your walk? In what areas did you see the humidity rise? Where did it fall? Why would this happen?

Answers will vary depending on student data. Students should see the relative humidity (%) rise in wet or damp areas (around rivers, creeks, wet grass, and so on). The humidex should fall in dry areas (sand, dry bark, and so on). This happens because of the change in moisture between areas.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Based on your findings, can you suggest a method for keeping the temperature lower or higher at your school?

Answers will vary, but should include the introduction of natural and reflective/cool surfaces onto the campus (add cool roof surfaces, increase number of trees on campus, plant additional gardens and grassy areas, possible roof-top gardens, and so on.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which of the following items contribute to higher urban temperatures?

- **A.** Waste heat from automobiles, air conditioners and factories
- **B.** Displacing natural surfaces and, therefore, decreasing the amount of evapotranspiration in the area
- **C.** Heat radiated from tall buildings warms trapped air
- **D.** A and B only
- **E.** **A, B, and C**

2. Over which of the following features would you expect to find the highest air temperature on a sunny day?

- **A.** Football field
- **B.** Lake
- **C.** Gravel-covered clearing
- **D.** **Highway**
- **E.** Park

3. Which of the following community actions would *not* help to mitigate the heating effects of urbanization?

- **A.** Planting trees around buildings and in street medians
- **B.** **Building taller structures**
- **C.** Replacing dark commercial building rooftops with reflective metal surfaces
- **D.** Establishing outdoor parks
- **E.** Covering buildings with natural surfaces such as roof-top gardens

4. The effects of urban sprawl include:

- **A.** Increased pollution.
- **B.** Destruction of natural ecosystems for urban development.
- **C.** Negative impacts on health, including increases in obesity and blood pressure.
- **D.** Increased infrastructure costs.
- **E.** **All of the above.**

5. A megacity is defined as a city with a population of ____________ and a population density of ____________ or more.

- **A.** 1 million; 300 persons/square km
- **B.** 5 million; 1,000 persons/square km
- **C.** **10 million; 2,000 persons/square km**
- **D.** 15 million; 3,500 persons/square km
- **E.** 20 million; 5,500 persons/square km

The Living World

9. Cellular Respiration and the Carbon Cycle

Objectives

Students explore the relationships between cellular respiration, photosynthesis, and the carbon cycle by:

- ♦ Analyzing the process of aerobic cellular respiration, particularly the release of CO_2, in dormant and germinating seeds
- ♦ Explaining the contribution of cellular respiration to the global carbon cycle.
- ♦ Recognizing some of the different forms carbon can take.

Procedural Overview

Students use germinating bean seeds as a model to represent cellular respiration in a closed system, and conduct the following procedures:

- ♦ Observe, sketch, label, and compare the gross morphology of dormant and germinating bean seeds.
- ♦ Use a carbon dioxide sensor to measure and compare the carbon dioxide concentration in the air of a closed system containing first dormant and then germinating bean seeds.

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and experiment	20 minutes
♦ Lab experiment	50 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ CO_2 gas sensor
- ♦ Sensor extension cable
- ♦ Sampling bottle or Erlenmeyer flask (2), 125-mL
- ♦ Dissecting microscope or magnifying glass
- ♦ Knife or scalpel
- ♦ Parafilm® (if using an Erlenmeyer flask)
- ♦ Dry bean seeds (11)[1]
- ♦ Germinating bean seeds (11)[1]

[1] Dried pinto beans work well for this experiment.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Food provides molecules that serve as fuel and building material.
- ♦ Organisms get energy from oxidizing their food.
- ♦ The processes of extracting energy from food and getting rid of waste are carried out primarily in cells, which function similarly in all organisms.
- ♦ An independent variable in an experiment is the condition the scientist controls and changes.
- ♦ A dependent variable in an experiment is the condition that changes when the scientist changes the independent variable. The scientist is interested in how the dependent variable changes when the independent variable is changed.
- ♦ A controlled variable in an experiment is a condition, such as temperature, light, and volume, that the scientist keeps the same from one trial to another.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Photosynthesis and Primary Productivity
- ♦ Photosynthesis and Cell Respiration in a Terrarium

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment �(1.2)
- ♦ Connecting a sensor to the data collection system �(2.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Displaying two data runs in a graph �(7.1.3)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Saving your experiment �(11.1)

Background

In the germinating seed, cells within the growing plant embryo use energy-storage molecules (oils, starches, and sugars) stored in the seed for food to fuel its life processes. The energy from the food is extracted through a process of cellular respiration. In a series of hundreds of biochemical reactions, the carbon atoms that are initially bound in the large energy-storage molecules combine with oxygen gas to produce carbon dioxide gas. Water vapor and energy, vital to living processes, are also products of these biochemical reactions that break down the large energy storage molecules.

During cellular respiration, part of the energy in the complex energy-storage molecules is captured as potential chemical energy in a molecule called ATP. The remainder of the energy is released as heat into the cell and ultimately into the surrounding environment. The ATP molecules provide energy to fuel the life processes of growth and reproduction. They also power the process of creating food used later by the organism to produce additional ATP molecules for life processes. Organisms, especially warm-blooded vertebrates, use the heat energy released by cellular respiration to maintain their internal temperature in the range needed for their life processes.

The carbon dioxide gas released into the environment becomes available to plants for use in photosynthesis. During photosynthesis, plants trap energy from the sun to convert carbon dioxide gas and water into complex sugar molecules that store potential chemical energy. The carbon dioxide gas and water vapor molecules released into the atmosphere during cellular respiration also function as natural "greenhouse gases," causing the atmosphere to retain more of the sun's energy through the natural greenhouse effect.

Pre-Lab Discussion and Experiment

Hold a brain-storming discussion regarding seed germination. What do students already know? During the brainstorming experiment, accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment.

Ask students the following questions as appropriate:

1. What do students think that seed germination is? Have students ever noticed seeds germinating?

Answers will vary based on student experience.

2. How many have seen bean sprouts in the store? What happens inside the bean seed to change it from a hard, seemingly inert object to a green, growing plant?

Answers will vary based on student experience. It may be a good idea to bring in some bean sprouts to show students. Typically, a series of complex chemical reactions takes place within the seed to begin germination.

3. What do seeds need in order to germinate?

Germination usually begins after the seed has been exposed to adequate levels of moisture (water) and are at the proper temperature, have a sufficient amount of oxygen and light levels. The amount of water needed and the proper temperature vary from species to species.

4. Where does the energy come from to power this change? What kind of energy is it?

The embryo inside the seed has lipids, proteins, and carbohydrates stored in it. This provides the energy for the growing seedling until it can begin to make its own carbohydrates through photosynthesis. Those macromolecules are broken down in the mitochondria of the plant cells to produce ATP. The energy stored in the chemical bonds of the ATP molecule is then used as an energy source for the plant.

5. What is the process called that generates the energy that the plant needs to grow?

The process that creates ATP is called *cellular respiration*.

Review an illustration that summarizes the global carbon cycle.

6. What is the role of living things in the carbon cycle? Brainstorm ideas, recording them for class viewing.

Plants use the carbon dioxide in the environment during the process of photosynthesis to create carbohydrates. All living organisms then use the carbon stored in the carbohydrates as an energy source during the process of cellular respiration. An end product of cellular respiration is carbon dioxide.

Ask students to observe the water covering the germinating seeds. Ask them if they can see evidence of chemical activity.

7. How would you determine what kind of gas is in the bubbles?

Students may recommend adding a dissolved oxygen sensor to the water with the seeds, to see if the oxygen level is increasing or decreasing. They may also recommend a variety of other chemical tests

Instructor Tip: Students may have the misconception that plants do not undergo aerobic cellular respiration, giving off CO_2 in the process, but rather only undergo the process of photosynthesis, giving off only O_2 in the process. At this stage, don't correct these misconceptions. Let them find out for themselves during the laboratory experiment!

Instructor Tip: Many high school students have difficulty grasping the concept that matter can be transformed during a chemical reaction from a solid form into an invisible gas. By using a CO_2 sensor, students can extend their senses to enable them to detect CO_2 gas, which is odorless and invisible to the human eye.

Instructor Tip: To make better use of time, students could evaluate seed morphology and collect data simultaneously, either dividing the tasks or using the data collection time to perform the morphologic evaluation.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

- Twenty-four to 48 hours before starting the lab experiment, place the seeds (11 per student or group) in a large beaker and cover them with water. Put the beaker in a dark location.

Safety

Add this important safety precaution to your normal laboratory procedures:

- Use care with the knife or scalpel.

Procedure with Inquiry

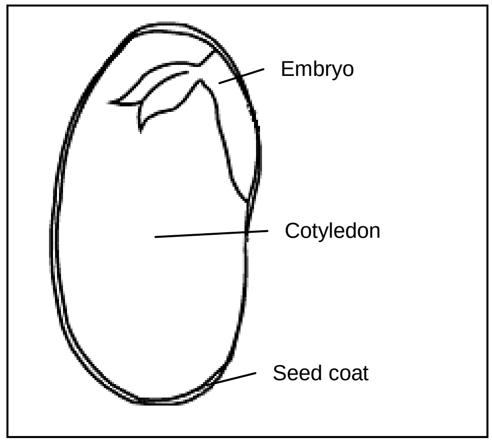
Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Observing and comparing the morphology of dormant and germinating bean seeds

1. Obtain one dry seed and one soaked seed. Use a knife or scalpel to bisect the seeds longitudinally into halves.

2. Use a magnifying glass or dissecting microscope to observe the interior of the seed.

3. Sketch the major morphologic features of the bean seed. Label the cotyledon, embryo, and seed coat.



4. List some differences you observe in the appearance of the dry versus the soaked seed.

The seed coat of the soaked seed is softer and wrinkled.

The embryo is larger in the soaked seed.

The cotyledon is softer in the soaked seed.

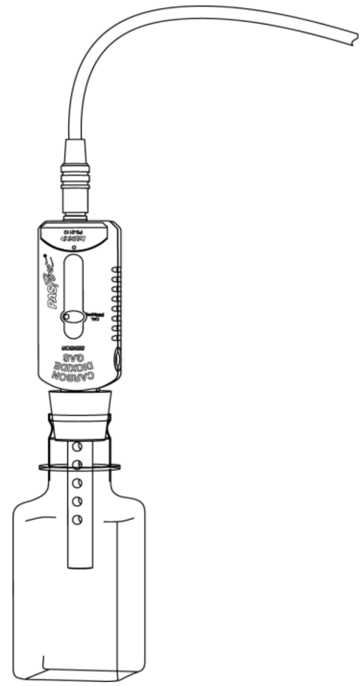
5. What is a sign that the seed has changed from a dormant state to a growing state, in other words, that the seed is germinating?

The primary sign that the seed is growing is that the embryo is larger in the soaked seed. Also, the fact that the cotyledon is softer may suggest some changes associated with germination.

Part Two – Comparing the CO_2 gas concentrations of a closed system containing dormant seeds versus a closed system containing germinating seeds

Set Up

6. Start a new experiment on the data collection system. �(1.2)



7. Connect a CO_2 gas sensor to the data collection system using an extension cable. �(2.1)

8. Display CO_2 gas concentration on the y-axis of a graph with Time on the x-axis. �(7.1.1)

9. Why is a parameter versus time graph chosen to view the data? What is another way to view the data?

The parameter versus time graph was chosen to display the data because it gives the best overall graphical representation of an activity in which data for a parameter is collected over time. Another way to view that data would be on a table.

10. Put 10 dry seeds into one sampling bottle and 10 soaked seeds in the other sampling bottle.

11. Insert the end of the CO_2 gas sensor into the sampling bottle containing the dry seeds and firmly plug the end of the sampling bottle with the rubber stopper.

Note: If you are using an Erlenmeyer flask rather than a sampling bottle, seal the top with Parafilm®.

12. Why are you using dry and soaked seeds?

Dry seeds are being used because they are dormant and presumably not undergoing cellular respiration. Soaked seeds are being used because water has softened the seed coat and entered the cells of the seed so the process of cellular respiration can start. Therefore, it will be possible to compare seeds that are not undergoing cellular respiration with seeds that are.

13. Why are you sealing the bottles with a rubber stopper or Parafilm?

The rubber stopper or Parafilm is used to seal the sample bottles to prevent any gas from escaping, thus creating a closed system.

14. Predict what will happen to the CO_2 concentration during data recording? Why?

Answers will vary, but students should predict what they expect to happen to the level of CO_2 in the bottle, and they should relate this to what they think is different in the two experimental situations.

Collect Data

15. Start data recording and record data for 10 minutes. �(6.2)

Note: Avoid bumping the equipment because jarring or bumping the sensor might cause the sensor to record erratically.

16. Stop data recording. �(6.2)

Write the run number here____1_____.

17. Switch the sensor to the other sampling bottle, seal with Parafilm if necessary.

18. Record data for 10 minutes. �(6.2)

19. Stop data recording. �(6.2)

Write the run number here___2___.

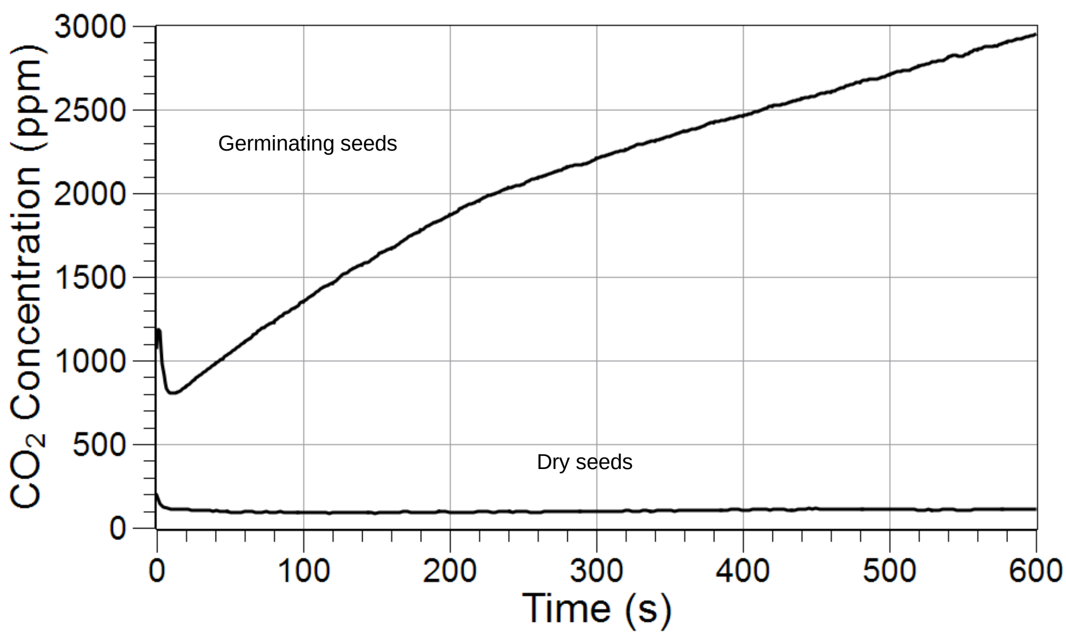
20. Save your experiment, �(11.1) and clean up according to your instructor's instructions.

Data Analysis

1. Display both data runs on the graph display. �(7.1.3)

2. Adjust the scale of the graph to show all data. �(7.1.2)

3. On the graph below, sketch the plotted data on your graph display. Be sure to label the x-axis and y-axis regarding parameter and units of measurement. Label each data run.



CO_2 gas concentrations versus time graphs of germinating seeds and dry, dormant seeds

4. Find the initial and final CO_2 concentrations for each run �(9.1) and record them in the data table.

5. Calculate the change in CO_2 concentration for each experimental condition and record these values in Table 1.

Table 1: CO_2 concentration of dry seeds and germinating seeds

	Initial CO_2 Concentration (ppm)	Final CO_2 Concentration (ppm)	Change in CO_2 Concentration (ppm)
Dry seeds	111	108	–3
Germinating seeds	810	2935	2125

Analysis Questions

1. Compare the change in CO_2 concentration for dry seeds versus soaked seeds.

The concentration of CO_2 did not change much in the sample bottle containing dry seeds. In contrast, the concentration of CO_2 increased in the sample bottle containing soaked seeds.

2. What can you conclude about the soaked seeds regarding CO_2?

The dry seeds don't seem to affect the concentration of CO_2 in the air, but soaked seeds seem to release (give off) CO_2.

3. Compare your prediction to the data you collected. Were you correct or incorrect in your prediction? Explain.

Students should tell whether their prediction was correct or not. Expect more than just a "yes" or "no" answer. Answers should include reasons related to cellular respiration.

4. In this experiment, what is the independent variable and what is the dependent variable?

The independent variable is the presence or absence of germination, and the dependent variable is the level of CO_2 gas in the bottle. Students may state that the independent variable is water, but the important variable is whether or not germination is occurring.

5. What would you expect to happen to the concentration of oxygen gas in the bottle? Why? How could you test this hypothesis?

The concentration of oxygen gas should go down in the bottle because oxygen gas is being used up during the process of cellular respiration. You could test this by measuring the oxygen gas in the bottle using an oxygen gas sensor.

6. What are the gaseous products of cellular respiration that are released from the cells of the germinating seeds?

The gaseous products of cellular respiration that are released from the cells of the germinating seeds are carbon dioxide gas (CO_2) and water vapor (H_2O).

7. Where did the seed get the fuel (glucose) for cellular respiration?

The seed got the fuel (glucose) for cellular respiration from the plant that produced it. The green plant, through photosynthesis, made sugar molecules from carbon dioxide gas and water (using energy captured from the sun). The plant stored the fuel as oils, starches, or sugars in the seed's cotyledons.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Consider the following overall summary equation of the hundreds of biochemical reactions involved in aerobic cellular respiration:

$$C_6H_{12}O_6 + 6O_2 + ADP + P_{\text{inorganic}} \rightarrow 6CO_2 + 6H_2O + ATP$$

Write this equation using words instead of chemical symbols. Write an equation for this process using chemical notation.

glucose (energy storage molecule) + oxygen gas +ADP (low-energy molecules) + phosphate →
carbon dioxide gas + water vapor + ATP (high-energy molecules)

2. In this experiment, a germinating seed is used as a model to represent cellular respiration in all living things. Why is it reasonable to create a model for cellular respiration?

Using a germinating seed as a model to represent cellular respiration in all living things is possible because the process of cellular respiration is essentially the same for most organisms.

3. What is the effect of cellular respiration on the atmosphere? How is the natural greenhouse effect influenced?

The effect of cellular respiration on the atmosphere is to increase the concentration of carbon dioxide gas and water vapor in the air. Carbon dioxide gas and water vapor are natural greenhouse gases, so cellular respiration contributes to the natural greenhouse effect of the atmosphere. Therefore, these gases cause the atmosphere to retain some of the sun's energy in the form of heat, causing the atmosphere to be warmer than it would be without cellular respiration.

4. What role does cellular respiration in plants and other living organisms play in the carbon cycle?

Cellular respiration in plants, animals, and microbes helps keep carbon circulating in the environment so it can be available as a building block for life processes. Cellular respiration is responsible for converting carbon, bonded in solid forms, to carbon dioxide gas that is released to the atmosphere or into bodies of water, including the ocean, lakes, and rivers. Carbon dioxide gas in the atmosphere is available to plants for the photosynthetic process which converts carbon from the atmosphere into carbon bonded in molecules that exist in solid forms within organisms.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. The chemical elements that make up the molecules of living things pass through food webs and are combined and recombined in different ways. In this experiment, which of the following is an example of a chemical element being recombined as it passes through a link in the food web?

- **A.** Carbon dioxide is being passed from the energy storage molecule in the bean seed to the atmosphere.
- **B.** Carbon from the energy storage molecule (glucose) in the bean seed is being recombined with oxygen and passed as CO_2 gas into the atmosphere.
- **C.** Oxygen gas (O_2) from the atmosphere is being recombined in the bean seed into different molecules (H_2O and CO_2).
- **D. Both B and C are examples.**

2. How did the energy-storage molecules in the bean seed get there?

- **A.** The bean seed gathered these molecules from its surrounding environment.
- **B. The plant that made the seeds gathered energy from the sun through photosynthesis and stored it in the energy-storage molecules in the seed.**
- **C.** The germinating seed gathered energy from the sun and stored it in the energy-storage molecules.
- **D.** Both B and C are correct answers.

3. The food energy that the plant uses for cellular respiration is stored in the seed's

- **A.** Cell wall
- **B.** Embryo
- **C. Cotyledons**
- **D.** DNA

4. Beans and coal both have stored energy. Where did the energy originally come from that is stored in beans and coal?

- **A.** From the earth's gravity
- **B. From the sun's light**
- **C.** From the heat in the earth's core
- **D.** From the carbon dioxide in the air

5. What natural "greenhouse gases" were produced by the bean seeds during cellular respiration?

- **A.** Carbon dioxide gas
- **B.** Oxygen gas
- **C.** Water vapor
- **D. Both A and C are correct**

Extended Inquiry Suggestions

Ask students to plant the seeds in a PASCO EcoChamber and continue monitoring the CO_2 gas concentration. When green leaves appear, what effect does photosynthesis have on CO_2 gas concentration?

Challenge students to design an experiment using an O_2 gas sensor to answer the question: Is the cellular respiration by the bean seeds an aerobic or anaerobic process?

Challenge students to carry out an Internet investigation concerning the magnitude of the contribution of cellular respiration by marine plants and animals to the total carbon cycle.

Challenge students to investigate the current understanding of the magnitude of the role of cellular respiration in contributing to greenhouse gases and climate change. Conduct a classroom debate focused on the question: Does cellular respiration play a significant part in climate change?

10. Yeast Respiration

Objectives

Students use yeast cells as a simple model for studying both aerobic and anaerobic cellular respiration. As part of this investigation, they:

- Analyze evidence of aerobic and anaerobic respiration by yeast cells
- Discuss the role of cellular respiration in the carbon and oxygen cycles
- Explain the role yeast cells play in scientific exploration

Procedural Overview

Students gain experience conducting the following procedures:

- Creating a closed-system for collecting and interpreting data collected by CO_2 gas and dissolved oxygen sensors
- Using a microscope to observe and describe yeast cells

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and experiment	15 to 30 minutes
♦ Lab experiment	45 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dissolved oxygen sensor
- Carbon dioxide gas sensor
- Stainless steel temperature sensor
- EcoChamber
- Beaker, 1-L
- Graduated cylinder, 500-mL or 1-L
- Pipet, disposable
- Microscope with magnification to 400x
- Microscope slide and cover slip
- Activated baker's yeast, 7-g packet
- Sugar, 100 g
- Hot plate with magnetic stirrer and stir bar
- Magnetic stir plate with stir bar
- Water, 1 L

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Food provides molecules that serve as fuel and building material.
- Organisms get energy from oxidizing their food.
- The processes of extracting energy from food and getting rid of wastes are carried out primarily in cells, which function similarly in all organisms.

Related Labs in This Guide

Labs conceptually related to this one include:

- Cellular Respiration and the Carbon Cycle
- Determining Soil Quality
- Toxicology Using Yeast

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to your data collection system �(2.2)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple variables on the y-axis of a graph �(7.1.10)
- Finding the values of a point in a graph �(9.1)
- Saving your experiment �(11.1)

Note: Provide a copy of the user manual for the carbon dioxide and dissolved oxygen sensors for student reference.

Background

The term "respiration" refers to the exchange of gases between an organism and its environment. This intake of oxygen gas and exhalation of carbon dioxide gas is closely linked to the production of ATP at the cellular level, a process called cellular respiration. ATP is generated by mitochondria within the cell. During cellular respiration, the energy stored within macromolecules such as glucose is released and harnessed to phosphorylate ADP, producing ATP.

In the presence of oxygen, glucose can be fully oxidized releasing large amounts of energy. The process of cellular respiration also produces water and carbon dioxide gas as waste products.

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6H_2O + 6CO_2 + \text{energy}$$

Organisms that obtain their energy primarily by utilizing oxygen for the breakdown of glucose are called aerobic organisms. Plants and animals are both examples of aerobic organisms. Even dormant plant seeds undergo respiration, although at a much lower level than after germination starts.

Yeasts are actually facultative anaerobes, organisms that have the ability to undergo aerobic respiration and anaerobic respiration. With oxygen present, yeast will preferentially undergo aerobic respiration. If no oxygen is present, yeast cells use an anaerobic respiration. These reactions are summarized as follows:

glucose + ADP → carbon dioxide gas + ethanol + ATP

Yeast cells participate in the carbon cycle by breaking down large, organic molecules, releasing carbon into the environment as carbon dioxide gas. The carbon dioxide gas is then available to plants for use in the photosynthesis process. Yeast cells participate in the oxygen cycle by using oxygen gas during aerobic cellular respiration to oxidize glucose, producing carbon dioxide gas and water vapor.

Pre-Lab Discussion and Experiment

Engage your students by discussing the historical role that yeast has played in the progress of science.

You may be able to find a multimedia presentation on the discoveries of Louis Pasteur as related to the French beer and wine industries in the 1860s. If not, you can present the following information:

Only 150 years ago, nobody knew how important the single-celled fungi called yeasts are to humankind. We now know that yeast cells are involved in common medical conditions and are promising genetic research tools. Yeast also turns grape juice into wine; converts sugar, water, and hops into beer; and causes bread dough to rise. However, until 1860, people thought that magic or “the grace of God” was responsible. Beer makers knew that they needed to stir the wort (the sugar, hops, and water) with a special stick that they handed down from generation to generation in order to get the proper fermenting action. Bread makers knew they had to preserve a culture that they carefully kept fresh with regular additions of sugar. Wine makers knew that when they crushed the grapes and let the juice sit in vats with the grape skins for awhile, the juice would ferment and turn into wine.

Louis Pasteur was the scientific genius who discovered that yeast cells cause these changes. When the French government called on him to figure out why the wine and beer industries were literally going sour, he used classic microbiological methods to determine that rogue bacteria had invaded the beer and wine, preventing the yeast cells from growing and doing their job of fermenting sugar into alcohol. He invented the pasteurization process to kill the bacteria, and then he inoculated the sterile solutions with the proper kinds of yeast cells.

Review the chemical reactions involved in aerobic respiration and anaerobic respiration as they occur in yeast cells.

Point out that the process of aerobic respiration in yeast cells is virtually identical to that of human cells. However, the process of anaerobic respiration in yeast cells is different from that occurring in human muscle cells. In yeast cells, ethanol is produced as a waste product of anaerobic respiration. In human muscle cells, lactic acid is produced as a waste product of anaerobic respiration.

Ask students*:*

Do you think your cells undergo anaerobic respiration?

Students may be surprised to learn that every time they exercise until their muscles get sore, their muscle cells have used the process of anaerobic respiration. The lactic acid that is produced as a byproduct of anaerobic respiration makes their muscles feel sore.

If necessary, review with your students the proper use of microscopes.

Lab Preparation

Although this experiment requires no specific lab preparation, allow 10 minutes to assemble the equipment needed to conduct the lab.

Instructor Tip: It is not necessary to calibrate the sensors in this experiment because it is not concerned with accuracy but rather with relative levels within the data run.

Safety

Follow all standard laboratory procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up

1. Heat a liter of water and 100 g sugar solution in the 1-L beaker on a hot plate to about 40 °C.

a. Connect the temperature sensor to your data collection system. �(2.1)

b. Insert the temperature sensor into the solution and adjust the hot plate temperature control until 40 °C is reached.

Note: Make sure the sensor is not in contact with the bottom of the beaker when you measure the temperature.

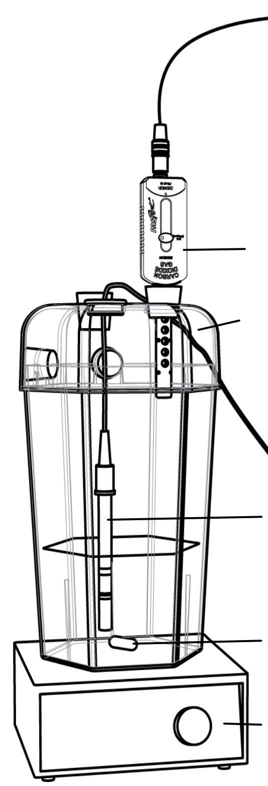
c. Adjust the temperature control on the hot plate to maintain the solution at 40 °C. Monitor the temperature for two minutes to make sure it has stabilized.

2. Set up the EcoChamber to measure dissolved oxygen (DO) and carbon dioxide (CO_2) gas simultaneously.

a. Place a stir bar in the chamber and set it on a magnetic stirrer.

b. Make sure the end of the dissolved oxygen sensor is about 1 cm above the bottom of the chamber.

c. Arrange the CO_2 gas sensor so the end is completely inside the container but will not get wet.



3. Start a new experiment on the data collection system. �(1.2)

4. Connect the DO and CO_2 sensors to your data collection system. �(2.2)

5. Display both DO and CO_2 on the y-axis of the graph, with time displayed on the x-axis. �(7.1.10)

6. Pour 500 mL of the sugar water into the chamber, and seal the chamber airtight.

7. Turn on the magnetic stirrer.

8. Maintain the remaining solution at about 40 °C.

Note: The goal is to pour enough liquid into the chamber to allow the dissolved oxygen sensor to be submerged up to the silver ring.

9. What do you predict will happen to the levels of dissolved oxygen and CO_2 gas with this setup?

Answers will vary. However, students should mention what kind of change they expect for both dissolved oxygen and CO_2 gas. Note: The dissolved oxygen concentration will decrease and the carbon dioxide concentration will stay approximately the same.

Collect Data

10. Start data recording. �[6.2] Record data for about 10 minutes, but *do not stop recording data.*

11. Adjust the scale of the graph so the data fills the screen. �[7.1.2]

Note: While you record data, you can continue with the next two steps.

12. Pour a package of activated baker's yeast into the remaining sugar-water, and stir until the yeast is dissolved in the water.

13. Observe the yeast solution, and describe its appearance and any activity in it. What do you think is happening?

Students should see gas bubbles forming. They may be able to guess that these are bubbles of CO_2 gas.

14. After recording data for 10 minutes, pour about 250 mL of this mixture into the chamber, and re-seal the chamber so that it is airtight.

Note: The goal is to pour about half of the yeast solution into the chamber.

15. Why do you seal the chamber to isolate it from the surrounding air?

You seal the chamber to create a closed system so that all of the carbon dioxide gas produced by the yeast cells will remain in the chamber to be measured.

16. What do you predict will happen to the levels of dissolved oxygen and CO_2 gas with this setup?

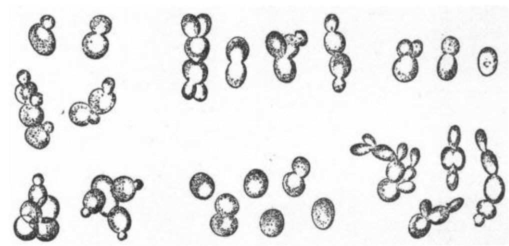
Answers will vary, but students should mention what kind of change they expect for both dissolved oxygen and CO_2 gas as a result of adding yeast cells to the system. Note: The dissolved oxygen concentration will go down and the carbon dioxide concentration will go up.

17. Continue recording data for 20 minutes. While data is recording, perform the following three steps.

18. Using the pipet, put a drop of the yeast solution on a glass slide and cover it with a cover slip.

19. Examine this preparation under a microscope at up to 400x magnification. Record your observations below, including a sketch of what you see at the highest magnification.

Students should record their observations of the yeast solution.



20. In studying cellular respiration in yeast, why would you measure dissolved oxygen and carbon dioxide gas?

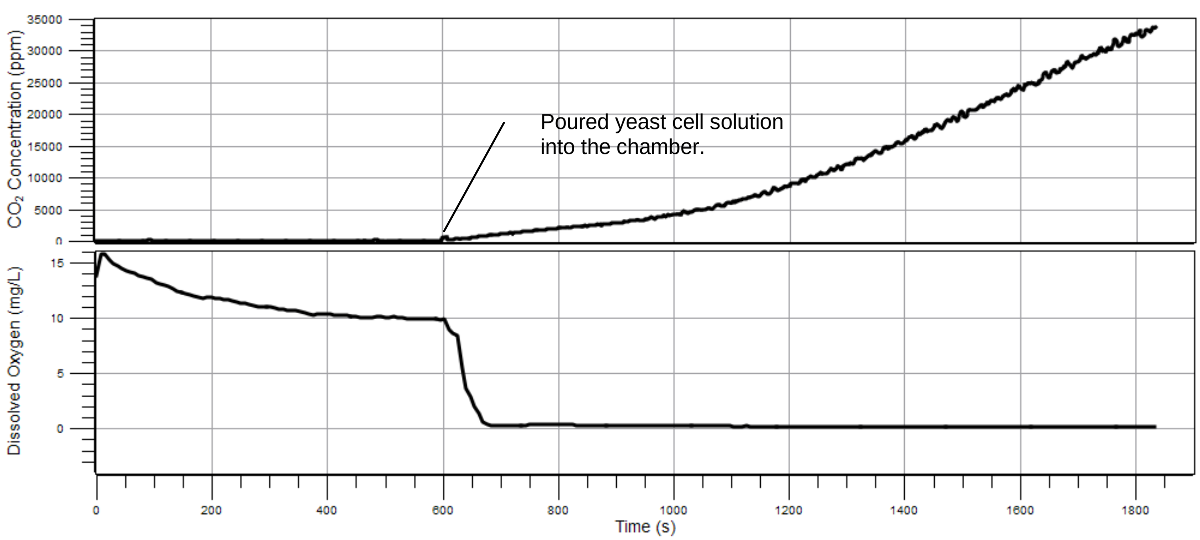
You would measure dissolved oxygen and CO_2 gas as evidence that cellular respiration is occurring.

21. After 20 minutes, stop recording data �(6.2) and save your experiment. �(11.1)

Data Analysis

1. Sketch graphs of your recorded data in the spaces provided, including the appropriate scale. Indicate when the yeast cell solution was added.

Graph of [DO] in sugar-water and CO_2 gas concentration, before and after activated baker's yeast is added.



2. Use graph tools to identify the data points �(9.1) to complete Table 1.

Table 1: Change in dissolved oxygen and carbon dioxide gas concentrations

	Dissolved Oxygen (mg/L)			CO_2 gas (ppm)		
	Initial	**Final**	**Δ**	**Initial**	**Final**	**Δ**
Sugar water	15.9	10.0	-5.9	14	55	31
Sugar water with yeast	10.0	0	-10.0	55	33768	33763

Analysis Questions

1. How do the results of the data compare with your predictions?

Answers will vary. However, students should specifically mention what actually happened to carbon dioxide gas concentrations and dissolved oxygen concentrations compared with what they predicted.

2. The following summarizes the chemical reactions during aerobic cellular respiration:

oxygen gas + glucose → carbon dioxide gas + water vapor + energy (ATP)

Did you see any evidence that aerobic cellular respiration took place? Record all kinds of evidence, including visual observations.

When the yeast cells are first poured into the chamber, the level of dissolved oxygen drops off precipitously. At the same time, the level of CO_2 gas starts rising. This combination of events suggests that aerobic respiration is occurring.

3. The following summarizes the chemical reactions during anaerobic cellular respiration:

glucose → carbon dioxide gas + ethanol + energy (ATP)

Did you see any evidence that anaerobic cellular respiration took place? Record all kinds of evidence, including visual observations.

After the dissolved oxygen seems to be consumed, the level of CO_2 gas continues to rise. In fact, it seems to rise at a faster rate.

Synthesis Questions

Use available resources to help you answer the following questions.

1. How do yeast cells participate in the carbon cycle?

Yeast cells participate in the carbon cycle by breaking down large, complex organic (containing carbon) molecules and releasing the carbon into the environment as carbon dioxide. The carbon dioxide gas is then available to plants for use in the process of photosynthesis.

2. How do yeast cells participate in the oxygen cycle?

Yeast cells participate in the oxygen cycle by using oxygen gas during cellular respiration, causing the oxygen to combine with carbon atoms to form carbon dioxide and to combine with hydrogen atoms to form water molecules.

3. List one reason why yeast cells are frequently used as models in medical and scientific research.

Answers might include one of the following: Yeast cells have many metabolic processes that are similar to those of organisms higher in phylogeny, including humans. Yeast cells are easy to grow. Most yeast cells are not pathogenic. Yeast cells are relatively simple organisms yet are eukaryotic.

4. List one way that yeast cells are now being used in medical or scientific research.

Answers might include one of the following: Yeast cells are currently being used in genetic engineering studies, toxicology studies, and molecular biology studies.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Yeasts are

- **A.** Single-celled organisms containing chlorophyll
- **B.** Single-celled organisms that do not have a nucleus
- **C. Single-celled organisms that have a nucleus and organelles typical of eukaryotes**
- **D.** Single-celled bacteria
- **E.** Multicellular organisms

2. Yeasts get their energy for life processes from

- **A.** Aerobic cellular respiration
- **B.** Anaerobic cellular respiration
- **C.** Alcoholic fermentation
- **D.** Only A and B are correct
- **E. A, B, and C are all correct**

3. Yeasts release the following as byproducts of cellular respiration:

- **A.** Oxygen gas
- **B.** Carbon dioxide gas
- **C.** Ethanol
- **D.** Water
- **E.** Only B and C are correct
- **F.** **Only B, C, and D are correct**

4. Yeasts participate in the carbon cycle by

- **A.** Decomposing complex carbohydrates
- **B.** Capturing CO_2 gas from the atmosphere and incorporating it into sugars
- **C.** Incorporating elemental carbon into foods that other organisms can use
- **D.** Fermenting sugars, releasing CO_2 gas
- **E.** A and B are correct
- **F.** **A and D are correct**

5. Yeasts participate in the oxygen cycle by

- **A.** Decomposing complex carbohydrates
- **B.** Capturing O_2 gas from the atmosphere and incorporating it into sugars
- **C.** Incorporating elemental carbon into foods that other organisms can use
- **D.** Fermenting sugars, releasing CO_2 gas
- **E.** A and B are correct
- **F.** **A and D are correct**

Extended Inquiry Suggestions

Challenge students to design a more detailed inquiry into yeast cellular respiration by adding oxygen gas and ethanol sensors to the experimental system. Have them look for additional evidence of aerobic and anaerobic cellular respiration.

Ask students to investigate the role of yeast in the creation of biofuel.

11. Photosynthesis and Primary Productivity

Objectives

Students determine the primary productivity of an aquatic plant.

Procedural Overview

Students will gain experience conducting the following procedures:

- Use a dissolved oxygen sensor to measure the rate of change in dissolved oxygen concentrations in a closed chamber while exposing an *Elodea* plant to bright light and in darkness.
- Calculate the net primary productivity (NPP) rate, cellular respiration (R) rate, and gross primary productivity (GPP) rate.
- Estimate the total GPP, R, and NPP of the *Elodea* plant if maintained in the experimental condition for 24 hours.

Time Requirement

♦ Preparation time	1 to 3 hours (depending on the availability of *Elodea sp.* plants)
♦ Pre-lab discussion and experiment	50 minutes
♦ Lab experiment	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Dissolved oxygen or water quality sensor
- Photosynthesis tank
- Rubber stopper, #3 (included with photosynthesis tank)
- *Elodea sp.* plant (several sprigs)
- Magnetic stirrer and stir bar
- Black cloth, opaque, 50 cm x 50 cm
- Lamp, 100 W or high-intensity
- Dechlorinated tap water, 1 L[1]
- Ice (optional)

Alternative to the photosynthesis tank:

- Shallow pan or dish, large
- Large base and support rod
- Mineral oil
- Erlenmeyer flask, 250-mL
- 3-finger clamp

[1]Methods for dechlorinating tap water are detailed in the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Most food energy comes originally from sunlight.
- ♦ Plants use light energy to make sugars from carbon dioxide and water, releasing oxygen gas as a byproduct.
- ♦ Plants can make their own food and use it immediately or store it to use later.
- ♦ The cells of green plants, but not animals, contain chloroplasts, which are organelles in which photosynthesis takes place.
- ♦ Chlorophyll, a molecule found in chloroplasts, is required for the process of photosynthesis; chlorophyll is responsible for the green color of plants and algae.
- ♦ During photosynthesis, carbon dioxide gas is consumed and oxygen gas is released.
- ♦ During cellular respiration, oxygen gas is consumed and carbon dioxide gas is released.
- ♦ To identify the independent variable, ask "What do I change?"
- ♦ To identify the dependent variable, ask "What do I observe?"
- ♦ To identify the controlled variables, ask "What do I keep the same?"

Related Labs in This Guide

Prerequisite:

- ♦ Cellular Respiration and the Carbon Cycle

Labs conceptually related to this one include:

- ♦ Photosynthesis and Cell Respiration in a Terrarium

Using Your Data Collection Systems

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to your data collection system �(2.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)

- Adjusting the scale of a graph �[7.1.2]
- Selecting data points in a graph �[7.1.4]
- Finding the values of a point in a graph �[9.1]
- Finding the slope and intercept of a best-fit line �[9.6]
- Saving your experiment �[11.1]

Note: Provide for reference to your students the user manual for the dissolved oxygen sensor or water quality sensor.

Background

Primary productivity is principally the production of carbohydrates from carbon dioxide gas, electromagnetic radiation from the sun, and water, through the process of photosynthesis. All life on Earth is directly or indirectly reliant on primary production. The organisms responsible for primary production are known as primary producers, or autotrophs, organisms that can make their own food, usually through the process of photosynthesis. These primary producers form the base of the food chain, functioning at the first trophic level.

In terrestrial ecosystems, autotrophs are primarily vascular plants. In aquatic ecosystems, primary producers include photosynthetic bacteria, phytoplankton (single-celled photosynthetic aquatic organisms), multicellular algae, and vascular plants, such as *Elodea sp*. Most photosynthetic autotrophs contain chloroplasts, organelles that contain chlorophyll and in which photosynthesis takes place.

It has been estimated that aquatic autotrophs carry out about 50% to 70% of the primary production on Earth. Although most of the autotrophs are consumed by zooplankton or aquatic animals, some of the organic material in dead autotrophs sinks to the ocean floor and remains there for as long as millions of years. This entombed organic carbon material is an important carbon sink in the global geochemical carbon cycle.

In this part of the carbon cycle, carbon dioxide (CO_2) from the atmosphere is captured by aquatic autotrophs and sequestered in solid form at the bottom of the ocean, removing it from the carbon cycle indefinitely. Scientists are currently trying to better quantify this carbon sink because it affects levels of atmospheric CO_2 concentrations and thus its greenhouse gas effect, as well as the level of dissolved CO_2, which affects the pH of oceans.

Aquatic plants and photosynthetic microorganisms release oxygen gas (O_2) (the byproduct of photosynthesis) into the water, where it dissolves and forms dissolved oxygen gas (DO). Water can hold only a limited amount of dissolved O_2. When the concentration of DO reaches a certain level (saturation), the DO diffuses (or out-gases) into the air as O_2 gas. When all other conditions remain constant, cold water will hold more dissolved gasses than warm water.

Primary productivity can be expressed as gross primary productivity (GPP) or net primary productivity (NPP). Net primary productivity is the total amount of carbohydrates produced in the ecosystem (the GPP) minus the carbohydrates consumed by the producers for their own aerobic cellular respiration (R). Net productivity reflects the carbohydrates available to other organisms in the ecosystem. Net primary production is the excess food produced by autotrophs that is available for consumption by other organisms in the food chain. The equation for calculating NPP is: NPP = GPP – R.

Pre-Lab Discussion and Experiment

Hold the following discussion with your students.

Emphasize that the process of photosynthesis is the chemical pathway by which all plants, and some protists and monerans, make food, specifically carbohydrates. The entire photosynthetic pathway is a complex series of biochemical transformations that take place in association with chlorophyll. During these transformations, hydrogen from water is added to molecules of carbon dioxide to make carbohydrates. The generalized equation for photosynthesis is

$$6CO_2 + 6H_2O + \text{electromagnetic energy} \rightarrow C_6H_{12}O_6 + 6O_2$$

(carbon dioxide + water + energy → glucose + oxygen gas).

Remind students of the generalized equation for aerobic cellular respiration:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{energy}$$

(glucose + oxygen gas → carbon dioxide + water + potential chemical energy + heat)

Emphasize that for every molecule of glucose produced in photosynthesis, the plant gives off 6 oxygen gas molecules. Likewise, for every molecule of glucose used in aerobic cellular respiration, the plant takes up 6 molecules of oxygen gas. Thus, tracking oxygen gas molecules is a good way to measure rates of photosynthesis and aerobic cellular respiration.

Correct a misconception: Many students do not realize that the process of cellular respiration occurs in plants (and all living things) 24 hours a day in conditions of both light and darkness, whereas photosynthesis requires light energy to drive it.

Point out the contributions to primary productivity by both terrestrial and aquatic organisms.

Brainstorm reasons it might be important to determine global primary productivity. Ask students: What would happen to life on Earth if plants did not make more food than they need for their own life processes?

Instructor Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the brainstorming experiment.

Help students understand the relationship between net primary productivity (NPP), gross primary productivity (GPP), and cellular respiration (R).

NPP is GPP reduced by R. In other words, NPP is what is left over from GPP after subtracting what the plant (or system) needs for its own survival (R).

In this lab, students will determine the rates of GPP, NPP, and R for the *Elodea* plants. They will be asked to determine the GPP rate as expressed as the change in dissolved oxygen concentration over time. Help students develop the formulas they will use for this calculation (rates are in "mg dissolved O_2/(L·s)":

$$GPP_{rate} = NPP_{rate} + R_{rate}$$

Emphasize the difference between measuring an amount (such as NPP) and measuring a rate (such as NPP rate). In the lab, students will measure rates (changes over time).

Remind students of two methods for determining rate: slope of a linear fit line and the 2-point method. If students have not studied these techniques, show them examples of each procedure.

Students will then estimate from the rate the amount of glucose (NPP and GPP) produced in a period of time (24 hours), assuming the plant was kept in light for 12 hours and in darkness for 12 hours. For this calculation, students will need to know the molecular weight of oxygen gas (32) and glucose (180).

You may want to challenge students to calculate the molecular weights of glucose and oxygen gas using their chemical formulas and a periodic chart of the elements.

Depending on their background preparation, students may need help with these computations. Provide them with the following example to help them become familiar with the use of the equations.

Dissolved oxygen concentration measured over a 10-minute period

Light Setup	Initial Dissolved Oxygen Concentration ([DO]) (mg/L)	Final [DO] (mg/L)	Total Change in [DO] (mg/L)
Bright light	8	11	3 (NPP)
Darkness	8	7	–1 (oxygen gas used in respiration)

NPP: measure of the carbohydrates produced during photosynthesis, determined by the change in dissolved oxygen concentration under lighted conditions.

R: measure of the carbohydrates used during respiration to release energy needed by the cell.

It is important to note that the absolute value of the change in dissolved oxygen concentration measured with the plant in darkness (which corresponds to R), is added to NPP to determine the total amount of carbohydrate synthesized by the plant (GPP).

The GPP is the total amount of carbohydrates produced in the ecosystem in ten minutes:

$$GPP = NPP + R$$

$$GPP = 3 \text{ mg/L} + 1 \text{ mg/L} = 4 \text{ mg/L}$$

To calculate the GPP rate in mg/(L·s):

$$\text{GPP rate} = 4 \text{ mg/L} \div (10 \text{ min x } 60 \text{ s/min}) = 0.0066 \text{ mg/(L·s)} = 6.6 \times 10^{-3} \text{ mg/(L·s)}$$

The rates for NPP and R can be similarly calculated. Then the total GPP, NPP, and R for other time periods can be estimated by multiplying the rate (in seconds) by the length of time in question (in seconds).

To express the total amount of carbohydrate (glucose) produced in the length of time in question, multiply the GPP by the ratio of the molecular weight of glucose (180) to the molecular weight of 6 oxygen gas molecules (193). (There is one glucose molecule produced per six oxygen molecules, as indicated by the photosynthesis equation.)

Lab Preparation

These are the materials and equipment to set up prior to the lab.

It would be best to complete the "Cellular Respiration and the Carbon Cycle" lab before doing this lab. In that experiment, students focus on the chemical reactions involved in aerobic cellular respiration they need to understand in order to interpret their findings in this lab experiment.

1. Obtain healthy *Elodea* plants from a store specializing in aquaria. Plan to use 1 bunch per student group. Store the plants in dechlorinated water with a pinch of $NaHCO_3$ (sodium bicarbonate, also known as baking soda). Store them near a sunny window or fluorescent light. These can be stored for several days.

Note: It is important to work with healthy *Elodea* plants.

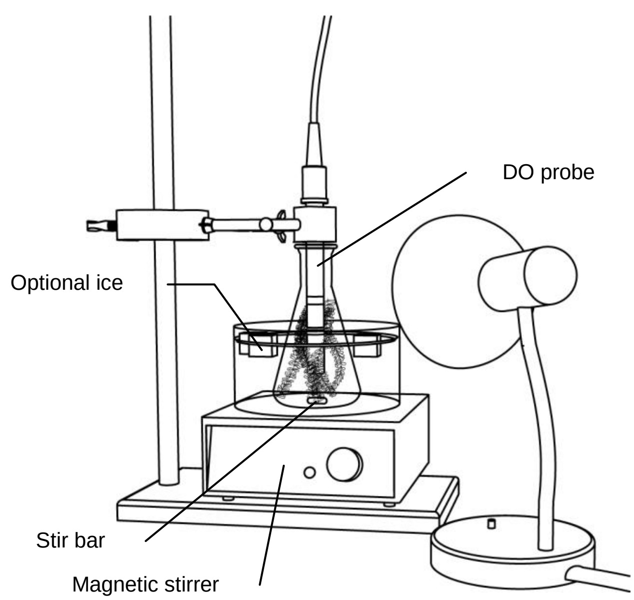
To reduce the contribution of microorganisms to the effect measured, use fresh tap water that has been allowed to stand in an open container overnight or that has been dechlorinated (using a reagent from an aquarium supply store, for example).

2. Find the highest intensity lights that you can, such as those with a 100 W fluorescent bulb or a high-intensity halogen or incandescent light.

3. Ensure that the dissolved oxygen probes are in good working order (see the user manual for the dissolved oxygen or water quality sensor).

4. As an alternative setup, use an Erlenmeyer flask and a dish or beaker in place of the photosynthesis tank, as shown. To prevent out-gassing, drop a thin layer of mineral oil on top of the water in the flask.

Note: It is not necessary to calibrate the dissolved oxygen sensor for this experiment because the measurements will be relative to each other, not related to standard measurements or intended for comparison with measurements by other groups.



Safety

Follow all standard laboratory procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up

1. Start a new experiment on the data collection system. �(1.2)

2. Connect the dissolved oxygen sensor (or water quality sensor) to the data collection system. �(2.1)

3. Display Dissolved oxygen concentration (mg/L) on the y-axis of a graph with Time on the x-axis. �(7.1.1)

Note: Another way of indicating "dissolved oxygen concentration" is by using brackets around the abbreviation for dissolved oxygen, "DO" as follows: [DO].

4. Put a stir bar into the photosynthesis tank.

5. Put several sprigs of *Elodea* plant in the tank so that it is loosely full of the plant, and fill the tank to the top with dechlorinated tap water.

6. Put the large two-hole stopper into the top of the tank.

Note: Water will overflow into the outer chamber.

7. Fill the outer tank to within about 2 cm from the top with tap water.

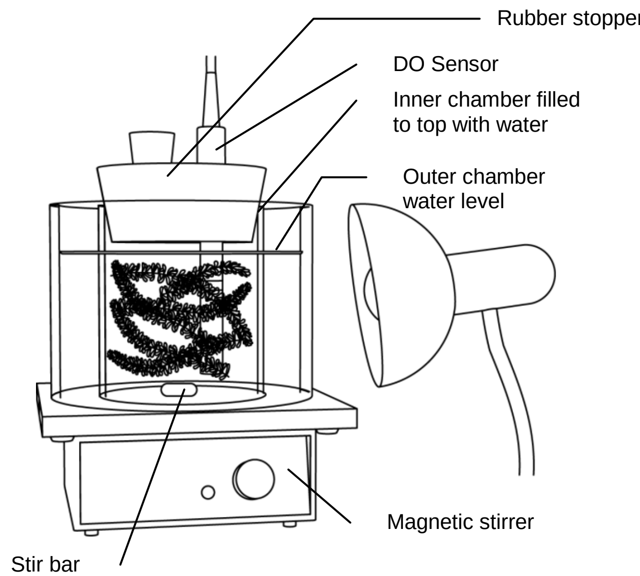
8. Why are you putting water in the outer chamber?

The water in the outer chamber will absorb heat from the light, maintaining a more constant temperature in the inner chamber.

9. Place the photosynthesis tank on the magnetic stirrer.

10. Remove the dissolved oxygen sensor from the storage bottle.

Be sure to remove the white cap from the sensor, being careful not to touch the membrane at the end of the sensor.



11. Insert the end of the dissolved oxygen probe carefully through the larger opening in the two-hole stopper. Push the probe down until the end is positioned just above the stir bar (within 1 cm of the stir bar) and so the end is not touching the plant.

Note: Positioning the end of the probe is important so that the vigorous motion of the water will knock any air bubbles off the end of the probe.

Note: If the plant obstructs the end of the probe, take the stopper out of the tank and rearrange the plant. You may need to add more water to ensure the tank stays completely full and to eliminate all air pockets.

12. Place the photosynthesis tank on the magnetic stirrer.

13. Put a #2 or #3 rubber stopper into the other hole of the large two-hole stopper.

14. Place the lamp very near the photosynthesis tank so the light will shine on the *Elodea* plant.

Collect Data

15. Turn on the magnetic stirrer to a high speed so that the water circulates in the tank.

16. Turn on the light to its brightest setting.

17. Why are you using a magnetic stirrer? *Hint:* Consult the user manual for the dissolved oxygen sensor.

The DO sensor uses up a small amount of DO in the process of measuring, which would create a microenvironment of reduced DO around the tip of the probe if the water were allowed to remain still.

18. Start data recording. �(6.2)

19. Adjust the scale of the graph so the data fills the graph vertically and you can better see the changes in concentration of DO while recording. �(7.1.2)

Note: The initial concentration of DO should be between 4 and 8 mg/L; if it is not in that range, check the DO sensor to be sure it is in good working order.

20. Continue to record data with the light on for 15 minutes. *Do not stop recording data!*

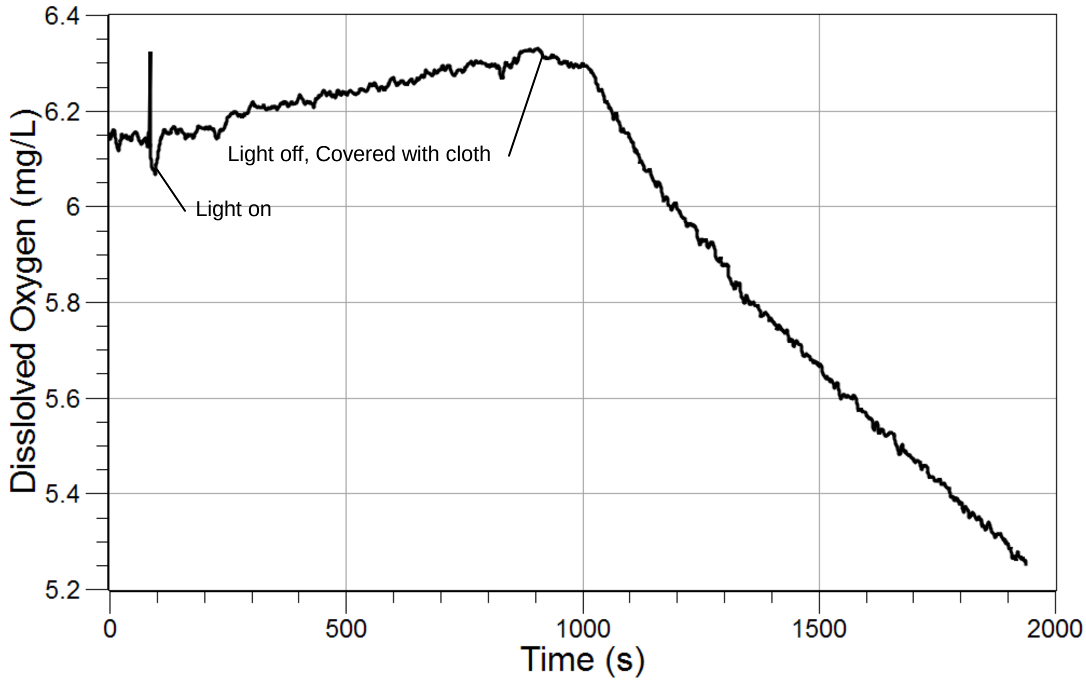
21. Turn the lamp off and carefully cover the setup with a black opaque cloth so the plant is in darkness.

22. Record data with the plant in darkness for 15 minutes, and then stop recording data. �(6.2)

23. Save your experiment. �(11.1)

Data Analysis

1. Draw a sketch of the Dissolved oxygen concentration versus Time graph. Label the x-axis and y-axis, including parameters and units as well as the point at which you turned off the light and covered the setup with the black opaque cloth.



2. Use your recorded data to find the rate of change in DO concentration when the light is shining on the plant and the rate of change in DO concentration when the plant is in darkness. Use 2 methods: 1) the slope of a linear fit line �[9.6] [7.1.4] and 2) the 2-point method. �[9.1] Show your work.

Answers will vary. Students should use the linear fit tool of the graph display to find the slope of selected regions of the graph that correspond to the two experimental conditions: light and darkness.

Answers will vary. Students should then use the graph tools to identify data points at the ends of these selected regions to do the 2-point analysis. Using the data in this example, calculating the slope using the 2-point method:

Slope = [final – initial DO concentration (mg/L)] ÷ length of time (s) between these measurements.

For this example the rate of change of dissolved oxygen concentration is:

In light: the slope is (6.3 – 6.1 mg/L) ÷ 900 s = 2.2×10^{-4} mg/(L·s)

In darkness: the slope is (5.4 – 6.3 mg/L) ÷ 900 s = -1.0×10^{-3} mg/(L·s)

3. Record these values in Table 1.

Note: The rate of change in [DO] in darkness correlates to the consumption of carbohydrates due to cell respiration. A negative slope, which indicates a decrease in the dissolved oxygen concentration, refers to a positive value of cell respiration (R). For example, if the rate of change in [DO] is -1.0×10^{-3} mg/(L·s), then R is 1.0×10^{-3} mg/(L·s).

Table 1: Rate of change of dissolved oxygen concentration comparison

Light Setup	Initial [DO] (mg/L)	Final [DO] (mg/L)	Total Change in [DO] (mg/L)	Rate of Change in [DO] (mg/(L·s) (Linear Fit)	Rate of Change in [DO] (mg/(L·s) (2-Point Method)
Bright light	6.1	6.3	0.2	2.2 x 10–4	2.2 x 10–4
Darkness	6.3	5.4	–0.9	–1.0 x 10–3	–10.0 x 10–4

Analysis Questions

1. Describe how you would find the GPP rate, and then perform the calculation.

GPP_{rate} is calculated as follows:

GPP_{rate} equals the rate of change of carbohydrate produced under lighted conditions (NPP_{rate}) plus the rate of change of carbohydrate consumed under dark conditions (R_{rate}).

(As noted above, it is important to notice that the absolute value of the change in dissolved oxygen measured in the dark, which corresponds to R, is added to NPP to determine the total amount of carbohydrate synthesized by the plant.)

Answers will vary, but an example, based on the above data, follows:

$GPP_{rate} = NPP_{rate} + R_{rate}$

$GPP_{rate} = 2.2 \times 10^{-4}$ mg DO/(L·s) + 10×10^{-4} mg DO/(L·s)

$GPP_{rate} = 12.2 \times 10^{-4}$ mg DO/(L·s) = 1.2×10^{-3} mg DO/(L·s)

2. Describe how you would calculate the net amount (in mg) of glucose produced (NPP) by the plant in 24 hours if the present conditions were maintained and the plant was in darkness for 12 of those hours. Then perform the calculation.

Respiration occurs when the plant is in the light as well as in the dark, and is assumed in these calculations to occur at the same rate in both conditions.

1) To find GPP, multiply GPP_{rate} by 12 h x 60 min x 60 s to find out how much oxygen gas was produced by the plant during photosynthesis during the 12 hours.

2) To find R, multiply $|R_{rate}|$ by 24 h x 60 min x 60 s to find out how much oxygen gas was used up by the plant during 24 hours.

3) To find NPP for 24 hours in terms of oxygen gas, you would subtract R from GPP.

4) To express the result in terms of glucose, multiply the result from Step 3 (NPP) by the ratio of the molecular weight of glucose (180) to the molecular weight of 6 oxygen gas molecules (192) (from the photosynthesis formula).

Calculations will vary, depending upon the experimental results. For the sample data shown:

1) $GPP_{24\ h} = 1.2 \times 10^{-3}$ mg O_2/(L·s) x 12 h x 60 min/h x 60 s/min

GPP for 1 day = 52 mg O_2/L

2) $R_{24\ h} = 1.0 \times 10^{-3}$ mg O_2/(L·s) x 24 h x 60 min/h x 60 s/min

R for 1 day = 86 mg O_2/L

3) $NPP_{24\ hr}$ = GPP – R = 52 mg O_2/L – 86 mg O_2/L

NPP for 1 day = –34 mg O_2/L

4) Net glucose produced in 24 h = –34 mg O_2/L x (180 mg/mol glucose ÷ 192 mg)/ 6 mol O_2

Net glucose produced in 1 day = –32 mg glucose/L

3. How did the rate of change calculated using the two-point method compare with the rate of change as determined by the slope at a linear region of the plotted data?

The two methods of calculating the rate of change should yield approximately equivalent answers.

4. What does a negative slope (rate of change) value indicate?

A negative slope or rate of change value indicates that the concentration of the dissolved oxygen is declining due to cellular respiration.

5. What processes are causing the change in dissolved oxygen concentration under the conditions of bright light?

Under bright light, the process of photosynthesis causes the concentration of dissolved oxygen to increase, while the process of aerobic cellular respiration causes dissolved oxygen to decrease. However, because more dissolved oxygen is being formed than consumed in this example, the net result is for the concentration of dissolved oxygen to increase.

6. What process causes the change in dissolved oxygen concentration under the conditions of darkness?

Under the condition of darkness, the process of aerobic cellular respiration causes the change in dissolved oxygen concentration.

7. Does the dissolved oxygen that you measured under lighted conditions represent the gross primary productivity (GPP) or the net primary productivity (NPP) rate? Explain.

The measured rate under the lighted condition represents the NPP rate. The NPP rate is the net result of the rate of all O_2 produced by photosynthesis (GPP) plus the rate of O_2 being consumed (which is a negative rate of O_2 production) by aerobic cellular respiration by the plant and any microbes growing in the water (R).

8. In this exploration, which is the independent variable, which is the dependent variable, and which factors are controlled?

The independent variable is the presence or absence of light. The dependent variable is the concentration of dissolved oxygen. The factors controlled include all the aspects of the experimental setup, including the equipment, temperature, rate of spin of the stir bar, dissolved oxygen sensor, and length of time of data collection.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What do you think would happen to this closed system if it were maintained for 2 weeks under these conditions?

Answers will vary. If students found a positive NPP, they would predict that the plant would grow. If students found a negative NPP, as in this example, they would predict that the plant would get smaller and perhaps die if this trend continued, because the plant wasn't producing enough food for its needs.

2. What are some of the methods currently used by scientists to determine primary production levels regionally and globally?

Currently, various methods for determining biomass are used to estimate terrestrial net primary productivity. For aquatic primary productivity, the rate of incorporation of the radioactive atom ^{14}C is commonly used. Additionally, new methods of measuring chlorophyll or carbon concentrations from satellite imagery are currently being developed.

3. What are some limitations to these methods of determining primary production?

For determining terrestrial primary production, biomass estimates are difficult to determine for all the plant growth that occurs below the surface, including roots and microscopic organisms or fallen dead plant materials. These methods are also difficult to apply to global estimates. For determining aquatic primary production, satellite methods are limited to observing activity on the surface, whereas photosynthesis can occur deeper in the water column. The method that uses ^{14}C incorporation cannot be applied globally due to practical considerations.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. The first trophic level in an ecosystem refers to

- **A.** Carnivores
- **B.** Consumers
- **C.** Herbivores
- **D.** **All autotrophs**
- **E.** B and D

2. Autotrophs responsible for primary productivity in the oceans include

- **A.** Kelp
- **B.** Zooplankton
- **C.** Photosynthetic bacteria
- **D.** Phytoplankton
- **E.** **A, C, and D**
- **F.** All of the above

3. Most of the primary production in the oceans occurs in the

- **A. Euphotic zone**
- **B.** Dysphotic zone
- **C.** Aphotic zone
- **D.** Abyssal zone
- **E.** Twilight zone

4. Gross primary productivity is equivalent to net primary productivity plus

- **A.** The amount of dead organic material that sinks to the bottom of a body of water or falls as litter to the ground
- **B. The amount of organic material consumed in cellular respiration**
- **C.** The amount of water transpired by plants
- **D.** None of these is true

5. In this experiment, the gross primary productivity was measured by

- **A.** Determining the mass of the plant
- **B.** Determining the rate of oxygen gas consumption during cellular respiration
- **C.** Determining the rate of oxygen gas production during photosynthesis
- **D. B and C**
- **E.** All of the above

Extended Inquiry Suggestions

Ask students to research some of the new methods for estimating global primary production using satellite images. What are some of the new technologies being developed? Have students report on the patterns that are being observed in primary production using these methods. What can these studies reveal about the global environment?

Challenge students to design and conduct a study to determine the effect of light intensity on the rate of photosynthesis. How could these findings be applied to studies of primary production?

12. Photosynthesis and Cell Respiration in a Terrarium

Objectives

Students demonstrate that a terrarium, a closed system, is an excellent tool for conducting environmental studies such as determining the rates of photosynthesis and cell respiration in plants. As part of this process, students:

- Learn to use this closed system to change one variable at a time, control other variables, and monitor multiple variables
- Design additional investigations on photosynthesis and cellular respiration using the terrarium

Procedural Overview

Students gain experience conducting the following procedures:

- Designing controlled investigations
- Identifying the causes of the changes in the rates of O_2 and CO_2 gas concentration shown on the graphed results of these measurements
- Using sensor technology to monitor independent and dependent experimental variables

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	60 minutes

Materials and Equipment

For each student or group:

- Data collection system
- Oxygen gas sensor
- Carbon dioxide gas sensor
- Temperature sensor
- Sensor extension cable
- USB hub (depending on data collection system)[1]
- EcoChamber™[2]
- Fast-growing, small, potted plant [3]
- Opaque cloth, about 1 m^3
- Strong incandescent or full-spectrum fluorescent light source

[1] To determine if a USB hub is required, refer to the data collection system Tech Tip file.

[2] PASCO's EcoChamber is specifically desgned for ease of use with sensors. If not available, use a sealed terrarium as a substitute.

[3] See the Lab Preparation section for small plant suggestions.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Most food energy comes originally from sunlight.
- Plants use light energy to make sugars from carbon dioxide and water, releasing oxygen gas as a byproduct.
- Plants can make their own food and use it immediately or store it for use later.
- Green plant cells contain chloroplasts, which are organelles in which photosynthesis takes place.
- Chlorophyll is a molecule found in chloroplasts that is required for photosynthesis; it is responsible for the green color of plants and algae.
- During photosynthesis, carbon dioxide gas is consumed and oxygen gas is released. Photosynthesis requires light energy, generally from the sun.
- During cellular respiration, oxygen gas is consumed and carbon dioxide gas is released. Cellular respiration occurs continuously in living cells.
- Human beings are part of the earth's ecosystems. The activities of people can alter the equilibrium in ecosystems.
- To identify the independent variable, ask "What do I change?"
- To identify the dependent variable, ask "What do I observe?"
- To identify the controlled variables, ask "What do I keep the same?"

Note: It would be best to have students complete the lab, “Photosynthesis and Primary Productivity,” before doing this investigation.

Related Labs in This Guide

Suggested prerequisites:

- Cellular Respiration and the Carbon Cycle
- Determining Soil Quality
- Photosynthesis and Primary Productivity

Labs conceptually related to this one include:

- Yeast Respiration

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Changing the sample rate �(5.1)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Environmental studies require investigations both in the field and in the laboratory. Because the earth's environment is complex, an investigator in the field must collect a wide variety of data and look for patterns and correlations. When patterns or correlations are discovered, these can be further investigated in controlled laboratory environments. Terrariums are excellent closed systems for environmental studies, allowing the investigator to change one variable at a time, control other variables, and monitor multiple variables in an easily maintained system.

Student-designed investigations are important components of College Environmental Science courses, and long-term projects are appropriate. During this experiment, students become familiar with a test system, pose a hypothesis, and then design an investigation to test their hypothesis. This experiment provides some ideas for investigation and a structure to get students started with their inquiries. It also includes methods for reporting results, and you can choose which are appropriate for the classroom situation.

The test system for this lab is a closed system for examining factors that affect photosynthesis and cellular respiration. The end points (dependent variables) are the rate of change in concentration of CO_2 gas and O_2 gas. The rates of change in CO_2 gas and O_2 gas are used as end points because these factors are tightly coupled with plant growth and aerobic cellular respiration, often manifesting within minutes of changing the independent variable. These types of evidence of effects on plant growth and cellular respiration can be augmented with other evidence, such as rates of increase in plant mass, visual evidence of growth, or visual evidence of disease.

Some of the independent variables that could be investigated using the terrarium include the effect on the rates of photosynthesis or aerobic cellular respiration, or both, of the following: light intensity, light wavelength, light source types, elevated CO_2 gas in the atmosphere, acidic conditions, introduced organisms, fertilizers, toxins, soil type, and temperature. No doubt your students will have many more ideas for using this test system.

Pre-Lab Discussion and Experiment

Inform students they will be learning about a test system that will allow them to conduct their own investigations regarding environmental effects on photosynthesis and cellular respiration.

Help students brainstorm environmental issues that may affect plant growth.

Instructor Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment.

Some topical environmental issues that may affect plant growth include the following: global warming, greenhouse gas emissions, acidification of soils and water, pollution of waterways with nutrients and toxins, droughts, invasive species, invasive pests, and diseases. From this list, students should be able to pick a topic that interests them.

With this list of topics, address each one and identify parameters that could serve as independent variables in an investigation. For example, if a student is interested in the effects of global warming, a test of the system at elevated temperatures would be useful. Students interested in greenhouse gas emissions might test the effect of an atmosphere with elevated CO_2 or water vapor (humidity) levels. Students interested in acid rain could test the effect of acidic water on plant growth and the side effects on the environment, and so on.

List the sensors you have available that might be used in such investigations.

Tell students that after they learn how to set up and use the test system, they will be expected to:

1. Develop a hypothesis to test, identify the independent variables, the dependent variables, and the variables they will strive to control
2. Design an experiment or set of experiments to help them develop data related to their hypothesis.
3. You can then have students write a proposal and submit it to you for your approval and guidance. They can conduct the study, collect and analyze the data, draw conclusions, and report on their study. Students could report in a variety of ways, including a formal research report, an oral presentation, or a response to a set of questions that you design.

If necessary, review the process of photosynthesis and aerobic cellular respiration with your students. Refer to the Pre-lab Discussion section of the "Photosynthesis and Primary Productivity" experiment in this guide for details on such a review.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Purchase the small potted plants.

Suggested small plants include: tomato plant, basil, mint, or other herbs in small pots. Any plant in a pot small enough to fit into the EcoChamber™ will suffice.

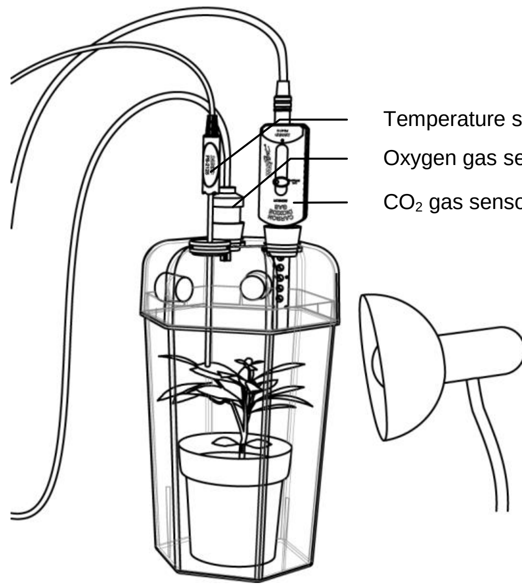
Safety

Follow all standard laboratory procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up



1. Put a fast-growing potted plant that has moist (not wet) soil into the EcoChamber.

2. Arrange the CO_2 gas sensor, O_2 gas sensor, and temperature sensor so they can detect changes inside the EcoChamber.

3. Seal the EcoChamber so it is airtight.

Hint: One way to be sure that the EcoChamber is airtight is to exhale several times into the empty EcoChamber to raise the CO_2 level of the air in the EcoChamber relative to the room air. Then seal the EcoChamber and monitor the CO_2 level for several minutes. After the reading stabilizes, the level should not drop. If it does, you probably have a leak. Once you have learned how to make the EcoChamber airtight, use this procedure in your investigations.

4. Start a new experiment on the data collection system. �(1.2)

5. Connect all three sensors to the data collection system. �(2.2)

Note: Use the sensor extension cable to connect the CO_2 gas sensor.

6. Set up appropriate displays to view the data while it is being collected.

Note: For longer investigations, you may need to decrease the sampling rate of the sensors. Choose a time interval that will provide adequate information while limiting the number of data points collected to a practical quantity. �(5.1) For example, if you choose to monitor the EcoChamber for 24 hours, you might set the sampling rate to 1 sample every 10 minutes. Or if you choose to monitor for a week, you might set the sampling rate to 1 sample every 30 minutes.

7. Set up a strong light source near the EcoChamber and shine it directly at the plant inside.

Collect Data

8. Start data recording. �(6.2)

9. Continue to record data with the light on for 15 minutes.

10. After 15 minutes, turn the lamp off and carefully cover the setup with an opaque cloth so the plant is in darkness. *Do not stop recording data.*

11. Record data with the plant in darkness for 15 minutes, and then stop data recording. �(6.2)

12. Save your experiment �(11.1) and clean up according to your instructor's instructions.

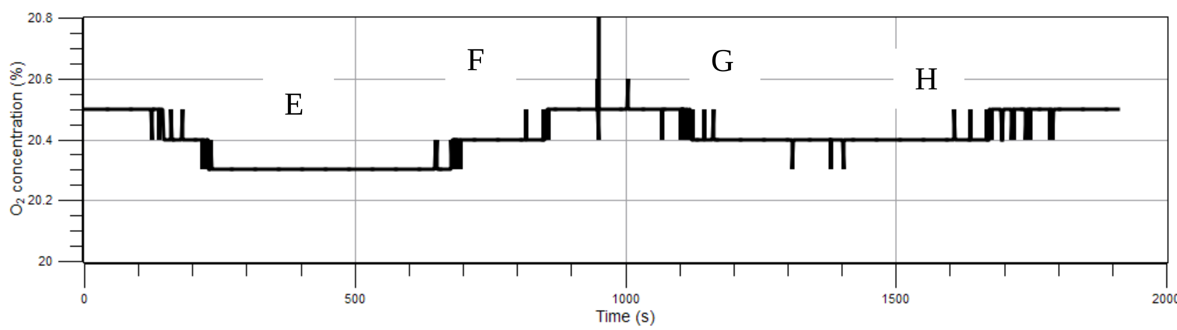
Data Analysis

1. Display your data as graphs. �(7.1.1)

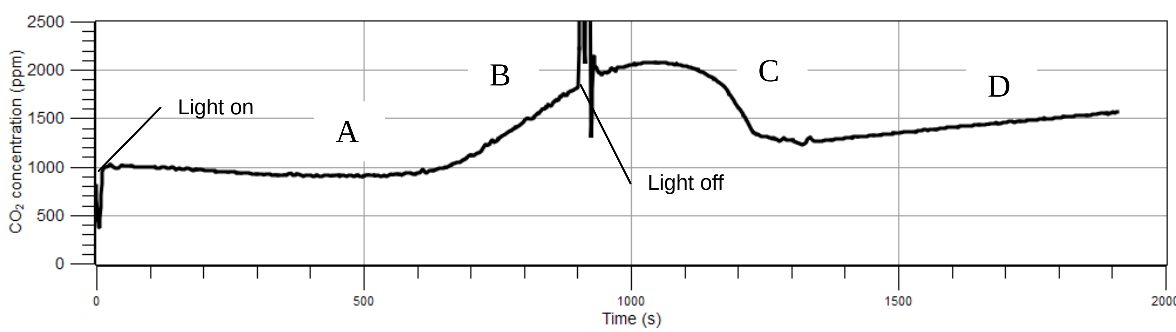
2. Adjust the graphs to fill the screen vertically, and adjust the x-axis to make the time scales equivalent between graphs. �(7.1.2)

3. Sketch your graphs. Label the overall graph, the x-axes, the y-axes, and include units on your axes.

4. Indicate on your graphs where you turned on the bright light and where you turned the light off and covered the EcoChamber with a cloth.



5. Label the areas on the graphs where the pattern of data changes with numbers or letters.



Analysis Questions

1. Which does the CO_2 gas concentration represent: the rate of aerobic cellular respiration, the rate of photosynthesis, or the combination of rates of aerobic cellular respiration and photosynthesis? Why?

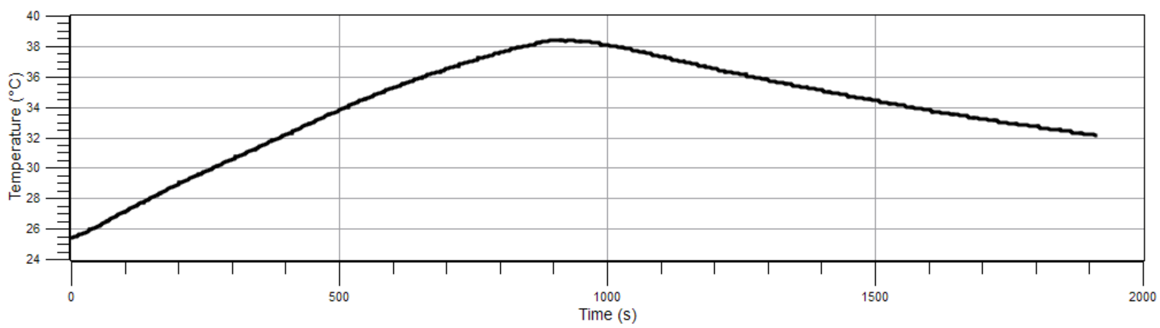
The CO_2 level represents the combination of aerobic cellular respiration and photosynthesis rates. This is because the plant is consuming CO_2 during photosynthesis, and at the same time, the plant and the soil organisms are producing CO_2 during cellular respiration. This can be accurately measured in a closed system.

2. Which does the O_2 gas level represent: the rate of aerobic cellular respiration, the rate of photosynthesis, or the combination of rates of aerobic cellular respiration and photosynthesis? Why?

The O_2 level represents the combination of rates of aerobic cellular respiration and photosynthesis. This is because the plant is producing O_2 during photosynthesis, and at the same time, the plant and the soil organisms are consuming O_2 during cellular respiration. This can be accurately measured in a closed system.

3. Why are the changes in CO_2 gas concentration more apparent than those of O_2 gas? *Hint:* Think about the relative levels of these gases in the atmosphere.

The changes in CO_2 gas concentration are more apparent than those of O_2 gas because of the relative amounts



of these gases in the atmosphere to start with. In air at sea level, CO_2 constitutes about 0.033% of the molecules in air, while O_2 constitutes 21%. To view an equivalent change in the absolute number of molecules of these gases, the scale of the graph showing O_2 concentration needs to be significantly more sensitive than the scale showing CO_2 concentration. For example, the CO_2 concentration in this example showed changes that more than doubled the concentration, while the O_2 concentration changed by 0.1%.

4. Discuss what was occurring in the areas where the pattern of data changed (label or letter the areas on your graph for easy reference).

Answers may vary. For this example:

A. This area represents the net productivity of the system under lighted conditions. Since the concentration of CO_2 gas is decreasing, it seems that the rate of photosynthesis under lighted conditions is slightly greater than the rate of cellular respiration.

B. This area really surprised me at first. I expected the CO_2 concentration to continue to go down under lighted conditions. Then I remembered that the CO_2 concentration represents a combination of the processes of photosynthesis and cellular respiration. So apparently, the rate of cellular respiration has increased more than the rate of photosynthesis. Taking into account that the temperature rose during the light period, this makes sense. The microorganisms in the soil could have contributed significantly to the levels of CO_2 concentration and their metabolic processes and those of the plant speed up under the warmer temperatures.

C. This area was the most interesting to me. After putting the EcoChamber in darkness, all of a sudden the CO_2 concentration dropped. This was the opposite of what I expected, because I thought photosynthesis would stop when I turned off the light. However, could this be evidence of the dark reaction of photosynthesis?

D. This area is more like what I expected when the EcoChamber was placed in darkness. This area shows only the effects of aerobic cellular respiration. It seems that the energy absorbed during the light reaction of photosynthesis has all been consumed during the dark reaction, so photosynthesis has shut down. Cellular respiration is free to drive up the CO_2 concentration, but at lower rates than in area B because the temperature is lower.

E, F, G, and H. These areas are interesting, but it is difficult to assess whether they have any real meaning because the changes are so small and are close to the limits of the oxygen gas sensor's reliability.

5. What was the independent variable in this experiment?

The independent variable in this experiment was light energy (presence or absence of it).

6. What were the dependent variables in this experiment?

The dependent variables were O_2 gas concentration, CO_2 gas concentration, and temperature.

7. What factors did you try to hold constant during this experiment?

Factors that were held constant included the volume of the container, the plant, the soil, and the closed nature of the system. It would be best to hold the temperature constant, but it rose under lighted conditions and fell under dark conditions.

8. How could you design an investigation that controls the change in temperature?

You could place the EcoChamber in a room-temperature or controlled-temperature water bath. The water would absorb much of the heat energy from the bright light, reducing considerably the change in temperature during the experiment. Also, using a fluorescent light source would generate less heat than an incandescent light source.

Synthesis Questions

Use available resources to help you answer the following questions.

Begin designing an experiment that investigates an aspect of the weather, using the EcoChamber. These questions will assist you in developing a proposal.

1. What question would you like to investigate using this system?

Here is where students will propose how they want to use this test system in their own investigation.

An example: I would like to remove the variables of soil organisms and change in temperature to get a better picture of what the plant itself is doing regarding photosynthesis.

2. What independent variables will you test to investigate the question? Why?

Students need to think about which factor they will change to find out its effect on the system.

In this example: the presence or absence of soil would be the independent variable and the use of a fluorescent light and water bath would help keep the temperature constant.

3. What will be the hypothesis to test this issue using the EcoChamber?

Students need to state the hypothesis they intend to test. The following are some examples of appropriate hypotheses:

- Using this test system, increased light intensity will result in increased rates of photosynthesis.
- Using this test system, increased acidity of the water in the soil will result in decreased rates of photosynthesis.
- Using this test system, increased air temperature will result in increased rates of aerobic cellular respiration.
- Using this test system, increased levels of carbon dioxide gas added to the atmosphere will result in increased rates of photosynthesis.
- Using this test system, removing the soil will reduce the amount of cellular respiration in the system and result in a better understanding of the photosynthesis in the plant.

You may need to guide students to create an appropriate hypothesis.

4. How will you design the investigation to test your hypothesis?

Students should state exactly what they plan to do in their investigation. The exact specifications of how they will change their independent variable should be stated. Examples of appropriate plans include the following:

- To vary the light intensity reaching the EcoChamber, the distance of the light source from the EcoChamber will be varied by set amounts. We will run 4 trials with the light source being pulled back from the EcoChamber 2 cm each time. We will run each trial for 15 minutes. We will put the plant in darkness for 5 minutes before starting each trial. The light sensor will record the effect on light intensity of this action, which will quantify our independent variable, light intensity. We will record carbon dioxide gas and oxygen gas levels to determine rates of photosynthesis and aerobic cellular respiration.
- The concentration of CO_2 gas will be increased by injecting a blast of it into the EcoChamber using a CO_2 cartridge bike tire inflator. We will run 2 trials, one at an ambient CO_2 gas concentration and one at an elevated CO_2 gas concentration. We will run each trial for 15 minutes. We will put the plant in darkness for 5 minutes before starting each trial. We'll use the CO_2 gas sensor to quantify our independent variable: CO_2 gas concentration. We will record CO_2 gas (which will become a dependent variable once the light is turned on) and O_2 gas concentrations to determine the rates of photosynthesis and aerobic cellular respiration.
- To control the soil and temperature variables, all the soil from the plant will be removed and a little water will be put in the bottom of the EcoChamber. The EcoChamber will be placed in a controlled water bath. Then we will conduct the experiment exactly as the first one was conducted.

You will need to guide students to create an appropriate design plan for their investigations.

5. How will you analyze the results of your experiment?

Students should state the types of comparisons and statistical analyses they will use.

For this example, you would compare rates of CO_2 gas production in both lighted and dark conditions with those in the first experiment.

6. What materials and equipment will you need to conduct your investigation?

Students should specify the materials and equipment they will need to a similar level of detail as that in the Materials and Equipment sections of these lab activities.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **The design of a research study generally includes:**

   A. A hypothesis to test
   B. A defined test system that controls variables
   C. A controllable independent variable
   D. A measurable dependent variable
   E. Control or baseline measurements
   F. **All of the above**

2. **In a scientific experiment, an independent variable is:**

   A. A variable that has nothing to do with other variables
   B. Something that changes in response to another variable
   C. **Something that you change to affect another variable**
   D. Something that you try to keep constant

3. **In a scientific experiment, a dependent variable is:**

   A. A variable that has nothing to do with other variables
   B. **Something that changes in response to changes in another variable**
   C. Something that you change to affect another variable
   D. Something that you try to keep constant

4. **In the test system in this experiment, the independent variable is:**

   A. Temperature
   B. **Light energy**
   C. Carbon dioxide gas level
   D. Oxygen gas level
   E. Both C and D

5. **In the test system in this experiment, the dependent variable is:**

   A. Temperature
   B. Light energy
   C. Carbon dioxide gas level
   D. Oxygen gas level
   E. **A, C, and D**

Extended Inquiry Suggestions

Have students conduct the experiment they designed in the Synthesis Questions section. Have students report on their experiment, including the hypothesis, the method, the results, and conclusions regarding why the results did or did not support their hypothesis.

Provide the opportunity for more than one student-designed experiment. In science, the answer to one question usually leads to more questions that seem interesting to explore.

13. Weather in a Terrarium

Objectives

Students demonstrate that a terrarium, a closed system, is an excellent tool for conducting environmental studies such as weather investigations. As part of this process, students

- ♦ Learn to use this closed system to change one variable at a time, control other variables, and monitor multiple variables
- ♦ Design additional investigations of weather using the terrarium

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Designing controlled investigations
- ♦ Determining the effect of a plant on the weather inside a terrarium
- ♦ Using sensor technology to monitor independent and dependent experimental variables

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	45 minutes

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Weather sensor
- ♦ Light sensor
- ♦ Sensor extension cable (2)
- ♦ EcoChamber
- ♦ Strong incandescent or full-spectrum fluorescent light source
- ♦ Fast-growing, small, potted plant

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- The difference between climate and weather
- To identify the independent variable, ask "What do I change?"
- To identify the dependent variable, ask "What do I observe?"
- To identify the controlled variables, ask "What do I keep the same?"

Related Labs in This Guide

Labs conceptually related to this one include:

- Investigating Specific Heat
- Insolation and the Seasons
- Photosynthesis and Cell Respiration in a Terrarium

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Starting and stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Saving your experiment �(11.1)

Background

Environmental studies require investigations both in the field and in the laboratory. Because the earth's environment is complex, an investigator in the field must collect a wide variety of data and look for patterns and correlations. When patterns or correlations are discovered, these can be further investigated in controlled laboratory environments. Terrariums are excellent closed systems for environmental studies, allowing the investigator to change one variable at a time, control other variables, and monitor multiple variables in an easily maintained system.

Student-designed investigations are important components of College Environmental Science courses, and long-term projects are appropriate. During this experiment, students become familiar with a test system, pose a hypothesis, and then design investigations to test the hypothesis. This experiment provides some ideas for investigation and a structure to get students started with their inquiries. It also includes methods for reporting results, and you can choose which are appropriate for the classroom situation.

The test system for this experiment is a closed system for examining factors that affect weather. The terrarium functions as a model for the earth and its troposphere. The dependent variables are temperature, barometric pressure, relative humidity, absolute humidity, and dew point. Some topics that could be investigated include the effect on the dependent variables of the following: light intensity, vegetation, water bodies, and land materials. No doubt your students will have many more creative ideas for what they would like to test.

Pre-Lab Discussion and Experiment

Inform students they will be learning about a test system that will allow them to conduct their own investigations regarding environmental effects on aspects of weather.

Note: This is a good "starter" experiment to help students learn to design scientific investigations because it is simple to set up and execute.

Help students brainstorm environmental issues that may affect weather.

Instructor Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment.

Some environmental issues that may affect weather include the following: diurnal changes, seasonal changes, deforestation, local water bodies, and urbanization. From this list, students should be able to pick a topic that interests them.

With this list of topics, address each one and identify parameters that could serve as independent variables in an investigation. For example, a student interested in the effects of deforestation could compare the effects on weather of dirt and a potted plant versus dirt without the potted plant. Students interested in effects of urbanization might test the effect of ground cover versus dark gravel. Students interested in seasonal variations could test the effect of the intensity of the light source, and so on.

Tell students that after they have a chance to learn about the test system, they will be expected to develop a hypothesis to test, identify the independent variables, the dependent variables, and the variables they will strive to control. They will be expected to design an experiment or set of experiments to help them develop data related to their hypothesis. They will be expected to write a proposal and submit it to you for your approval and guidance. Then they will conduct the study, collect and analyze the data, draw conclusions, and report on their study. Students could be expected to report in a variety of ways, including a formal research report, an oral presentation, or response to a set of questions that you design.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Purchase the small potted plants.

   Suggested small plants include: tomato plant, basil, mint, or other herbs in small pots. Any plant in a pot small enough to fit into the terrarium will suffice.

Safety

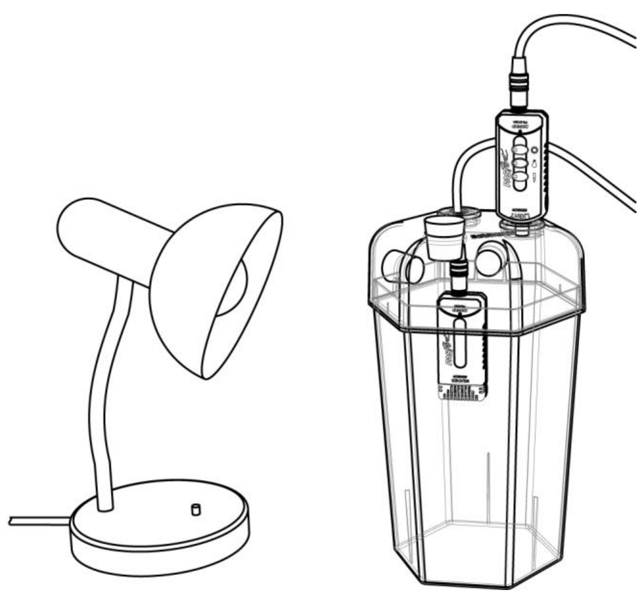
Follow all standard laboratory procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up

1. Arrange the weather and light sensors so they can detect changes inside the terrarium.
2. Seal the terrarium so it is airtight.
3. Start a new experiment on the data collection system. �(1.2)
4. Connect the sensors to the data collection system using the sensor extension cables. �(2.2)
5. Set up appropriate displays to view the data while it is being collected.
6. Set up a strong light source near the terrarium to shine directly at it. *Do not turn it on yet.*



7. What is the light source a model for? What is the terrarium a model for?

The light source is a model for the sun. The terrarium is a model for the earth and its troposphere.

Collect Data

8. Start recording data. �(6.2)

9. Continue to record data with the light off for 5 minutes. *Do not stop recording data.*

10. Turn the light on and continue recording data for 5 minutes. *Do not stop recording data.*

11. Open the terrarium and add a potted plant. Close the terrarium. Continue recording data for 5 minutes.

12. Stop recording data. �(6.2)

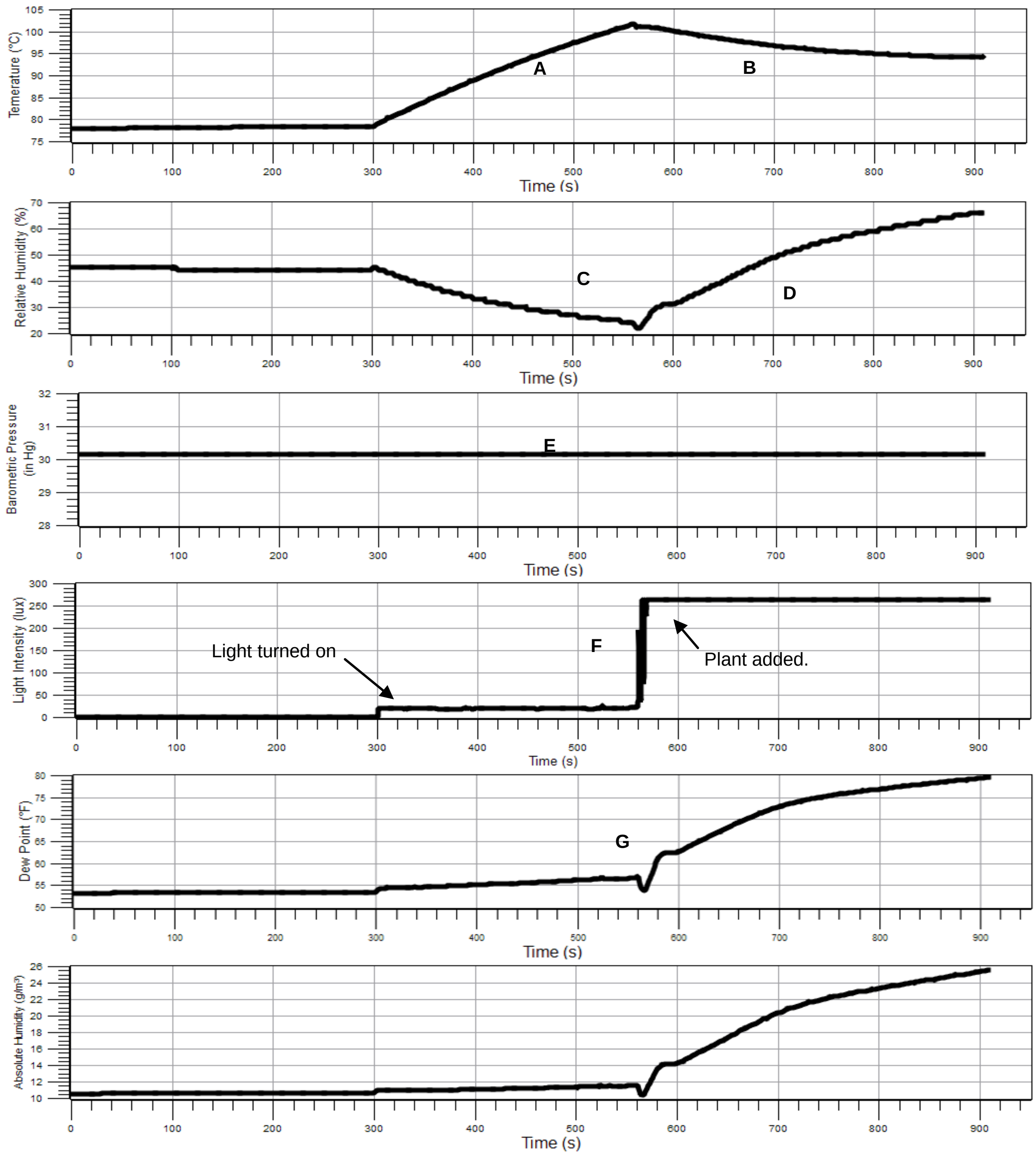
13. Turn off the light.

14. Save your experiment �(11.1) and clean up according to your instructor's instructions.

Data Analysis

1. Display your data as graphs, and adjust the graphs to fill the screen vertically. �(7.1.1)
Adjust the x-axis to make the time scales equivalent between graphs. �(7.1.2)

2. Sketch the graphs of light intensity, temperature, barometric pressure, relative humidity, absolute humidity, and dew point. Label the graphs and the axes, including the units and scales.



3. Indicate on the graph where you turned on the bright light and where you added the plant.

4. Label the areas you think are interesting on the graphs with numbers or letters.

Analysis Questions

1. Discuss the different patterns on the graphs. What do you think are explanations for the patterns?

For this example:

A. When we turned the light on, the temperature inside the chamber rose, probably because the light energy is converted to heat energy inside the chamber. Note: temperature variation will depend upon the type of light used.

B. After we added the plant, the temperature went down, probably because the plant absorbed the light energy for photosynthesis, so some of the light energy was converted to chemical energy in the plant rather than heat energy. Also, the plant was transpiring, adding water to the air as shown by the increase in relative humidity and absolute humidity when the plant was added. Energy is absorbed by the water as it changes phase from liquid to gas during transpiration.

C. When we turned on the light, the relative humidity went down. However, the dew point and absolute humidity went up a little. This might be because relative humidity depends on the temperature. Relative humidity is the percentage of water vapor that the air can hold at a given temperature.

D. After we added the plant, the relative humidity, absolute humidity, and dew point all went up dramatically. This is due to plant transpiration, respiration, and possibly evaporation of water in the soil.

E. The barometric pressure didn't change, because we didn't do anything to significantly change the number of molecules in the air inside the chamber.

F. It was interesting that when we put the plant in the chamber, the light intensity went up dramatically. I would have thought the light intensity would have gone up dramatically when we turned on the light and would have decreased when we added the plant. The increase is probably due to the position of the light sensor, which was out of the direct path of the light. The light that was not changed to heat energy just passed through the chamber (the chamber is relatively transparent to visible light. When we put the plant in it, it scattered the light rays so some of them bounced up to be detected by the light sensor. So even though the plant was absorbing a lot of the light, it looked like the light intensity increased because light rays were reflected towards the light sensor.

G. The dew point and the absolute humidity curves look identical. This could be because they basically are measuring the same thing: the amount of water vapor in the atmosphere. The dew point just reports this in terms of the temperature at which the water vapor would be at 100% saturation, whereas, the absolute humidity is in grams of water vapor/m^3.

2. What were the independent variables in this experiment?

The independent variables in this experiment were light energy (less or more of it) and vegetation (absence or presence of it).

3. What were the dependent variables in this experiment?

The dependent variables were temperature, humidity, absolute humidity, barometric pressure, and dew point.

4. What factors did you try to hold constant during this experiment?

Factors that were held constant included the volume of the container and the closed system.

Synthesis Questions

Use available resources to help you answer the following questions.

Begin designing an experiment that investigates an aspect of the weather, using this test system. These questions will assist you to develop a proposal.

1. How could you use the data you collected in this experiment in additional investigations?

You could use the data you collect in this experiment as a control, or to provide baseline values for comparison when you introduce experimental variables.

2. What question would you like to investigate using this system?

This is where students will propose how they want to use this test system in their own investigation.

3. What independent variables will you test to investigate the question? Why?

Students need to think about and should state which factor they will change to find out its effect on the system.

4. What will be a hypothesis for a test of this issue using this system?

Students need to state the hypothesis they intend to test. The following are some examples of appropriate hypotheses:

- Using this test system, increased light intensity will result in increased temperature.
- Using this test system, the addition of light-colored rocks will result in a lower air temperature than the addition of dark-colored rocks.
- Using this test system, the addition of water will result in lower temperature and higher humidity.
- Using this test system, condensation will occur if the system is cooled below its dew point.

You may need to guide students to create an appropriate hypothesis.

5. How will you design the investigation to test your hypothesis?

Students should state exactly what they plan to do in their investigation. The exact specifications of how they will change their independent variable should be stated. Examples of appropriate plans include the following:

- To vary the light intensity reaching the terrarium in a manner that mimics the sun, the intensity of the light source will be varied by set amounts. We will run 3 trials with the light source being positioned progressively further away from the terrarium. Each trial will last 5 minutes, allowing the chamber to cool for 15 minutes between trials. The light sensor will record the effect on light intensity of this action, which will quantify our independent variable, light intensity. We will record temperature, humidity, barometric pressure, and dew point to determine the effect on these weather parameters.

- To determine the effect of a water body on weather, we will add 1 L of room-temperature water to an empty terrarium. We will run 2 trials, one with an empty terrarium, and the other with water. Each trial will last 5 minutes, allowing the chamber to cool for 15 minutes between trials. We'll keep the amount of light entering the system constant as verified by the light sensor. We will record temperature, humidity, barometric pressure, and dew point to determine the effect of the water on these weather parameters.

You will probably need to guide students to create an appropriate design plan for their investigations.

6. How will you analyze the results of your experiment?

Students should state the types of comparisons and statistical analyses they will use.

7. What materials and equipment will you need to conduct your investigation?

Students should specify the materials and equipment they will need to a similar level of detail as that in the Materials and Equipment sections of these lab activities.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. **The design of a research study must include:**
   - **A.** A hypothesis to test
   - **B.** A defined test system that controls variables
   - **C.** A controllable independent variable
   - **D.** A measurable dependent variable
   - **E.** Control or baseline measurements
   - **F.** **All of the above**

2. **In a scientific experiment, an independent variable is:**
   - **A.** A variable that has nothing to do with other variables
   - **B.** Something that changes in response to another variable
   - **C.** **Something that you change to affect another variable**
   - **D.** Something that you try to keep constant

3. **In a scientific experiment, a dependent variable is:**
   - **A.** A variable that has nothing to do with other variables
   - **B.** **Something that changes in response to changes in another variable**
   - **C.** Something that you change to affect another variable
   - **D.** Something that you try to keep constant

4. **In the test system in this experiment, an independent variable is:**
   - **A.** Temperature
   - **B.** Light energy
   - **C.** Vegetation
   - **D.** Humidity level
   - **E.** **Either B or C**

5. **In the test system in this experiment, a dependent variable is:**
   - **A.** Temperature
   - **B.** Light energy
   - **C.** Vegetation
   - **D.** Humidity level
   - **E.** **Either A or D**
   - **F.** Either B or C

Extended Inquiry Suggestions

Have students conduct the experiment they designed in the Synthesis Questions section. Have students report on their experiment, including the hypothesis, the method, the results, and conclusions regarding why the results did or did not support the hypothesis.

Provide the opportunity for more than one student-designed experiment. In science, the answer to one question usually leads to more questions that seem interesting to explore.

14. Ecological Niche: Coral Reefs

Objectives

In this experiment, students predict which regions worldwide satisfy the basic requirements of temperature, salinity, and water depth for coral reef growth. They also:

- ♦ Compare their predicted habitat locations with the actual locations of coral reefs they find using available resources.
- ♦ Research threats to coral reefs and ways scientists have found to counter them.

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Using the databases in My World GIS™ to locate environments suitable for coral reefs
- ♦ Comparing the locations of actual coral reefs to those identified as suitable for coral reefs using My World GIS
- ♦ Using available resources, including the Internet, to list threats to coral reefs, as well as to identify ways people are trying to reduce or eliminate these problems and repair damage

Time Requirement

♦ Preparation time	30 minutes
♦ Pre-lab discussion and experiment	15 to 30 minutes
♦ Lab experiment	20 minutes

Materials and Equipment

For each student or group:

- ♦ Computer with My World GIS™ software installed
- ♦ Computer with access to the Internet
- ♦ Reference books containing information about coral reefs

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ The earth has many natural resources of great importance to human life. Some of these are readily renewable, some are renewable only at great cost, and some are not renewable at all.
- ♦ Disposal of waste materials has become a problem. Solving this problem requires systematic efforts involving both social and technological innovations.

- Salinity is the measure of dissolved salts in a body of water.

- Salts are ionic compounds composed of cations (positively charged ions) and anions (negative ions) so that the compound is electrically neutral (has no net charge). These ions can be inorganic, such as sodium (Na^+), organic, such as acetate (CH_3COO^-), monoatomic, such as fluoride (F^-), or polyatomic, such as sulfate (SO_4^{2-}).

Related Labs in This Guide

Labs conceptually related to this one include:

- Monitoring Water Quality

- Pollution and Harmful Algal Blooms

Using My World GIS

Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

- Launching My World GIS �(12.1)

- Adding a layer to the Layer List �(12.2.1)

- Arranging layers �(12.2.2)

- Hiding and showing a layer �(12.2.4)

- Editing the appearance of the a layer �(12.2.5)

- Opening a data table �(12.4.1)

- Selecting records from a table �(12.4.1.2)

- Opening the Analysis Window �(12.5)

- Selecting records from a layer by value �(12.5.1)

Background

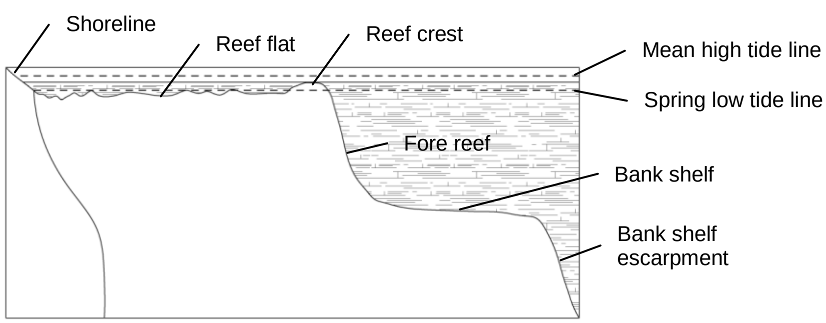
Corals, members of the animal phylum Cnidaria, are simple animals living colonially on the rocky substrate of continental shelves. These invertebrates are simple polyps with stinging cells called nematocysts. They live in dense colonies and excrete calcium carbonate to construct their housing structure, which builds up from the continental shelf until it forms a reef. Production of free-swimming larvae helps the reef grow in size as they attach themselves to new areas of rock or build the reef vertically. As the coral grows, the rocky substrate it is attached to changes as well, usually eroding.

There are hundreds of species of corals with a wide range of coloration. The color of the coral depends on its symbiotic relationship with various species of *zooxanthellae*, tiny unicellular algae that live inside the coral polyp and provide the polyp with most of its food. Since *zooxanthellae* photosynthesize, the coral must live in water shallow enough for sunlight penetration. Therefore, the symbiotic relationship of coral with *zooxanthellae* also limits where coral reefs are located.

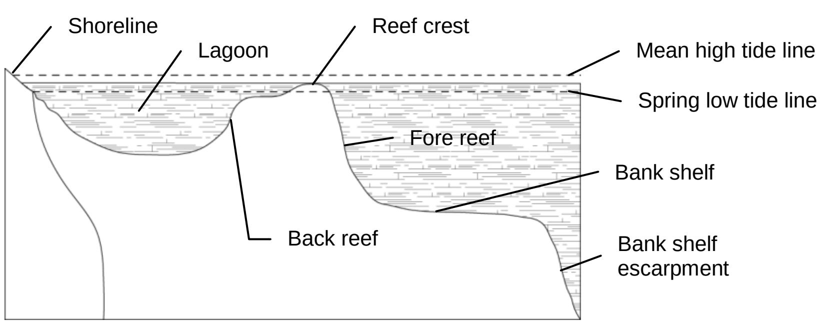
Coral reefs are important for many reasons and are a current focus of concern. Not only do they possess great intrinsic natural value, but coral reefs provide protection and shelter for many different species of fish and mollusks. Therefore, corals are responsible for increasing the biodiversity of the ocean. In addition, coral reefs protect coasts from strong currents and waves.

Types of Coral Reefs

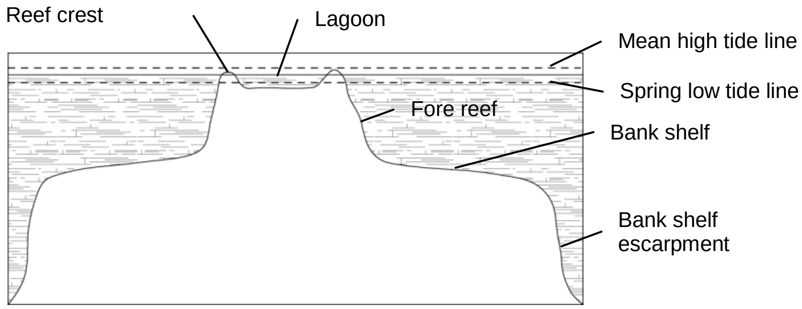
Coral reefs form as one of three major types: fringing reefs, barrier reefs, or atolls. Fringing reefs are the most common type and are found nearest to the shoreline. As the island or shoreline erodes, the coral continues to grow and a lagoon forms between the shoreline and the coral reef. At this point, the reef is called a barrier reef. Atolls are circular reefs that form when a volcano surrounded by a fringing reef subsides while the reef continues to grow upward toward the sunlit waters.



Fringing reef



Barrier reef



Atoll

Limiting Factors

While corals may be found living under various conditions, reef-building corals exist only in a narrow range of temperature, salinity, and depth conditions between 35 degrees north and 35 degrees south latitude. Coral reef polyps cannot survive in temperatures below 18 °C and prefer temperatures as warm as 31 °C. Sudden increases or decreases in water temperature can adversely affect coral reefs. Ideal salinity for supporting coral growth is 34 to 37 parts per thousand. Coral reefs develop in clean, warm, well lit water at ideal depths of 5 to 10 meters and even as deep as 40 meters. Some rare types have been found to depths of 90 meters (300 ft) according to Garrison (Oceanography 2002 Brooks/Cole).

Because of the narrow range of conditions that support coral reef building, corals can be used to gauge the health of the oceans and climate change. Fossil evidence of corals in rock strata has provided valuable information for paleoclimates and continental drift. When coral fossils are found in a rock layer, we can understand the climate during which the coral grew and possibly the location where the corals were growing. How the corals became buried and ended up in the rock strata can also be investigated. These fossils help us match up rock layers and piece together the geologic history of the rock.

Threats to Habitat

Scientists are concerned about coral reefs because of increased reports of coral bleaching during the past 20 years. Changes in temperature, pH, light penetration, or salinity can cause corals to become stressed, which then makes them expel their *zooxantheallae*. Since it is the *zooxantheallae* that give corals their color, a loss of these algae leads to a lighter or completely white appearance, which makes the coral look bleached. Coral bleaching is a sign of declining reef health, and the polyps may starve to death.

According to the National Oceanic and Atmospheric Administration, (NOAA), an estimated 10% of the world's coral reefs are classified as "degraded beyond recovery" and another 30% are in "critical condition." Natural events, such as coral disease outbreaks and hurricanes, are responsible for some of this degradation, but human activities seem to be the most prominent threat.

Although the concentration of carbon dioxide in the atmosphere is very small (less than 1% by volume), the level of carbon dioxide responds to cycles in plant productivity and humans burning fossil fuels. Increased levels of atmospheric carbon dioxide lead to elevated levels of carbon dioxide dissolved in the ocean as these two carbon reservoirs are in equilibrium with one another. Increased carbon dioxide in the ocean leads to a decrease in pH because more carbonic acid forms. This leads to a phenomenon known as "ocean acidification." (See carbon cycle reactions in the box below for further explanation.) Thus, global warming not only leads to increased temperatures and sea levels but also contributes to ocean acidification, a major threat to coral reefs across the globe.

Other human-induced threats to coral reefs include changes in water chemistry resulting from increased nutrient content through runoff from cities and agriculture, increased toxic metals through industrial pollution, and increased sedimentation due to silt runoff from agriculture. The suspended silt reduces sunlight penetration and decreases photosynthesis in the *zooxantheallae*.

Pre-Lab Discussion and Experiment

After students have reviewed the lab experiment, hold a classroom discussion. Ask students to comment from their reading on the following: Why are coral reefs important? What value comes from studying coral reefs? What environmental factors affect the growth of coral reefs? This would be a good time to view a video showing the biodiversity of coral reefs.

Assign the following question as homework for preparing for the lab experiment:

What physical and chemical parameters determine where corals will grow? That is, why do corals grow where they do? Record your ideas before you begin working on this experiment.

Corals grow where they do because salinity, temperature, and depth conditions are ideal for polyp growth. In particular, these include the following conditions: temperature 18 °C to 31°C; depth to 45 meters; salinity between 31 and 34 parts per thousand (ppt). Additionally, corals need nutrient-poor, clear water.

Instructor Tip: If this is the first time students have used My World GIS, guide the students through the tutorial that appears in the Welcome Window when you start the program (or you can access the Welcome Window from the Help menu).

Lab Preparation

To prepare for this lab, you could show a video about coral reefs or pictures of coral bleaching, or both.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

Set Up

1. Open the Coral Reefs project file (Coral Reefs.m3vz). �(12.1.1) The following layers are in the Layer List:

- ***Average Ocean Salinity & Temperature*** – displays the average salinity and temperature of the oceans.
- ***Elevation & Bathymetry*** – displays the elevation of landmasses and the depth of the ocean and ocean features.
- ***Countries*** – displays the outlines for all countries.
- ***Lines of Latitude & Longitude*** – displays parallels of latitude and meridians of longitude.

Collect Data

2. In the Analysis window, select records that are in the range that is supportive of coral growth. �(12.5.1) Convert these selected records into layers for each of the following parameters:

- Temperature
- Salinity
- Bathymetry

Note: Bathymetry measurements are negative numbers. For example, a coral reef located at a depth of six meters of water would have a bathymetry reading of -6 meters.

Data Analysis

Use your selected data in My World GIS to predict the locations of habitats that could support coral growth.

Part 1 – Visualize the temperature, salinity, and bathymetry data

1. Hide all layers but the following: �(12.2.4)

- Lines of Latitude and Longitude
- Countries
- The layer you created of ocean temperatures that support coral growth (records selected from the Avg. Ocean Salinity and Temperature table)

Note: To rearrange layers, drag the layer to the desired position. �(12.2.2)

Note: Make sure the "Fill Color" is set to "Temperature."

2. Describe what your selected temperature data revealed.

The ocean temperatures that support coral reefs are generally found between latitude 30°N and 30°S.

3. Hide the temperature selection and show the salinity selection. �(12.2.4)

Note: Make sure the "Fill Color" is set to "Salinity."

4. Describe what your selected salinity data revealed.

The salinity selection reveals that most of the oceans have appropriate levels of salinity to support coral reef growth.

5. Hide the salinity selection and show the Elevation and Bathymetry selection. �(12.2.4):

6. Describe what was revealed when you showed the selected bathymetry data.

There are not many data points in this database in the selected range. However, all data points occur around the shoreline of continents or islands. Coral reefs grow near shorelines of continents or islands.

Part 2 – Predict coral reef locations

7. Based on what you learned in Part 1, predict where coral reefs would be found. What is the latitude range in which you are likely to find coral reefs? Name 5 areas, using names of countries or island groups. Describe the general assumptions you made in making your predictions.

Answers will vary. Valid predictions include the shoreline of northern Australia, the islands of Indonesia, the islands of the Caribbean, the eastern shore of Central America, the shoreline of Southeast Asia, and the shoreline of New Guinea.Conditions supporting coral reef growth are between the latitude 30°N and 30°S.

8. Predict the oceanic regions where you would not expect to find coral reefs.

Answers will vary. However, locations above latitude 40°N and below 40°S would not be expected to support coral reef growth.

Analysis Questions

1. Find reference material that shows the location of coral reefs worldwide. (*Hint:* Use your textbook or search the Internet). Compare the actual locations of coral reefs to the predictions you made in Part 2 of where they might be found.

Answers will vary, but students should find that actual locations of coral reefs coincide with the global locations for the environmental conditions they selected in My World GIS, including the following: the shoreline of northern Australia, the islands of Indonesia, the islands of the Caribbean, the eastern shore of Central America, the shoreline of Southeast Asia, and the shoreline of New Guinea.

2. Compare the map of coral reefs to your prediction of where coral reefs would not be likely to be found.

Answers will vary. In general, students will not find coral reefs outside the global locations for the environmental conditions they selected in My World GIS. However, newer maps based on satellite observations will also designate some cold-water coral reefs.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Describe the structure of a coral reef and at least five types of organisms found there. Classify these organisms in terms of producers, primary consumers, and carnivores.

Coral reefs are mounds or ridges of living coral, coral skeletons, and calcium carbonate deposits from other organisms such as calcareous algae, mollusks, and protozoa. Coral reefs grow upward from the sea floor as the polyps of new corals cement themselves to the skeletons of those below. These provide support for algae and other organisms whose secretions serve to bind the skeletons together. The resulting structure provides a critical habitat for a wide variety of fish and marine invertebrates.

Most coral reefs are composed of coral that contains microscopic symbiotic algae (zooxanthellae). These complexes form the substrate on which the reef ecosystems are based.

The producers in coral ecosystems are mainly corals and their zooxanthellae, sea grasses, macro-algae and the microphytobenthos and pelagic groups such as the phytoplankton.

The primary consumers are herbivores, including several kinds of mollusca, sea urchins, and fish. The secondary consumers include filtering organisms, such as echinodermata; detritivores, such as crustaceans; and carnivores, such as fish.

2. Although coral polyps are animals and do not contain chlorophyll, why is healthy coral colored green or reddish brown?

Many types of corals have symbiotic relationships with algae, which can be colored green or reddish brown. The coral skeletons are transparent-to-translucent, so the color of the algae shows through.

3. When corals are stressed, they turn white, a phenomenon called coral bleaching. Why do they turn white? Are bleached corals dead? How can you tell?

When corals that have symbiotic relationships with algae get stressed, they expel the algae, which was the source of their color. The color of their exoskeletons is translucent-to-white. These corals are usually not dead. They normally can recover their symbiotic relationships with algae if the stressor is removed or lessened.

4. Conduct an Internet search for threats to coral reefs. List three threats.

Threats to coral reefs include abnormally high water temperatures, abnormally low water temperatures, abnormally low pH, sediment, excess nutrients in the water from runoff, cyclones, abnormal exposure to UV light, some diseases, and damage from excess harvesting or tourism.

5. Conduct an Internet search for restoration efforts with coral reefs. Describe one of these efforts.

Some examples of coral reef restoration efforts include the following:

- "Mineral accretion technology" is a method that applies safe, low-voltage electrical currents through seawater, causing dissolved minerals to crystallize on structures. The crystallized mineral grows into a white limestone, similar to that which naturally makes up coral reefs and tropical white sand beaches. This material is used to make robust, artificial reefs on which corals grow at very rapid rates. Coral reefs built this way are now growing in the Maldives, the Seychelles, Thailand, Indonesia, Papua New Guinea, Mexico, Panama, and Saya de Malha Banks in the Indian Ocean.
- Removal of coral predators
- Reintroduction of herbivores to reduce algal cover
- Culturing of coral fragments, resulting from hurricanes and other disturbances, in laboratory and field nurseries, to be transplanted onto degraded sites. Transplanting fragments of coral has been successful in the coral reefs of the Virgin Islands.

6. What do you think would be two effective ways to help conserve our coral reef resources?

Answers will vary, but effective ways might include: 1) reducing the nutrient runoff into the oceans; 2) using the methods mentioned in question 5 to repair reefs that have been physically damaged by storms or other abnormal weather conditions; and 3) raising awareness among tourists and commercial interests regarding the value and vulnerability of coral reefs.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. When corals become stressed and expel the symbiotic algae in them, the process is called:

- **A. Coral bleaching.**
- **B.** Coral erosion.
- **C.** Algal blooming.
- **D.** Zooxanthellae bleaching.
- **E.** Zooxanthellae erosion.

2. Why are coral reefs so vulnerable to damage?

- **A.** They have a slow growth rate.
- **B.** They are sensitive to increases in temperature.
- **C.** They live in tropical water.
- **D. A and B are true.**
- **E.** All of the above are true.

3. Which of these is *not* a current threat to coral reefs?

- **A.** Increased temperature
- **B.** Increased erosion and sedimentation
- **C.** Increased UV exposure
- **D.** Increased sea levels
- **E. Increased salinity**

4. Which area would have the *greatest* biodiversity?

- **A.** Open ocean water
- **B.** Pelagic zones
- **C. Coral reefs**
- **D.** Freshwater streams
- **E.** Vernal pools

5. The Great Barrier Marine Park is closest to what country?

- **A.** Cuba
- **B. Australia**
- **C.** Costa Rica
- **D.** Brazil
- **E.** Ecuador

6. The phenomena known as coral bleaching is caused by:

- **A. The loss of the coral's zooxanthellae algae.**
- **B.** The illegal harvesting of coral.
- **C.** The cooling of tropical oceans due to polar ice melting.
- **D.** Touching the coral polyps.
- **E.** The greenhouse effect.

Extended Inquiry Suggestions

Report on the latest findings regarding coral reef health. Which areas seem to be under greatest stress? What new information is being developed? Where are areas of upcoming research?

Visit coral reef exhibits or parks in your area. Document the types of coral represented and any signs of stress that have been noted.

15. Pollution and Harmful Algal Blooms

Objectives

Students investigate the life cycle, causes, and effects of an algal bloom. They also:

♦ Examine instances of major HAB events in the southern California and Florida vicinities.

♦ Use the information provided by the major HAB events and other layers to determine the species of algae responsible for blooms seen in southern California and Florida.

Procedural Overview

Student gain experience by conducting the following procedures:

♦ Analyzing scientific data from bloom survey programs in southern California and Florida

♦ Using information, such as nearby instances of harmful blooms and kill data, to determine whether the bloom is harmful, and, if so, what kind of algae is blooming

Time Requirement

Preparation time	10 minutes
Pre-lab discussion and experiment	30 minutes
Lab experiment	60 minutes

Materials and Equipment

For each student or group:

♦ Computer with My World GIS™ installed

♦ Harmful Algal Blooms.m3vz

Concepts Students Should Already Know

Students should be familiar with the following concepts:

♦ The importance of nutrient concentration with respect to algal blooms

♦ The function of the nutrients in the composition and life cycle of the bloom

♦ The four types of shellfish poisoning, their toxins, and their effects

♦ The life cycle of an algal cyst and how several cysts can form a bloom

♦ Light transmittance and absorbance and their roles in photosynthesis

♦ Scatter plots, correlation coefficients, negative and positive correlations

Related Labs in This Guide

Labs conceptually related to this one include:

♦ Ecological Niche: Coral Reefs

♦ Monitoring Water Quality

Using My World GIS

Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

♦ Opening a project file �(12.1.1)

♦ Hiding and showing a layer �(12.2.4)

♦ Opening a table �(12.4.1)

♦ Using the Zoom In Tool �(12.4.3)

♦ Using the Pointer Tool �(12.4.6)

♦ Using the Get Information Tool �(12.4.7)

♦ Opening the Analysis window �(12.5)

♦ Selecting records from a layer by distance relationship �(12.5.3)

♦ Creating a scatter plot �(12.6)

♦ Showing correlation statistics and best-fit lines �(12.6.1)

Background

Conditions that lead to harmful algal blooms

Harmful algal blooms (HABs) are produced by microscopic plants. Most algae and phytoplankton are not toxic or harmful in any way at normal concentration, but when conditions are right, they can bloom into large, dense patches, which visibly discolor the water and cause toxicity to animal life. These blooms are colloquially referred to as red tides. This term, however, is not entirely correct.

True red tides occur almost annually off the Florida coast, where thick, red blooms of algae can be seen. The microscopic dinoflagellates responsible for the red tide, *Karenia brevis*, carry photosynthetic pigments, and, as a result, they are seen as being red when their numbers exceed several millions per liter of sea water. The color of the algal bloom is dependent upon the photosynthetic pigments within each species of algae and can range in color from brown to yellow to green. Secondly, algal blooms are not often associated with the tidal movement of the ocean. Harmful species do not have to be so abundant as to discolor the water, and harmless species can grow to larger sizes than the largest red tides. Although it is often unclear what accounts for severe algal blooms, scientists have speculated that algal blooms are a result of nutrient overloading of the ocean from human activities.

Neurotoxins

Neurotoxins released by algae are responsible for toxic algal blooms. For example, *Karenia brevis* produces a group of neurotoxins called brevetoxins. These toxins are responsible for harmful effects in humans, marine organisms, and seabirds. In animals, neurotoxins affect the passage of sodium ions through the sodium ion channel of the cell membrane by exciting the membrane and depolarizing the cell. This causes the nutrient flow into and waste flow out of the cell to stop.

Four types of shellfish poisoning and one type of fish poisoning are recognized as health emergencies during algal blooms: paralytic shellfish poisoning (PSP), neurologic shellfish poisoning (NSP), diarrheal shellfish poisoning (DSP), amnesic shellfish poisoning (ASP) and ciguatera fish poisoning (CFP). The neurotoxins produced by each of the algal species associated with these illnesses collect in the digestive systems of organisms lower on the food chain, most specifically bivalve mollusks—clams, mussels, oysters, scallops, and so on.

Bivalve mollusks are filter feeders. As they feed on a toxic bloom, the toxins continue to build in their tissues. When a human being ingests the mollusk, for example, the toxicity is passed onto the higher-level organism. In the case of CFP, the toxicity continues up the food chain through several higher-level organisms, until other marine mammals, birds, or humans eat that organism. The CFP neurotoxin concentrates in predators as it travels up the food chain.

How harmful algal blooms form

According to the most popular theory for the formation of an algal bloom, a bloom caan start with a single cell, called a cyst. An algal cyst lies dormant just beneath the ocean floor, and if the cyst remains undisturbed, it can survive for years in this dormant state. When the nutrient concentration of the surrounding water increases and an abundance of dissolved oxygen is present, germination proceeds. Cysts can germinate only at certain times of the year when temperatures are warmer and increased amounts of sunlight are available to stimulate germination. The cyst breaks open and a swimming cell emerges. This cell reproduces through division within a few days. If conditions stay optimal, the swimming cells reproduce exponentially. At high concentrations, new cells—known as vegetative cells—form. When nutrients have been depleted, vegetative cells join in pairs to form one cell. This cell develops into a zygote and then a cyst, which falls to the ocean floor to lie dormant until conditions are conducive for the algae to germinate again.

The role of imaging

Algal blooms of all kinds are now monitored by satellite. Waters change colors to announce blooms that occur worldwide. Scientists search to find color schemes that help them identify potential harmful blooms. These images are widely available from NASA's earth observatory site for research and student groups and can be found in the Image of the Day collection.

Pre-Lab Discussion and Experiment

The evolution of an algal bloom is a complex blend of chemical, biological, and environmental influences. Plan to discuss with your students how each of these influences plays a part in the generation of a bloom. Additionally, plan to discuss how nitrates, nitrites, phosphates, and other compounds have an effect on the formation of a bloom.

Instructor Tip: Students will be relying on scatter plots to determine whether a bloom is occurring in a certain location. Plan to discuss correlation coefficients and the difference between negative, positive, and perfect correlations.

The Southern California Blooms data are derived from an accredited scientific project, which monitored blooms off the coast of California. These data are a compilation of 10 years of data collection. Some of the data have been removed from the layer to simplify finding relationships between variables. However, there is still a great deal of data in this layer, and students might not understand it all at first glance.

Instructor Tip: Encourage students to refer to the layer details provided and talk about how these measurements help locate algal blooms. The Southern California Blooms layer contains approximately 1,800 measurement points and might take a minute to load on a slower computer.

Instructor Tip: You can ask students to visit the Channel Islands Plumes and Blooms Project website for information about the data found in the project file. This can be found in the Student section of the website under PnB Data Files. From this page, students can follow a link to see an explanation of the data parameters found in the data set.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Be sure students can access the My World GIS program from their computers.

2. Make the project file, Harmful Algal Blooms.m3vz, available to students.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

Set Up

1. Describe the effects of each of the neurotoxins associated with the several types of shellfish poisoning.

ASP – Symptoms include nausea, vomiting, cramps, and diarrhea. Severe headaches, dizziness, and memory loss can result due to neurological damage to the hippocampus. Severe symptoms such as convulsions and coma can occur.

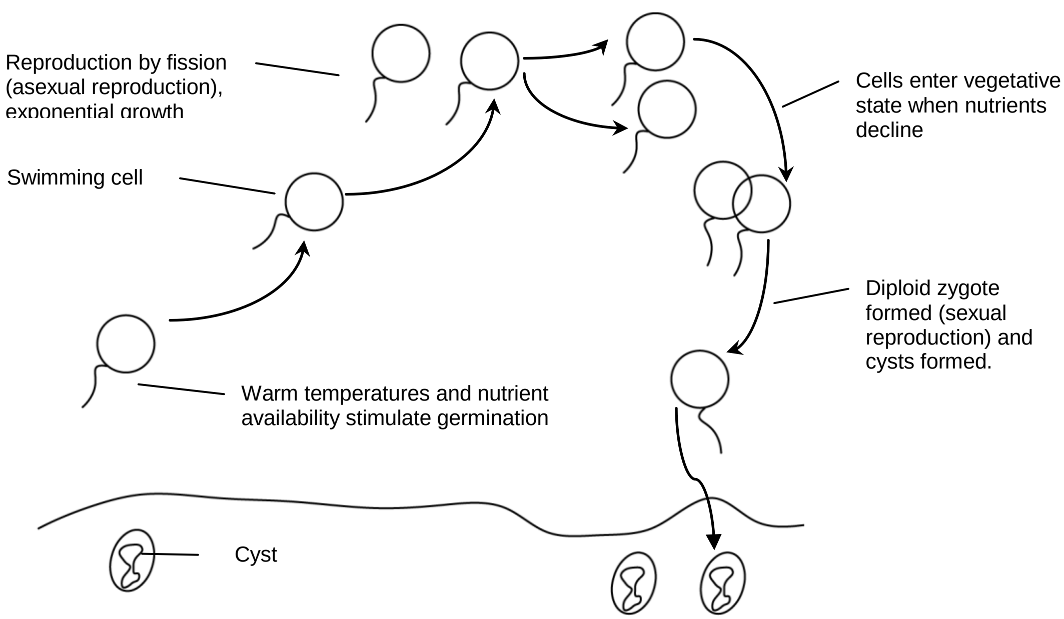
CFP – Symptoms include nausea, vomiting, headaches, numbness, hot-cold reversal, and hallucinations.

DSP – Symptoms include heavy diarrhea, nausea, vomiting, and cramps caused by serine and threonine phosphatase blockers.

NSP – Symptoms include nausea, vomiting, hot-cold reversal, headaches, and numbness.

PSP – Symptoms include numbness, weakness, and flaccid paralysis. Saxitoxin is fatal if inhaled.

2. Diagram and describe the growth of a bloom, starting from the single cell and ending with the bloom's termination.



Formation begins with a cyst. Algal cysts often lie dormant under ocean sediment. Germination of the cyst begins when the nutrient concentrations of the surrounding ocean are elevated. This is often when temperatures are warmer and increased sunlight concentrations stimulate germination. At this time, a swimming cell emerges from the cyst. These swimming cells exponentially reproduce if conditions stay optimal. When nutrient concentrations begin to decline, cells enter a vegetative state. Two vegetative cells then come together and join to form one cell. This cell develops into a zygote and then a cyst.

3. Open the HABs project file (Harmful Algal Blooms.m3vz). �(12.1.1) The following layers are in the Layer List:

- ***Major HAB events*** – displays all major HAB events in the United States between 1972 and 2007. All algal causes are listed (or can be inferred through the type of poisoning). This layer also denotes where certain kills (plant and animal) have taken place where the algae or poisoning type was not noted.
- ***Kills*** (annotation layer) – displaysa text caption of what has been killed by a specific algal bloom from the Major HAB events layer.
- ***Southern California Blooms*** – displays water quality data for sites off the coast of southern California. The fields in this layer are as follows:

Field Name	Field Content
Xmiss	Percent transmittance
PAR	Photosynthetic available radiation
COS/m	Conductivity
Chl a	Chlorophyll alpha concentration
PO4	Phosphates concentration
NO3NO2	Nitrate and nitrite concentration
TSM1	Total suspended materials
BSi	Biological silicates
LSi	Lithospheric silicates

- ***Chlorophyll anomalies*** – displays areas of unusually high chlorophyll concentration in the Florida area.
- ***U.S. States*** – displays an outline representing all 50 states.
- ***Countries*** – displays an outline of all world countries.

Data Analysis

1. In general terms, where are major HAB events most prominent— offshore from rural or urban areas? Why do you think this is so?

Major HAB events appear to be most prominent offshore from urban areas or large suburban areas. Examples include Seattle's Puget Sound and waters off of Miami and San Diego.

2. What marine life has been most drastically affected by HAB events? Why is this an issue? Use the Zoom In Tool if necessary to examine the annotation layer. �(12.4.3)

Some threatened species, such as the manatee and humpback whale, are being adversely affected by HAB events. Commercial fishing grounds are also being adversely affected because of a potential human hazard.

3. Use the Zoom In Tool to click and drag a box around the U.S. Gulf Coast area (from the east coast of Texas to the east coast of Florida). �(12.4.3) Show the Chlorophyll anomalies layer. �(12.2.4)

4. Chlorophyll anomalies are often monitored from space-based satellite photography. What colors do scientists look for to indicate an algal bloom?

Scientists generally look for any large discoloration in ocean water to indicate an algal bloom, most often red, brown, or green.

5. Is an algal bloom, as identified by satellite, enough information to determine whether there is danger to ocean life and human consumers of seafood?

No. An algal bloom identified solely from satellite imagery is not enough to determine whether there is a danger to ocean or human life. Blooms come in a variety of sizes and colors, and only a handful of these are harmful.

6. What other information should be used to determine whether a chlorophyll anomaly hosts a harmful algal bloom?

Information about HAB events in the surrounding areas is helpful in determining whether a harmful bloom is present. Nutrient concentrations around the chlorophyll anomalies are helpful in determining whether a bloom exists, but would give no indication that the bloom is harmful. Ideally, scientists would obtain samples of the bloom to test for the toxins associated with each alga.

7. The migration of predators that have ingested poisoned food at or near a chlorophyll anomaly can cause indicators of HAB events to appear as far as 100 miles away from the epicenter of the event. To examine this phenomenon, open the Analysis window �(12.5) and select records from a layer by distance relationship to create a layer that shows any major HAB events within 100 miles of chlorophyll anomalies. �(12.5.3)

8. Make this selection a new layer, give your layer a name or accept the default name, and click OK.

Note: You may choose any distance that you wish to fill into the query boxes. However, for the following questions, 100 miles works best.

9. The original layer recorded 81 major HABs events. How many of the original 81 events are within 100 miles of a chlorophyll anomaly? Does this seem like a lot? Explain.

Hint: To view the total number of HAB events in your new layer, open the table. �(12.4.1)

There do seem to be a lot of HAB events associated with the chlorophyll anomalies.

Out of the original 81 HAB events, 13 of the events are located near chlorophyll anomalies. The chlorophyll anomalies layer only covers the Florida area. There are approximately 21 HABs events extending from the east coast of Texas to the southern coast of North Carolina. Of these 21 events, 13 are within 100 miles of a chlorophyll anomaly.

10. How is it that an algal bloom as far as 100 miles away can be the culprit for animal poisonings?

Algal blooms can be responsible for poisonings several hundred miles away for many reasons. If conditions for growth are optimal, algal blooms can grow to span several hundred miles of ocean. A second possibility is transport by ocean current. When blooms first begin to develop, many swimming cells can be present without the bloom being visible. These swimming cells can be transported several hundred miles by ocean currents, and can be transported in the ballasts of ships. Cells can also be transported through the food chain. Filter feeders, such as bivalve mollusks, accumulate poisons over time. An animal much higher on the food chain, such as the humpback whale, might ingest an organism that has accumulated toxins in its tissues and then migrate to another part of the ocean. When this higher-level organism is reported dead as a result of a deadly bloom, it can be miles away from the point of origin.

11. Use the Pointer Tool to determine the type of events that occurred within 100 miles of a chlorophyll anomaly. �(12.4.6) The algae or type of shellfish poisoning associated with the HAB point will show in a legend to the right side of the map.

12. What are the most prominent types of poisoning in the Florida state area? Why is this problematic, especially in a state such as Florida?

The most prominent type of poisoning in the Florida area is NSP. Neurologic shellfish poisoning is especially concerning in a place such as Florida because of the amount of tourism coming in and out of Miami and other urban areas. Also, Florida’s fishing industry is one of the largest in the nation, and seafood is a heavily consumed item, which increases the chance for infection. Additionally, scuba diving and water sports are popular in Florida’s waters. Because algal blooms can exist without being visible, it is possible for humans to accumulate toxins in their tissue during increased water sport activity.

13. Hide the Chlorophyll anomalies layer. �(12.2.4)

14. Show the Southern California Blooms layer. �(12.2.4)

15. Click to highlight the Southern California Blooms layer and use the Zoom To Active Layer tool to zoom to the data. �(12.4.4)

16. Use the Pointer Tool to examine the values of chlorophyll alpha (Chl a) in the area. �(12.4.6)

17. Open the data table for the Southern California Blooms layer. �(12.4.1) Sort the values in the Chl a column in descending order. �(12.4.1.1)

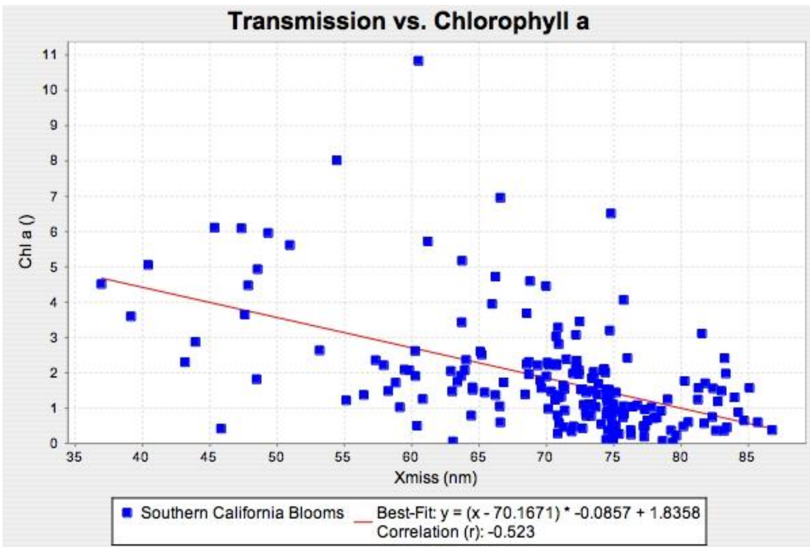
18. Carefully review the values for Chl a. Are any of these values unusually high (greater than 3)? Do these high values indicate a bloom?

At 164 different points, the Chl a concentration is greater than 3 (µgl/L). 49 of these points are 6 (µg/L) or more. These 164 chlorophyll anomalies are logical locations for blooms.

19. Create a scatter plot of Chl a versus each of the major parameters in the Southern California Blooms layer (PAR, PO4, and so on) and discuss whether a bloom could be occurring. �(12.6) Show the best-fit line for the graph. �(12.6.1)

a. Create a scatter plot for the Xmiss parameter versus Chl a, and explain how the parameter might indicate a bloom. �(12.6)

Note: Xmiss is an abbreviation for light transmission (%).

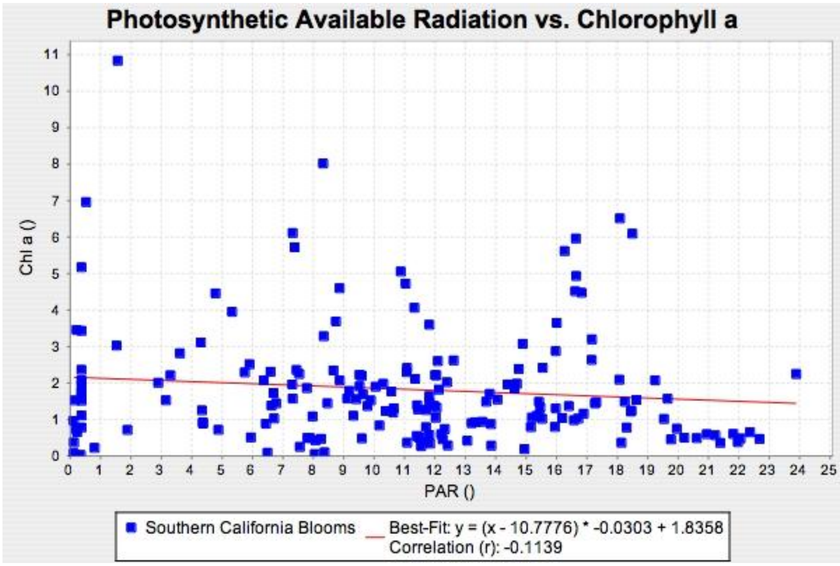


Example scatter plot showing the Xmiss parameter

Transmission of green light decreases as more algae grows and blocks the path of the beam of light. Scientists often use this parameter as one of the strongest indicators of a bloom.

b. Create a scatter plot for Chl a versus the PAR parameter and explain how the parameter might indicate a bloom. �(12.6)

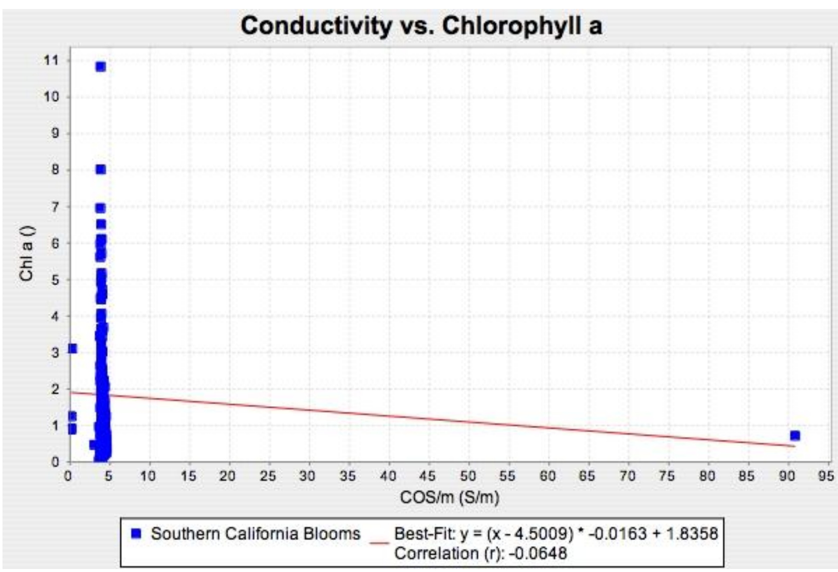
Note: PAR is an abbreviation for photosynthetic available radiation or photosynethetically active radiation and refers to the amount of light available for photosynthesis.



Example scatter plot showing the PAR parameter

Photosynthetically active radiation is important for plant growth, especially in areas that are low in sunlight. However, southern California and its surrounding waters receive plenty of sunlight all year round. This parameter is important but not a discriminating factor in the formation of algal blooms in these areas.

c. Create a scatter plot for Chl a versus the Conductivity parameter versus and explain how the parameter might indicate a bloom. �(12.6)

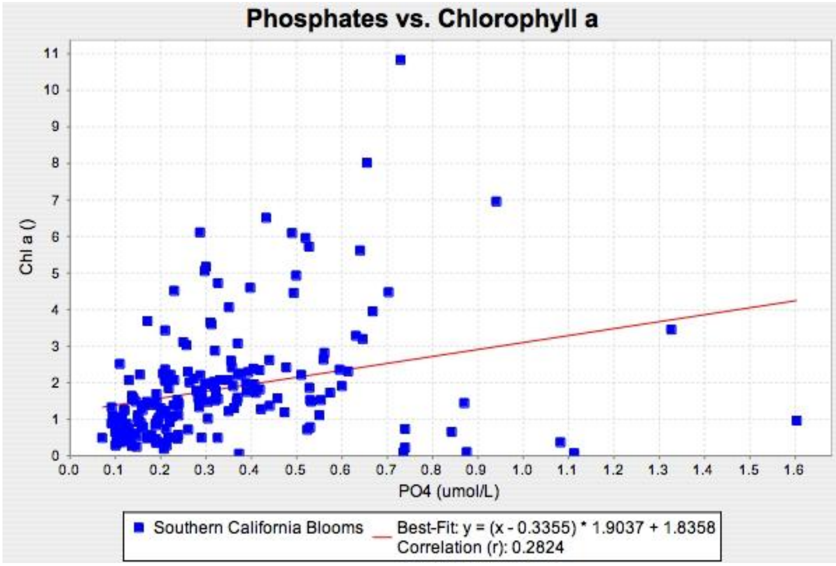


Example scatter plot showing the Conductivity parameter

Even when large amounts of runoff are present, the ocean is very salty. The conductivity is unlikely to change much.

d. Create a scatter plot for Chl a versus the PO4 parameter and explain how the parameter might indicate a bloom. �(12.6)

Note: PO4 is an abbreviation for phosphates.

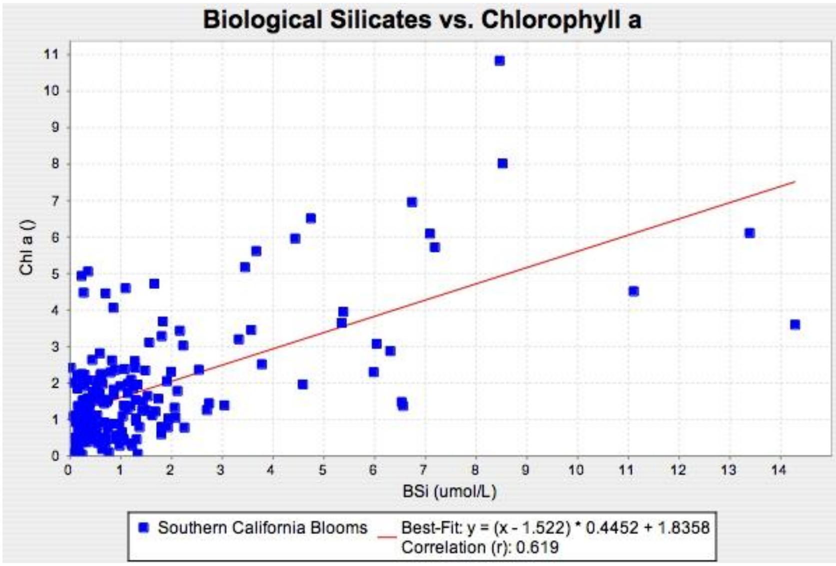


Example scatter plot showing the PO4 parameter

Phosphate from field fertilizers acts in much the same way as nitrate and nitrite compounds. Phosphate, however, acts much more as a limiting factor to plant growth than its nitrate and nitrite counterparts. Phosphate concentration might indicate a bloom.

e. Create a scatter plot for Chl a versus the BSi parameter and explain how the parameter might indicate a bloom. �(12.6)

Note: BSi is an abbreviation for biological silicates.

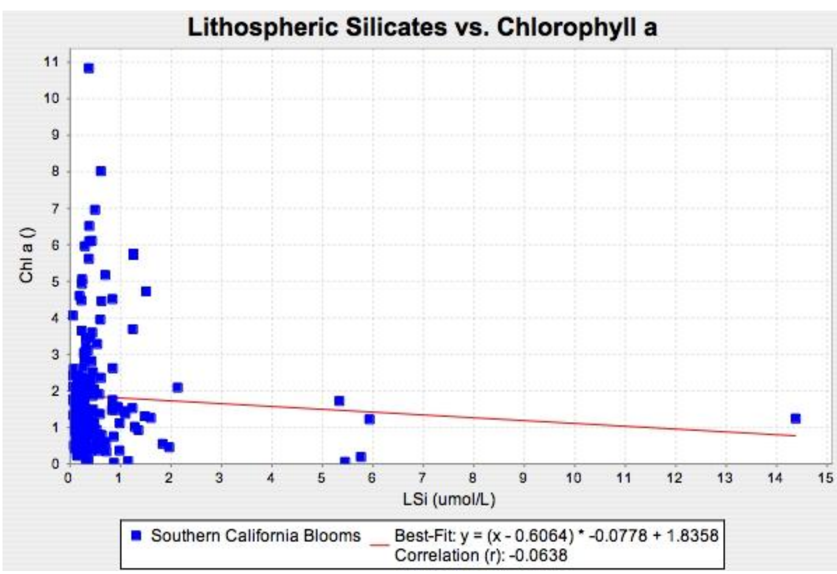


Example scatter plot showing the BSi parameter

Biological silicates are important in the composition of zooplankton shells. As more phytoplankton becomes available, more zooplankton is present. This might be indicative of a bloom.

f. Create a scatter plot for Chl a versus the LSi parameter and explain how the parameter might indicate a bloom. �(12.6)

Note: LSi is an abbreviation for lithospheric silicates.

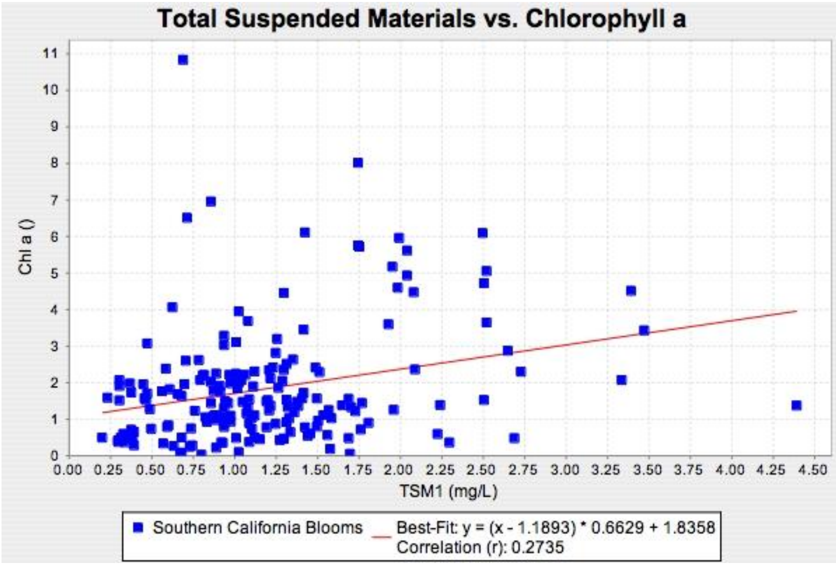


Example scatter plot showing the LSi parameter

Silicon from the lithosphere is not important in the composition of zooplankton. Algal blooms are not affected by LSi.

g. Create a scatter plot for Chl a versus the TSM1 parameter and explain how the parameter might indicate a bloom. �(12.6)

Note: TSM1 is an abbreviation for total suspended materials.

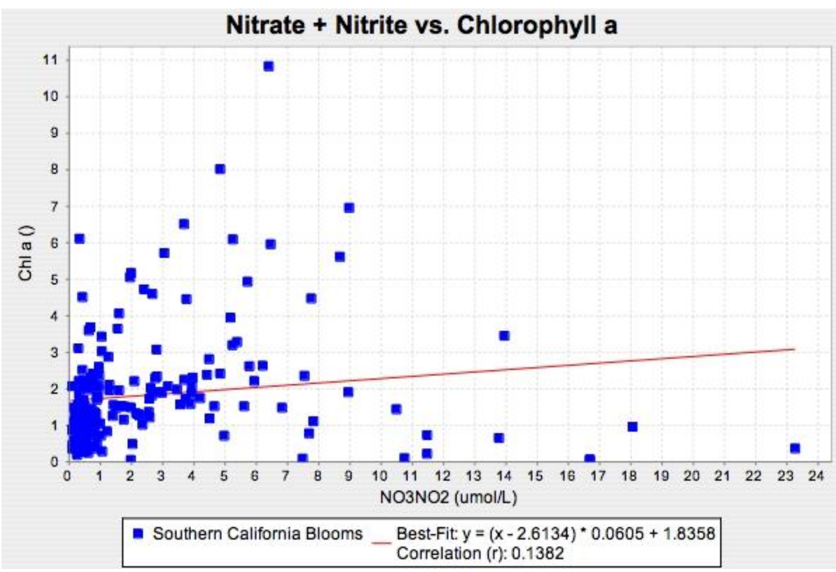


Example scatter plot showing the TSM1 parameter

Total suspended material can be of several different origins. Suspended material can be phytoplankton, zooplankton, or eroded soil in the water. The correlation here is not high, but in conjunction with the other parameters, this might be suggestive of a bloom.

h. Create a scatter plot for Chl a versus the NO3 NO2 parameter and explain how the parameter might indicate a bloom. �(12.6)

Note: NO3 NO2 is an abbreviation for nitrate plus nitrite.



Example scatter plot showing the NO3 NO2 parameter

Plants require nitrate and nitrites for growth. These compounds are present in the fertilizers that people use at home to fertilize lawns and gardens. High concentrations of nitrate and nitrites benefit blooms.

20. Show the Major HAB events layer again. �(12.2.4)

21. To examine this phenomenon, open the Analysis window �(12.5) create a layer that shows any major HAB events within 100 miles of the Southern California Blooms data. �(12.5.3)

21. How many HAB events are present in the vicinity of the blooms observed in southern California? Zoom out if necessary. �(12.4.3)

There are only two HABs events within 100 miles of the Southern California Blooms data.

Analysis Questions

1. Based on all of the information you have compiled, is there a bloom taking place off the coast of southern California? Explain why using information from the scatter plots you created.

Based on the water quality data provided by the scatter plots, an algal bloom in southern California is very likely. High volumes of nutrients required for bloom growth are present, including nitrates, nitrites, and phosphates. Additionally, the PAR levels are relatively low, suggesting that there is something blocking the light entering the ocean. The biological silicates scatter plot may indicate an increased level of zooplankton, which is strongly associated with an increased level of phytoplankton, further suggesting that phytoplankton may be block and absorbing most PAR. Furthermore, the chlorophyll anomalies observed in the area, combined with all of this data, provides a strong case for the presence of a bloom.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Determine whether the bloom you identified above is harmful. Explain why or why not. If the bloom is harmful, identify the algae that are blooming and explain your reasoning.

Chlorophyll anomalies from the southern California data stretch for approximately 30 miles SW. The proximity of the single ASP and NSP events within 100 miles may suggest that this bloom is harmful. However, because the rate of incidence is so low, it is unlikely that this bloom is a harmful one. Additionally, there are no wildlife kills in close proximity to the bloom to suggest a HAB.

2. Using the same reasoning that you did above, can you successfully identify any of the algae that might be responsible for the chlorophyll anomalies in Florida? If you cannot, explain why not.

An NSP bloom appears to be responsible for the chlorophyll anomalies seen in Florida. The prevalence of NSP reports within 100 miles of Florida's chlorophyll anomalies (5 out of 7) suggests that *Karenia brevis* is the responsible alga. Wildlife kills in close proximity to NSP reports suggest that these deaths were a result of a HAB.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Biotic potential refers to:

- **A. The maximum reproductive capacity of a given population.**
- **B.** The impact of a population on the environment.
- **C.** The maximum survivability for offspring.
- **D.** The crude birth rate of a given population.
- **E.** None of the above.

2. Algal blooms are most often a result of excess:

- **A.** Nitrates.
- **B.** Nitrites.
- **C. Phosphorous.**
- **D.** Silicates.
- **E.** Carbon.

3. Algae usually produce via:

- **A.** Sexual reproduction.
- **B. Asexual fission.**
- **C.** Budding.
- **D.** Allogamy.
- **E.** Parthenogenesis.

4. More than ____ percent of unusual marine deaths are associated with HABs.

- **A.** 10%
- **B.** 20%
- **C.** 35%
- **D.** 40%
- **E. 50%**

5. Physical ailments associated with the several types of shellfish poisoning do *not* include:

- **A.** Respiratory difficulty.
- **B.** Gastrointestinal symptoms.
- **C. Cancer.**
- **D.** Neurological symptoms.
- **E.** Both B and C.

16. Biodiversity and Native Species

Objectives

Students collect and analyze field data in order to monitor local native species of plants and animals. They also:

- Identify native species of plants and insects.
- Learn standardized procedures that allow investigations to be compared.
- Use the collected data to determine the population patterns of a species.

Procedural Overview

Students gain experience conducting the following procedures:

- Using quadrats to measure population numbers of plant and animal species
- Collecting temperature, light intensity, and global positioning system (GPS) data in the field
- Defining data types for research studies involving multiple research groups
- Visualizing and analyzing group field data using My World GIS™

Time Requirement

♦ Preparation time	45 minutes (or longer, depending on your study area)
♦ Pre-lab discussion and experiment	45 minutes
♦ Lab experiment	Two 90-minute sessions

Materials and Equipment

For each student or group:

- Mobile data collection system
- GPS position sensor
- Light sensor
- Temperature sensor with sensor extension cable
- Computer with My World GIS™ installed
- Spreadsheet program such as Microsoft Excel®
- Field guides of native plants and insects in your area
- Pictures of common native species in your area
- Tape measure
- Colored tape
- Graph paper
- Pen, pencil, or colored pencils
- Ruler
- Clipboard or notebook (writing surface)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- A great diversity of species increases the chance that an ecosystem can survive large changes or challenges.
- Primary productivity is the total amount of new organic matter produced by photosynthesis.
- The position of any point on the Earth can be specified by two numbers, longitude and latitude.
- A quadrat is a rectangular area of a habitat, randomly selected, used for ecological or population studies.
- Density d is the number of individuals n per unit area, or $d = n/m^2$ for an area of one square meter.
- Frequency is the number of occurrences of an individual in a given area:

$$\text{Frequency} = \frac{\text{number of quadrats in which a species ocurs}}{\text{number of quadrats examined}}$$

- Density and frequency can be used in describing change in species distributions. Ratios, equations, graphs, and scatter plots are various ways to create and visualize this type of data.
- Scientists try to observe as wide a range of parameters as possible to discern patterns.
- Considering whether and how two variables are correlated requires inspecting their distributions, such as in scatter plots.
- A correlation between two variables does not mean that one causes the other.
- Both percentages and actual counts have to be considered when comparing different groups. Using either by itself could be misleading.

Related Labs in This Guide

Prerequisites:

- "Weather in a Terrarium" and "Sunlight Intensity and Reflectivity" develop the skills needed to use the sensor and data collection system in this investigation.
- "Plate Tectonics," "Ecological Niche: Coral Reefs," "Human Population Dynamics," or "Acid Deposition and Natural Water Bodies" have fully developed project files, or are easy, basic labs that use the databases in My World GIS. Students can gain necessary My World GIS skills using the tools and program functions in these activities before building their own project in this one.

Labs conceptually related to this one include:

- Biodiversity and Invasive Species
- Monitoring Water Quality

- ♦ Determining Soil Quality
- ♦ Sunlight Intensity and Reflectivity
- ♦ Weather in a Terrarium

Using Your Data Collection System and My World GIS

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting multiple sensors to your data collection system �(2.2)
- ♦ Selecting a measurement range on the light sensor �(4.3)
- ♦ Monitoring latitude, longitude, and light intensity without recording �(6.1)
- ♦ Displaying data in a digits display �(7.3.1)
- ♦ Adding a variable to a digits display �(7.3.2)
- ♦ Launching My World GIS �(12.1)
- ♦ Importing a new data file into the Data Library �(12.1.2)
- ♦ Importing a data file or map from the Internet �(12.1.3)
- ♦ Saving your project �(12.1.4)
- ♦ Adding a layer to the Layer List �(12.2.1)
- ♦ Arranging layers �(12.2.2)
- ♦ Hiding and showing a layer �(12.2.4)
- ♦ Editing the appearance of a layer �(12.2.5)
- ♦ Displaying a histogram �(12.4.2)
- ♦ Creating a scatter plot �(12.6)

Background

Biodiversity refers not only to the variety of species within a given area, but to two other important factors as well: 1) genetic diversity within a given species population and 2) the variety of ecosystems across a geographic area. Ecological health depends on maintaining a diversity of life forms. Diversity supports a system's resilience, that is, its ability to adapt and cope with change.

Native species have evolved to make the best and most stable use of the existing resources. Healthy ecosystems build soil, prevent erosion, and store and cycle nutrients. They provide economic benefits through such valuable products as wood fiber, foodstuffs, dyes, resins, oils, and medicines. Other benefits and services provided by biodiverse ecosystems include: maintenance of air quality; maintenance of water quality; pest control; detoxification and decomposition of wastes; pollination and crop production; climate stabilization; prevention and mitigation of natural disasters; provision of food security; provision of medications; income generation; and spiritual and cultural significance.

To better understand the biodiversity in an ecosystem, it is necessary to conduct quantitative studies of the various species that inhabit it. It is also important to document the environmental factors and interdependence that exists among the living beings of the community. Environmental scientists have developed standardized procedures to conduct investigations that can be compared with each other. This experiment presents one typical approach for the study of biodiversity.

Pre-Lab Discussion and Experiment

Prior to doing the lab experiment, perhaps even weeks or months ahead of time, ask students to conduct research to learn which native species live in your area. Ask them to find locations that provide examples of these native species. If you do not have an appropriate area near your school, you will need to plan a field trip to the target area. Remember to contact the authorities and ask for permission prior to performing a study there.

In a brainstorming session, determine the 5 species of plants and 5 species of insects the class will study. If you are planning to compare data with the data collected in the "Biodiversity and Population Density of Invasive Species" experiment, be sure that some of the native species are included in the lists for both activities.

Assign a code to each species. Determine a short list of substitute species in case the species you select are not represented in your chosen research site.

Talk to students about the importance of the analysis and the connections that need to be made between certain measurements, such as pH and plant type.

Review the equations for density and frequency.

Work with students to set up a standardized protocol for their study so their measurements and observations can be compared with each other (see the arrangement of the sample data in Table 3).

Pre-Lab Homework (use available resources to help answer):

1. Find the density for the following measurement: You counted a total of 6 spikerush plants in a square measuring 10 cm x 10 cm. The plants seem to be distributed similarly over a large area. What is their density per square meter? (Show all work.)

10 cm x 10 cm = 100 cm^2
1 meter = 100 cm
1 square meter = 100 cm x 100 cm = 10,000 cm^2

$$\frac{6 \text{ spikerush plants}}{100 \text{ cm}^2} = \frac{x \text{ spikerush plants}}{10{,}000 \text{ cm}^2}$$

x = 600 spikerush plants in 1 square meter

2. Your class examined a total of 90 quadrats. Spikerush plants were found in 9 of these quadrats. What is the frequency of spikerush plants in this area? (Show all work.)

The frequency of spikerush in this area is 9/90, or 0.1.

3. List 5 native species that are common in your area.

Answers will vary. Online resources are readily available to help students identify these species.

4. Which do you think will be the most numerous of the 5 species your class has selected to study? Why?

Answers will vary according to student predictions. They should at least predict one of the species the class has selected to study and record a plausible reason.

The Research Protocol

1. Ask students to assess the population density of all 5 plant and insect species and take soil, temperature, light intensity, and location data within several 1-meter-square quadrats. Students should record data for as many quadrats as the time allows, but each student should collect data from a minimum of three to five randomly selected areas.

2. After collecting data, students will return to the classroom and enter their data into a central database file. Ask students to transfer their field data into a table in a spreadsheet (see Table 3). Make sure all students have access to the spreadsheet from the computers they are working on.

Note: The best way to manage this data input is to create a master spreadsheet on one computer where students take turns entering their data (see Table 3).

3. Review this composite data file to locate and correct errors in data entry. For example, note that the latitude entered in Table 3 for the first quadrat is incorrect when compared to the rest of the latitude entries; to show the correct location, it should begin with "38.803," but begins with "38.080."

Then make this file available to students for importing into My World GIS for analysis.

Instructor Tips

- The "Biodiversity and Population Density of Invasive Species" experiment could be conducted just after or concurrently with this one, so students can compare the data.
- The area you select for observation contains living organisms and may be private property. Be sure to obtain permission from property owners and remind students to be respectful of the organisms there.
- Choose easily identifiable species of insects and plants in an area where you expect to see a fair degree of variance.
- On site, before beginning data collection, verify that the species you have decided to study are present. If not, substitute a species that is present.
- Be sure to bring magnifying glasses and dissecting scopes (if available) to the research site, as well as field guides for the flora and fauna of your area.
- The ideal time of year for this experiment is in the spring, when flora is abundant and more easily identified through their flowers.

Depending on the time you have available and the ability of your students to inquire independently, you may choose to go through the analysis questions via either one of the following methods:

- Run through the analysis questions with the class using the completed quadrat data on your instructor computer. This could be accomplished by projecting your computer’s map view to the front of the class and performing the analysis at the direction of your students.
- Distribute the merged layer or project file via email or local area network (LAN) to each student group and give students time to work through the data analysis and end-of-lab questions in their small groups.

Lab Preparation

These are the appropriate preparations prior to the lab:

1. Perform an Internet search for lists of native species in your area. Find pictures of these species.
2. Find a suitable site for the field study. It should be accessible by the public, in a natural preserve (not cultivated), and a safe place for students to work.
3. Identify likely candidate species for study. Although you will be asking students to do this part, you will need to guide them to select a suitable location and appropriate species that would assist their learning.
4. Set up a field trip. Ideally, the study site is within walking distance.

Safety

Add these important safety precautions to your normal outdoor class procedures:

- ♦ Practice appropriate caution around water bodies, steep terrain, and harmful plants or animals. Point out hazards you observe at the site.
- ♦ Use a buddy system and follow the established procedure in case of trouble.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Field Survey

Set Up

1. Survey the area your class is going to study. If you have not already done so, work with your instructor and class to identify 5 species of native plants and 5 species of native insects you want to study. Record the species names and a brief description of each species in Table 1.

2. Classify each species regarding its distribution type (uniform, random, or clumped) based on qualitative visual observations of the study site as a whole. Record these classifications in Table 1.

Hint: Consult with your class members to establish this overall classification. You may decide to modify this classification for some of the species after your detailed analysis of the quadrats.

Note: After you have analyzed your data from the quadrat study, you will revisit Table 1 to record density.

Table 1: Species distribution

Species Code	Species Name	Brief Description of Species	Distribution Type*	Density (n/m^2)		
				Quad —	Quad —	Quad —
PA						
PB						
PC						
PD						
PE						
IA						
IB						
IC						
ID						
IE						

*U = uniform; R = random; C = clumped

3. Select 2 or 3 areas to measure a 1-m^2 quadrat. Mark the quadrat with the colored tape. Assign a unique number to your quadrat. Work with the class to decide on quadrat numbers.

4. For each of your quadrats, set up a sheet of graph paper as follows:

a. Outline the quadrat such that it occupies most of the page. Mark the boundaries of the quadrat, and divide it into a 10 x 10 grid.

b. Establish a key using a different color for each species you have selected. Use dots for plants and "x" for insects.

5. Start a new experiment on the data collection system. �(1.2)

6. Connect the light sensor, GPS position sensor, and temperature sensor to your data collection system. �(2.2) Use a sensor extension cable to connect the temperature sensor.

Collect Data

7. Select the widest measurement range on the light sensor. �(4.3)

8. Monitor latitude, longitude, light intensity, and temperature, without recording. �(6.1) To do this, observe the display of data in the digits display �(7.3.1) and, if need be, add a variable to the digits display. �(7.3.2)

9. For each quadrat, determine the following and write the values in Table 2.

- ♦ Date and time
- ♦ Latitude (record the number in decimal degree format to six decimal points)
- ♦ Longitude (record the number in decimal degree format to six decimal points)
- ♦ Soil temperature
- ♦ Air temperature

10. To measure the ambient light, hold the light sensor 1 meter above the ground, and orient it so it is perpendicular to the surface (the sensor should be pointing straight down). Write the value in Table 2.

11. Examine the soil in each quadrat and rate it regarding moisture content as follows:
1 = dry; 2 = damp; 3 = very damp; 4 = soggy

Table 2: Environmental elements of quadrats

Test	Quadrat __	Quadrat __	Quadrat __
Date			
Time measurements are made			
Latitude (decimal degrees, to six places)			
Longitude (decimal degrees, to six places)			
Soil Temperature (°C) (depth to 3 cm)			
Air Temperature (°C)			
Ambient Light (lux)			
Soil Moisture (1 to 4)			

12. Carefully survey each quadrat regarding the plant and animal species that your class has decided to study. Place a dot of the appropriate color on the graph paper for every individual of every plant species in your list. Place an "x" on the graph paper, in the appropriate color, for every individual of every insect species in your list. Attempt to place the marks on the graph paper in approximately the same relationship as the organisms are found in the quadrat.

13. For the most prevalent species, such as grass or ants:

- ♦ Survey a small subsample, counting each individual
- ♦ Multiply this number by the appropriate number (the ratio of the total area divided by the area of the subsample) to estimate the occurrence of that species in the entire quadrat.

Example: if you count all the ants in a 10-cm^2 area, and the ants cover a 50-cm^2 area, multiply the number counted by $(50\ cm/10\ cm)^2$, which is $(5\ cm)^2$ or 25 cm^2.

14. Use the back of your graph paper to record observations or to sketch the organisms you are studying, as is helpful to your analysis.

15. Record the density for each organism in Table1.

16. Use the data in Tables 1 and 2 to populate a spreadsheet, being sure to follow the data format and headings that have been established by your class for this experiment. (Table 3 is an example of a populated spreadsheet.)

Note: Double-check the data to be sure it has been entered properly. Especially important is proper entry of the longitude and latitude numbers because errors will result in incorrect placement of the data on the map within My World GIS.

Table 3: This spreadsheet shows sample data for 4 quadrats from the field studies. The numbers in the columns for the different species indicate the density (*n/m*^{2} or number of individuals/square meter).

LATITUDE	LONGITUDE	SOILTEMP	AIRTEMP	LIGHT	SOILMOIS	PA_DENSE	PB_DENSE	PC_DENSE	PD_DENSE	PE_DENSE	IA_DENSE	IB_DENSE	IC_DENSE	ID_DENSE	IE_DENSE	NAME	QUAD
38.080339	-121.317368	38	30	450	1	50	3	6	0	0	0	0	0	0	3	JC	1
38.803619	-121.317245	25	25	280	1	0	0	0	1	25	350	0	0	1	0	JF	2
38.803452	-121.317117	33	29	370	1	1	24	0	0	0	0	0	15	0	0	RG	3
38.803497	-121.317245	27	28	240	1	23	0	1	0	0	0	55	0	0	1	AL	4

Key:
LATITUDE (**Note**: you must use this data format)
LONGITUDE (**Note**: you must use this decimal degree data format)
SOILTEMP = soil temperature (°C) at 3-cm depth
AIRTEMP = air temperature (°C)
LIGHT = sunlight intensity (LUX)
SOILMOIS = soil moisture, rank 1 to 4 (driest to wettest)
PA_DENSE = density (n/m^2) of plant species A—white yarrow (n/m^2)
PB_DENSE = density (n/m^2) of plant species B—goldfields (n/m^2)
PC_DENSE = density (n/m^2) of plant species C—popcorn flower (n/m^2)
PD_DENSE = density (n/m^2) of plant species D—lupine (n/m^2)
PE_DENSE = density (n/m^2) of plant species E—blow wives (n/m^2)
IA = density (n/m^2) of insect species A—odorous ant (n/m^2)
IB = density (n/m^2) of insect species B—paper wasp (n/m^2)
IC = density (n/m^2) of insect species C—carpenter ant (n/m^2)
ID = density (n/m^2) of insect species D—monarch butterfly (n/m^2)
IE = density (n/m^2) of insect species E—honey bee (n/m^2)
NAME = Name of investigator
QUAD= ID of quadrat investigated

Note: Add columns for the time and date, which will help if projects are to be compared. Additional fields may be required to enter all categories of data you decide to collect.

17. Save the data file as a comma-delimited file. All students should have access to it from the computers you are working on.

Data Analysis

Part 1 – Import composite data and construct the My World GIS environment

1. Launch My World GIS �(12.1) and import your composite class data file. �(12.1.2)

2. Add the following layers to the Layer List: �(12.3.1)

- The composite class data set
- From the United States Data Library, the U.S. States layer �(12.2.1)
- MSR Maps Map Server - USGS Digital Ortho-Quadrangles (black and white) or Urban Areas Ortho-Imagery (color) �(12.1.3)

3. Arrange the layers so your class data set layer is on top and the aerial view map is on the bottom. �(12.2.2)

4. Save your project file. �(12.1.4)

Part 2 – Visualize the composite data

5. Use the Zoom In Tool to view the area where your data is located. �(12.4.3) Explore your data as it is plotted within the geographic framework.

6. Perform analyses of the data by displaying histograms �(12.4.2) and creating scatter plots to complete the Mean Density and Mean Frequency columns in Table 4. �(12.6) Use this information to help you answer the Analysis Questions.

Hint: You can explore the correlation of two parameters by editing the appearance of the layers. �(12.4.5)

Table 4: Class dataset

Species Name	Mean Density (n/m^2)	Mean Frequency	Predominant Distribution Type

Analysis Questions

1. Did you see any pattern of species preference to soil moisture? If so, explain.

Answers will vary. For the sample data in Table 3, the white yarrow was found in areas with dry soil, whereas the lupine only grew where the soil was moist.

2. Did you see any pattern of species preference to light level? If so, explain.

Answers will vary. For the sample data in Table 3, the light level was high for all quadrats, so we couldn't evaluate this.

3. Did you see any pattern of species preference to air temperature? If so, explain.

Answers will vary. For the sample data in Table 3, the air temperature was similar for all quadrats, so no differences were observed.

4. Did you see any pattern of species preference to soil temperature? If so, explain.

Answers will vary. For the sample data in Table 3, we did not see any particular correlation, probably because the soil temperature was nearly the same in all quadrats.

5. Did you find any value in analyzing the complete class data set compared with analyzing only your own data set? Explain.

Answers will vary. Students should have been able to see patterns more completely from the class data because of the increased number of data points.

6. Which species tended to occur in clumps (high density)?

Answers will vary. For the sample data in Table 3, the odorous ants and the carpenter ants tended to be clumped—either there were a lot of them or there were few or none of them.

7. Which species tended to be widely dispersed (high frequency)?

Answers will vary. For the sample data in Table 3, the white yarrow was most widely dispersed.

8. Which species occurred infrequently (had a low frequency and low density)?

Answers will vary. For the sample data in Table 3, the monarch butterfly occurred infrequently.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What is the relationship between species density and species frequency? Does a species with a high density necessarily have a high frequency? Explain.

Species density is the number of a particular species per unit area, whereas species frequency is the number of quadrats in which a species is found per total quadrats analyzed. A species can be dense in one quadrat, occupying a favorable microenvironment, but infrequent overall, because it has a narrow tolerance for changes in temperature, light, moisture, or some other factor. It may also be more vulnerable to predators outside of a specific area.

2. Of what value is calculating the frequency and density of a population?

Calculating the frequency and density of a population provides a quantitative measurement of the patterns of dispersal of a species. These quantitative measurements can be monitored and compared over time, and can be used as tools to measure the adverse or beneficial effects of various changes in environmental conditions.

3. How has human activity affected the distribution, frequency, and density of species in the area you sampled?

Answers will vary. They may reference the effect of habitat fractionation, loss of habitat, or preservation of habitat on the distribution, frequency, and density of species. Other effects that may be discussed are eradication efforts, farming or other harvesting efforts, and replanting, reforestation, or preservation efforts.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which of the following best defines the resilience of a community?

- **A.** The ability of a community to tolerate exponential population growth
- **B.** The ability of a community to become reestablished after a disturbance
- **C.** The ability of a community to be limited in size by its available resources
- **D.** **The ability of a community to resist being disturbed**
- **E.** The ability of a community to decrease its net primary productivity

2. Which of the following best explains why communities with high levels of biodiversity also have high net primary productivity?

- **A.** These communities have higher percentages of herbivores.
- **B.** These communities are more resistant to being disturbed.
- **C.** These communities are able to maintain equal percentages of each type of species established within.
- **D. Each species within is able to exploit a different portion of the available resources.**
- **E.** Each species within is able to compete more effectively.

3. Which of the following is not a cause of biodiversity loss?

- **A.** Habitat fragmentation
- **B.** Pollution
- **C.** Intrusion and overpopulation of invasive species
- **D. Exploitation of different resources by native species**
- **E.** Poor management and overuse by humans

4. Which of the following actions would help preserve global biodiversity?

- **A.** Reforming policies that lead to biodiversity decline
- **B.** Promoting more research on biodiversity
- **C.** Finding new ways to address the needs of the people living in highly-biodiverse areas whose livelihood is derived from exploiting wild species
- **D.** Practicing conservation at the landscape level through cooperation between governments, corporations, and private-property owners
- **E. All of the above**

Extended Inquiry Suggestions

Research a native species in your area, answering questions such as the following: What is its current status? How is it important in the ecosystems around your community? What is likely to happen in the future for this species in your area?

Take a second assessment in later weeks or months to determine how the data changes over time. A research protocol will need to be established for the first quadrat and followed precisely for subsequent quadrats. Students can take pictures and embed them in the project file.

Run a quadrat analysis on the same species through the school year to see how biodiversity and population density change with the climate, time of year, and so on.

Ask students to collect soil samples from your observation site and analyze them for pH, salinity, moisture content, and respiration levels. Use the procedures in the "Soil Quality" experiment in this guide. Students will need to devise a method to analyze soil moisture.

17. Biodiversity and Invasive Species

Objectives

Students collect and analyze field data in order to monitor local invasive species of plants and animals. They also:

- ♦ Identify native and invasive species of plants and insects
- ♦ Learn standardized procedures that allow investigations to be compared
- ♦ Use the collected data to determine the population patterns of a species

Procedural Overview

Students gain experience conducting the following procedures:

- ♦ Using quadrats to measure population numbers of plant and animal species
- ♦ Collecting temperature, light intensity, and global positioning system (GPS) data in the field
- ♦ Defining data types for research studies involving multiple groups
- ♦ Visualizing and analyzing group field data using My World GIS™

Time Requirement

♦ Preparation time	45 minutes (or longer, depending on your study area)
♦ Pre-lab discussion and experiment	45 minutes
♦ Lab experiment	Two 90-minute sessions

Materials and Equipment

For each student or group:

- Mobile data collection system
- GPS position sensor
- Light sensor
- Temperature sensor with sensor extension cable
- Computer with My World GIS™ installed
- Spreadsheet program such as Microsoft Excel®
- Field guides of native plants and insects in your area
- Pictures of common invasive species in your area
- Tape measure
- Colored tape
- Graph paper
- Pen, pencil, or colored pencils
- Ruler
- Clipboard or notebook (writing surface)

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- A great diversity of species increases the chance that an ecosystem can survive large changes or challenges.
- The position of any point on the Earth can be specified by two numbers, longitude and latitude.
- A quadrat is a rectangular area of a habitat, randomly selected, used for ecological or population studies.
- Density d is the number of individuals n per unit area, or $d = n/m^2$ for an area of one square meter.
- Frequency is the number of occurrences of an individual in a given area:

$$\text{Frequency} = \frac{\text{number of quadrats in which a species ocurs}}{\text{number of quadrats examined}}$$

- Density and frequency can be used in describing change in species distributions. Ratios, equations, graphs, and scatter plots are various ways to create and visualize this type of data.
- Scientists try to observe as wide a range of parameters as possible to discern patterns.
- Considering whether and how two variables are correlated requires inspecting their distributions, such as in scatter plots.
- A correlation between two variables does not mean that one causes the other.
- Both percentages and actual counts have to be considered when comparing different groups. Using either by itself could be misleading.

Related Labs in This Guide

Prerequisites:

- It would be best to complete the "Weather in a Terrarium" and "Sunlight Intensity and Reflectivity" activities before performing this experiment. In these activities, students develop the skills needed to use the sensor and data collection system in this investigation.

- Prior to beginning this experiment, it would be best to complete other My World GIS activities in this manual, such as "Plate Tectonics," "Ecological Niche: Coral Reefs," "Human Population Dynamics," or "Acid Deposition and Natural Water Bodies." These have fully developed project files, or are easy, basic labs that use the databases included in My World GIS. Students can gain necessary skills using the tools and program functions before building their own project in this experiment.

Labs conceptually related to this one include:

- Biodiversity and Native Species
- Monitoring Water Quality
- Determining Soil Quality
- Sunlight Intensity and Reflectivity
- Weather in a Terrarium

Using Your Data Collection System and My World GIS

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting multiple sensors to your data collection system �(2.2)
- Selecting a measurement range on the light sensor �(4.3)
- Monitoring latitude, longitude, and light intensity without recording �(6.1)
- Displaying data in a digits display �(7.3.1)
- Adding a variable to a digits display �(7.3.2)
- Launching My World GIS �(12.1)
- Importing a new data file into the Library �(12.1.2)

- Importing a data file or map from the Internet �(12.1.3)
- Adding a layer to the Layer List �(12.2.1)
- Arranging layers �(12.2.2)
- Hiding and showing a layer �(12.2.4)
- Editing the appearance of a layer �(12.2.5)
- Displaying a histogram �(12.4.2)
- Creating a scatter plot �(12.6)

Background

The introduction of a non-native species into an ecosystem can disrupt the equilibrium of that ecosystem. If the non-native species is successful in the new environment and crowds out some of the native species, it is termed an invasive species. Invasive species are able to disrupt the relationships among indigenous species due to lack of predators.

An invasive species may compete voraciously for a resource for which the indigenous species originally had no competitors. Because the indigenous species never had to compete for this resource, the invasive species could wipe out the resource, and thus, the indigenous species. Additionally, not having natural predators to limit its population growth, the population of the non-native species can rapidly overtake that of the native species. This can affect indigenous species from all levels of the food chain.

Invasive species maintain certain characteristics, regardless of their type. First, they are well adapted for dispersal into new environments. Plants are invariably adapted for dispersal because of their reproductive strategies. Their spores, seeds, and burrs can survive for a long time before growing and reproducing. Generally, these are small, making them lighter and abundant so they can be scattered widely. Also, many invasive plant species are apomictic, that is, their seeds can be produced without fertilization.

Species whose populations increase rapidly, often exponentially, and who quickly fill available environments, are referred to as r-selected species. R-selected animal species, having small body size, many offspring, and short life spans, are the most successful invasive animal species. They are able to eat a large variety of foods and adapt easily to changes in the environment.

Pre-Lab Discussion and Experiment

Prior to doing the lab experiment, perhaps even weeks or months ahead of time, ask students to conduct research to learn which invasive (non-native) species live in your area. A good place to start is online at the National Invasive Species Information Center website. Ask them to find out where in your area are good examples of these invasive species. If you do not have an appropriate area near your school, you will need to plan a field trip to the target area.

In a brainstorming session, determine the 5 species of plants and 5 species of insects that will be studied. These species can be a mix of invasive and native species, but at least 1 invasive plant and 1 invasive animal species should be included. If you are planning to compare data with the data collected in the *Biodiversity and Population Density of Native Species* experiment, be sure that some of the native species are included in the lists for both activities.

Assign a code to each species. Determine a short list of substitute species in case the species you select are not represented in your chosen research site.

Talk to students about the importance of the analysis and tell them that connections need to be made between certain measurements, such as pH and plant type.

Review the equations for density and frequency.

Work with students to set up a standardized protocol for their study so their measurements and observations can be compared with each other (see the arrangement of the sample data in Table 3).

Pre-Lab Homework (use available resources to help answer):

1. Find the density for the following measurement: You counted a total of 7 foxtail barley plants in a square measuring 10 cm x 10 cm. The plants seem to be distributed similarly over a large area. What is their density per square meter? (Show all work.)

10 cm x 10 cm = 100 cm^2
1 meter = 100 cm
1 square meter = 100 cm x 100 cm = 10,000 cm^2

$$\frac{\text{7 foxtail barley plants}}{100\ cm^2} = \frac{x\ \text{foxtail barleyplants}}{10{,}000\ cm^2}$$

x = 700 foxtail barley plants in 1 square meter

2. Your class examined a total of 90 quadrats. Foxtail barley plants were found in 18 of these quadrats. What is the frequency of foxtail barley plants in this area? (Show all work.)

The frequency of foxtail barley in this area is 18/90, or 0.2.

3. List 5 invasive species that are common in your area.

Answers will vary. Online resources are readily available to help students identify these species.

4. What do you think will be the most numerous of the 5 species your class has selected to study? Why?

Answers will vary according to student predictions. They should at least predict one of the species the class has selected to study and record a plausible reason.

The Research Protocol

1. Ask students to assess the population density of all 5 plant and insect species and take soil, temperature, light intensity, and location data within several 1-meter-square quadrats. Students should record data for as many quadrats as the time allows, but each student should collect data from a minimum of 3 to 5 randomly selected areas.

2. After collecting data, students will return to the lab to complete their soil analyses and enter their data into a central database file.

Note: The best way to manage this data input is to create a master spreadsheet on one computer where students take turns entering their data (see Table 3).

3. Review this composite data file to locate and correct errors in data entry. For example, note that the latitude entered in Table 3 for the first quadrat is incorrect when compared to the rest of the latitude entries; to show the correct location, it should begin with "38.803," but begins with "38.080."

Then make this file available to students for importing into My World GIS for analysis.

Instructor Tips

- The "Biodiversity and Population Density of Native Species" experiment could be conducted just prior to or concurrently with this experiment, so students can compare the data.
- The area you select for observation contains living organisms and might be private property. Be sure to obtain permission from property owners and remind students to be respectful of the organisms there.
- Choose easily identifiable species of insects and plants in an area where you expect to see a fair degree of variance.
- On site, before beginning data collection, verify that the species you have decided to study are present. If not, substitute a species that is present.
- Be sure to bring magnifying glasses and dissecting scopes (if available) to the research site, as well as field guides for the flora and fauna of your area.
- The ideal time of year for this experiment is in the spring, when flora is abundant and more easily identified through their flowers.

Depending on the time you have available and the ability of your students to inquire independently, you may choose to go through the analysis questions via either one of the following methods:

- Run through the analysis questions with the class using the completed quadrat data on your computer. This could be accomplished by projecting your computer's map view to the front of the class and performing the analysis at the direction of your students.
- Distribute the merged layer or project file via email or local area network (LAN) to each student group and give students time to work through the data analysis and synthesis questions in their small groups.

Lab Preparation

These are the appropriate preparations to perform prior to the lab:

1. Perform an Internet search for lists of invasive species in your area. Find pictures of these species.

2. Find a suitable site for the field study. It should be accessible by the public, in a natural preserve (not cultivated), and a safe place for students to work.

3. Identify likely candidate species for study. Find at least one invasive species of plants and animals. Although you will be asking students to do this part, you will need to guide them to select a suitable location and appropriate species that would assist their learning.

4. Set up a field trip. Ideally, the study site is within walking distance.

Safety

Add these important safety precautions to your normal outdoor class procedures:

- ♦ Practice appropriate caution around water bodies, steep terrain, and harmful plants or animals. Point out hazards you observe at the site.
- ♦ Use a buddy system and follow the established procedure in case of trouble.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Field Survey

Set Up

1. Survey the area your class is going to study. If you have not already done so, work with your instructor and class to identify 5 species of plants and 5 species of insects that you want to study. Be sure at least 1 of these species of plants and 1 of insects is a non-native species, and try to include as many non-native species as possible. Record the species names and a brief description of each species in Table 1.

2. Classify each species regarding its distribution type (uniform, random, or clumped) based on qualitative visual observations of the study site as a whole. Record these classifications in Table 1.

Hint: Consult with your class members to establish this overall classification. You may decide to modify this classification for some of the species after your detailed analysis of the quadrats.

Note: After you have analyzed your data from the quadrat study, you will revisit Table 1 to record density.

Table 1: Species distribution

Species Code	**Species Name**	**Brief Description of Species**	**Distribution Type***	**Density (n/m^2)**		
				Quad__	**Quad__**	**Quad__**
PA						
PB						
PC						
PD						
PE						
IA						
IB						
IC						
ID						
IE						

*uniform = U; random = R; clumped = C

3. Select 2 or 3 areas to measure a 1-m^2 quadrat. Mark the quadrat with the colored tape. Assign a unique number to your quadrat. Work with the class to decide on quadrat numbers.

4. For each of your quadrats, set up a sheet of graph paper as follows:

a. Outline the quadrat such that it occupies most of the page. Mark the boundaries of the quadrat, and divide it into a 10 x 10 grid.

b. Establish a key using a different color for each species you have selected. Use dots for plants and "x" for insects.

5. Start a new experiment on the data collection system. �(1.2)

6. Connect the light sensor, GPS position sensor, and temperature sensor to your data collection system. �(2.2) Use a sensor extension cable to connect the temperature sensor.

Collect Data

7. Select the widest measurement range on the light sensor. �(4.3)

8. Monitor latitude, longitude, light intensity, and temperature without recording. �(6.1) To do this, observe the display of data in the digits display �(7.3.1) and, if need be, add a variable to the digits display. �(7.3.2)

9. For each of your quadrats, determine the following and write the measurements in Table 2.

- ♦ Date and time
- ♦ Latitude (record the number in decimal degree format to six decimal points)
- ♦ Longitude (record the number in decimal degree format to six decimal points)
- ♦ Soil temperature
- ♦ Air temperature

10. To measure the ambient light, hold the light sensor 1 meter above the ground, and orient it so it is perpendicular to the surface (the sensor should be pointing straight down). Write the value in Table 2.

11. Examine the soil in each quadrat and rate it regarding moisture content as follows: 1 = dry; 2 = damp; 3 = very damp; 4 = soggy

Table 2: Environmental elements of quadrats

Test	Quadrat __	Quadrat __	Quadrat __
Date			
Time measurements are made			
Latitude (decimal degrees, to six places)			
Longitude (decimal degrees, to six places)			
Soil Temperature (°C) (depth to 3 cm)			
Air Temperature (°C)			
Ambient Light (lux)			
Soil Moisture (1 to 4)			

12. Carefully survey each quadrat for the plant and animal species that your class has decided to study. Place a dot of the appropriate color on the graph paper for every individual of every plant species in your list. Place an "x" on the graph paper of the appropriate color for every individual of every insect species in your list. Attempt to place the marks on the graph paper in approximately the same relationship as the organisms are found in your quadrat.

13. For the most prevalent species, such as grass or ants:

- ♦ Survey a small subsample, counting each individual
- ♦ Multiply this number by the appropriate number (the ratio of the total area divided by the area of the subsample) to estimate the occurrence of that species in the entire quadrat.

Example: if you count all the ants in a 10-cm^2 area, and the ants cover a 50-cm^2 area, multiply the number counted by $(50\ cm/10\ cm)^2$, which is $(5\ cm)^2$ or 25 cm^2.

14. Use the back of your graph paper to record observations or to sketch the organisms you are studying.

15. Record the density for each organism in Table1.

16. Use the data in Tables 1 and 2 to populate a spreadsheet, being sure to follow the data format and headings that have been established by your class for this experiment. (Table 3 is an example of a populated spreadsheet.)

Note: Double-check the data to be sure it has been entered properly. Especially important is proper entry of the longitude and latitude numbers because errors will result in incorrect placement of the data on the map within My World GIS.

Table 3: This spreadsheet shows sample data for 4 quadrats from the field studies. The numbers in the columns for the different species indicate the density (*n*/*m*^{2}, or number of individuals/square meter).

LATITUDE	LONGITUDE	SOILTEMP	AIRTEMP	LIGHT	SOILMOIS	PA_DENSE	PB_DENSE	PC_DENSE	PD_DENSE	PE_DENSE	IA_DENSE	IB_DENSE	IC_DENSE	ID_DENSE	IE_DENSE	NAME	QUAD
38.080339	-121.317368	38	30	450	1	50	3	6	0	0	0	0	0	0	3	JC	1
38.803619	-121.317245	25	25	280	1	0	0	0	1	25	350	0	0	1	0	JF	2
38.803452	-121.317117	33	29	370	1	1	24	0	0	0	0	0	15	0	0	RG	3
38.803497	-121.317245	27	28	240	1	23	0	1	0	0	0	55	0	0	1	AL	4

Key:
LATITIDE (**Note**: you must use this decimal degree data format)
LONGITUDE (**Note**: you must use this decimal degree data format)
SOILTEMP = soil temperature (°C) at 3-cm depth
AIRTEMP = air temperature (°C)
LIGHT = sunlight intensity (LUX)
SOILMOIS = soil moisture, rank 1 to 4 (driest to wettest)
PA_DENSE = density (n/m^2) of plant species A—purple thistle (n/m^2)—invasive
PB_DENSE = density (n/m^2) of plant species B—goldfields (n/m^2)—native
PC_DENSE = density (n/m^2) of plant species C—star thistle (n/m^2)—invasive
PD_DENSE = density (n/m^2) of plant species D—lupine (n/m^2)—native
PE_DENSE = density (n/m^2) of plant species E—popcorn flower (n/m^2)—native
IA = density (n/m^2) of insect species A—Argentine ant (n/m^2)—invasive
IB = density (n/m^2) of insect species B—red imported fire ant (n/m^2)—invasive
IC = density (n/m^2) of insect species C—carpenter ant (n/m^2)—native
ID = density (n/m^2) of insect species D—monarch butterfly (n/m^2)—native
IE = density (n/m^2) of insect species E—bee (n/m^2)—native
NAME = Name of investigator
QUAD= ID of quadrat investigated

Note: Add columns for the time and date, which will help if projects are to be compared. Additional fields may be required to enter all categories of data you decide to collect.

17. Save the data file as a comma-delimited file. All students should have access to it from the computers you are working on.

Data Analysis

Part 1 – Import composite data and construct the My World GIS environment

1. Launch My World GIS �(12.1) and import your composite class data file. �(12.1.2)

2. Add the following layers to the Layer List �(12.3.1):

- ♦ The composite class data set
- ♦ From the United States Data Library, the U.S. States layer �(12.2.1)
- ♦ MSR Maps Map Server - USGS Digital Ortho-Quadrangles (black and white) or Urban Areas Ortho-Imagery (color) �(12.1.3)

3. Arrange the layers so your class data set layer is on top and the aerial view map is on the bottom. �(12.2.2)

4. Save your project file. �(12.1.4)

Part 2 – Visualize the composite data

5. Use the Zoom In Tool to view the area where your data is located. �(12.4.3) Explore your data as it is plotted within the geographic framework.

6. Perform analyses of the data by displaying histograms �(12.4.2) and creating scatter plots to complete the Mean Density and Mean Frequency columns in Table 4. �(12.6) Use this information to help you answer the Analysis Questions.

Hint: You can explore the correlation of two parameters by editing the appearance of the layers. �(12.4.5)

Table 4: Class dataset

Species Name	Mean Density (n/m^2)	Mean Frequency	Predominant Distribution Type

Analysis Questions

1. Did you see any pattern of species preference to soil moisture? If so, explain.

Answers will vary. For the sample data in Table 3, the purple thistle, an invasive species, thrived in areas with dry soil, whereas the lupine only grew where the soil was moist.

2. Did you see any pattern of species preference to light level? If so, explain.

Answers will vary. For the sample data in Table 3, the light level variation was within a small range for all quadrats, so we couldn't evaluate this.

3. Did you see any pattern of species preference to air temperature? If so, explain.

Answers will vary. For the sample data in Table 3, the air temperature was similar for all quadrats, so no differences were observed.

4. Did you see any pattern of species preference to soil temperature? If so, explain.

Answers will vary. For the sample data in Table 3, the purple thistle preferred the warmer soil.

5. Did you see any pattern regarding the density of invasive species compared with the density of native species? If so, explain.

Students might notice a high density of invasive species compared with native species, especially in areas that invasive species prefer.

6. Did you see any pattern regarding frequency of invasive species compared with frequency of native species? If so, explain.

Answers will vary, but often the invasive species will have high rates of frequency compared with native species.

7. Did you find any value in analyzing the complete class data set compared with analyzing only your own data set? Explain.

Answers will vary, but students should have been able to see patterns more completely from the class data because of the increased number of data points.

8. What is your overall impression of the impact that the invasive species are having on the area you studied?

Answers will vary. For the sample data in Table 3, the invasive species appeared to take over portions, but not all, of the studied area. The invasive species were clumped in certain areas that were harsher in terms of soil moisture and light level.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Explain how an invasive species is introduced into a new environment and how it affects the ecosystem it invades. Provide examples from a case study that you have investigated.

Invasive species can be introduced by people travelling from one area to another and introducing new plants or animals, or birds might bring seeds from distant areas. For the sample data in Table 3, the purple star thistle was introduced by humans. The yellow star thistle was also introduced by humans. The Argentine ant was probably introduced by humans at another location and then spread on its own to this location. The purple and yellow star thistles are nuisance plants that crowd out native species. These thistles spread rapidly and can completely dominate an area. The Argentine ant kills the other ant species and reproduces rapidly so that it is, in many instances, the only species of ant left in the area.

2. What biological and physiological characteristics have invasive species, particularly plants, evolved that have made them better-suited for dispersal?

The characteristics that invasive species have evolved to make them better suited for dispersal are rapid reproductive rates, rapid growth rates, large numbers of offspring, and the ability to adapt to extremes of temperature and water availability.

3. How has human activity affected the distribution, frequency, and density of the invasive species in the area you sampled?

Answers will vary. For the sample data in Table 3, people have nurtured the existence of vernal pools, which have favored the growth of native species in those areas. The invasive species were found mostly in areas that did not contain vernal pools.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. The dispersion of an invasive species to a new environment depends upon which two factors?

- **A.** The absence of effective human management strategies and the proximity of the new environment to the invader's native environment
- **B.** The number of non-native species already present and the length of time that the invader has to become established
- **C.** The number of native species present and the rate of extinction in the new environment
- **D.** The dispersal capabilities of the invading species and the similarity of the new environment to the invader's native environment
- **E.** **A and D**

2. Species that are either accidentally or deliberately introduced into a community might potentially become a (an):

- **A.** Native species.
- **B.** Foundation species.
- **C.** **Invasive species.**
- **D.** Intensive species.
- **E.** Indicator species.

3. In 1851, red deer were introduced into New Zealand from England and Scotland and used for sport hunting. (Note that New Zealand has no natural predators of deer and sheep ranching is a staple of its economy.) The most probable, direct result of this introduction is that:

- **A.** Many hunters were attracted to the area, increasing human population, which in turn wiped out many other species.
- **B.** Deer were not able to adapt to the harsh environment of New Zealand and died.
- **C.** **The deer population increased rapidly due to lack of predators, leading to overgrazing of rangeland.**
- **D.** Many deer died, but, among those that survived, a superior breed emerged whose population was kept in check by the hunters.
- **E.** The deer population reached its carrying capacity and remained stable according to the laws of nature.

Extended Inquiry Suggestions

Based on students' initial evaluation of invasive species, design a new study that focuses on the dominant invasive species. Map its population over the course of a year. Determine whether it has increased its penetration into your study area. Students can take pictures of the species and embed them in the project file.

Ask students to research an invasive species locally, answering questions such as: Where did it come from? How did it get here? When did it arrive? What is its current status? What strategies did it use to become widespread in your area? What impact has it had? How widespread is its invasiveness and does it affect other areas? Are efforts being made to eradicate it? If so, what are they, and how effective are they? Who is involved in studying or working with the negative effects of this species? Are there positive effects of this species locally or in a wider area? What is likely to happen in the future for this species in your area?

18. Modeling an Ecosystem

Objectives

To use terrariums as a closed system to design and sustain a stable ecosystem, students:

- Configure multiple, interconnected terrariums in which they design and conduct investigations of the interrelationships of biotic and abiotic structures in ecosystems
- Learn to use this closed system to change one variable at a time, control other variables, and monitor multiple variables simultaneously

Procedural Overview

Students design, execute, and analyze controlled investigations using sensor technology to monitor independent and dependent experimental variables.

Time Requirement

♦ Preparation time	60 minutes
♦ Pre-lab discussion and experiment	60 minutes
♦ Lab experiment	Several days to several weeks

Materials and Equipment

For each student or group:

- Data collection system (one or more per group, depending on the experimental design)
- Oxygen gas sensor [1]
- Carbon dioxide sensor[1]
- Temperature sensor[1]
- pH sensor [1]
- Conductivity sensor[1]
- Weather sensor[1]
- Water quality colorimeter[1] and sample vials (nitrate and ammonia recommended)
- USB hub (depending on data collection system)[2]
- Sensor extension cable
- EcoZone™ System
- Different types of living organisms [3]
- Strong incandescent or full-spectrum fluorescent light source
- Plant seeds or seedlings, or moss
- Water, dechlorinated (quantity depends on design)
- Pollution source[4]
- Compost or soil

[1]These are a sample of the sensors for this student-designed experiment. Not all are needed for a successful experiment.

[2]To determine if a USB hub is required, refer to the data collection system Tech Tip file.

[3]See the Lab Preparation section for suggestions of live organisms students can use.

[4]See the Lab Preparation section for information on how to create pollution sources using fertilizer, HCl (or white vinegar), and detergent.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Most food energy originally comes from sunlight.
- ♦ During photosynthesis, carbon dioxide gas is consumed and oxygen gas is released. Photosynthesis requires light energy, generally from the sun.
- ♦ During cellular respiration, oxygen gas is consumed and carbon dioxide gas is released. Cellular respiration occurs continuously in living cells.
- ♦ Human beings are part of the earth's ecosystems. The activities of people can alter the equilibrium in ecosystems.
- ♦ To identify the independent variable, ask "What do I change?"
- ♦ To identify the dependent variable, ask "What do I observe?"
- ♦ To identify the controlled variables, ask "What do I keep the same?"

Related Labs in This Guide

Prerequisites:

- ♦ Weather in a Terrarium
- ♦ Photosynthesis and Cell Respiration in a Terrarium

Labs conceptually related to this one include:

- ♦ Monitoring Water Quality
- ♦ Photosynthesis and Primary Productivity
- ♦ Air Pollution and Acid Rain

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system�(1.2)
- ♦ Connecting a sensor to your data collection system�(2.1)
- ♦ Using an extension cable�(2.1)
- ♦ Connecting multiple sensors to your data collection system�(2.2)

- Calibrating a CO_2 gas sensor �(3.1)
- Calibrating a dissolved O_2 sensor �(3.3)
- Calibrating an O_2 gas sensor �(3.5)
- Calibrating a pH sensor �(3.6)
- Calibrating a turbidity sensor �(3.7)
- Setting up a conductivity sensor for a particular measurement range �(4.2)
- Changing the sample rate �(5.1)
- Starting data recording �(6.2)
- Stopping data recording �(6.2)
- Displaying data in a graph �(7.1.1)
- Adjusting the scale of a graph �(7.1.2)
- Displaying multiple data runs �(7.1.3)
- Selecting data points in a graph �(7.1.4)
- Finding the values of a point in a graph �(9.1)
- Measuring the distance between two points in a graph �(9.2)
- Saving your experiment �(11.1)

Background

The term "ecosystem," coined by British botanist Roy Clapham in 1930, refers to any system of living, or biotic, organisms that functions with non-living, or abiotic, chemical or physical factors in the environment. The central idea behind the ecosystem is that all biotic organisms are continually engaged in a relationship with other biotic and abiotic components. The ecosystem develops as a product of each organism's relationship with every other organism. Ecosystems are highly sensitive to change, and introducing new elements can have dramatic effects on both the biotic and abiotic organisms present.

An environment does not have to be large or exotic to be considered an ecosystem. A system as small as a single plant and soil, or one as large as a rainforest, can be considered an ecosystem. Any ecosystem is governed by the sum of individual responses from all organisms in the ecosystem. Prominent ecosystems include the Amazon Rainforest, the Great Barrier Reef, and Yellowstone Park.

In this experiment, students will be asked to design 3 individual chambers which will be interlinked. There are many types of environments they could attempt to emulate including aquatic, decomposition, and terrestrial ecosystems. They can add living organisms to their design, including plants, fish, and insects and they can use different soil types and organic material in the different chambers.

It is important to first brainstorm and then clearly identify what to put into each terrarium prior to setting up the experiment. Things they should keep in mind include: 1) the type of water to add (for example, distilled, tap, or from a local water source), 2) the types of living organisms to add to the ecosystem and how they will be obtained, 3) soil sources and how the soil will be obtained, and 4) the parameters they want to monitor.

Pre-Lab Discussion and Experiment

Engage students by explaining that they will be creating 3 interactive mini-ecosystems and monitoring several parameters in those ecosystems for several days. These ecosystems will not interact with the external environment. Make students aware that they will be responsible for designing the entire experiment.

Let the students know that you will provide the technology, a few resources, and a basic guideline for the experiment, but you will not provide step-by-step instructions on how to complete it. Discuss the following questions before you pass out the Student Inquiry Worksheet for this experiment.

1. What is required to create an ecosystem in a terrarium to maintain life?

The resources required for setting up an ecosystem to maintain life depend on the organisms living in that ecosystem. The typical terrestrial chamber may contain several plants and snails, worms, or insects. These plants will need sufficient CO_2 and light to perform photosynthesis, as well as sufficient water. Snails, worms, and insects will require sufficient food sources.

The typical aquatic chamber may contain aquatic plants, which will likewise require sufficient light to stay healthy. High levels of dissolved oxygen and a food source are necessary to maintain any aquatic life, such as fish or snails.

A decomposition chamber should only require decomposing material in order to sustain any decomposers.

2. Can the quality of life in one chamber affect the quality of life in adjoining areas?

Yes. If a pollutant is added to the terrestrial chamber, polluted water will wick from this chamber to the remaining chambers. This polluted water will affect the water quality of the aquatic chamber. In the same way, high levels of waste from aquatic organisms in the aquatic chamber (such as ammonia) can wick to the terrestrial chamber, damaging plants. Gases from the decomposition chamber, particularly CO_2, are necessary to maintain healthy plants in the terrestrial chamber, but high concentrations of these gases may affect the dissolved oxygen content of the aquatic chamber after time.

3. Brainstorm to obtain a broad list of materials students may need to put into the terrariums.

Instructor Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment. Highlight the most important components of an ecosystem—sufficient energy for all factors, reasonable competition for resources, et cetera.

Student suggestions should include a variety of live organisms, soil, and plants.

Continue the discussion by asking students these questions:

4. How can we link individual ecosystems together and still keep them isolated from the classroom environment? Why is this important?

If we are trying to see how the biotic and abiotic components of the *students'* designed ecosystem are working together, we need to eliminate as many outside variables as possible.

The EcoZone™ chambers have coupling devices that allow the 3 separate chambers to become affixed to each other and be sealed from external conditions. If you are using another system (such as 2-liter bottles) you will need to devise a way to create a seal.

5. How can we measure conditions inside the chambers? What types of parameters would we *want* to monitor? How are these parameters dependent upon what is placed in each of the chambers?

Placing sensors into the special holes pre-drilled in the EcoZone chambers will allow us to monitor different measurements inside the chambers without exposing them to external conditions.

Ideas for useful parameters may include: oxygen gas, dissolved oxygen in water, carbon dioxide gas, ammonia and nitrate levels in water, temperature, humidity, pH, conductivity, and light intensity.

Some of these parameters may be more important to monitor than others, depending on your setup. For example, if you do not have terrestrial plants or animals, gaseous CO_2 or O_2 may not be as important to monitor as dissolved oxygen levels.

6. Based on the ideas we have generated, will we be monitoring an open or a closed system?

Based on the information discussed so far, students will be attempting to create a closed system. However, it is difficult to create a 100% perfectly closed system, especially when student intervention may be required to keep organisms alive. The experimental designs should attempt to keep external environmental influences to a minimum.

7. We will be adding a pollutant to the ecosystem to simulate some effects people have on ecosystems. What pollutants could we add? If we add it to one of the chambers, will it affect them all?

There are many different kinds of pollutants that can be used to simulate some effect people have on ecosystems. Examples are: fertilizers, petroleum, detergent or simulated acid rain. Adding pollutants to one of the chambers will affect all of the chambers over time either directly or indirectly and may have either positive or negative influences.

After all students have been able to participate in the brainstorming experiment, inform them of the materials that you will be providing. Also, discuss the following ideas for creating different types of chambers.

a. Terrestrial chamber suggestions:

- ♦ To avoid opening the chamber to water any plants, soak a sponge or peat moss and place it in the chamber.
- ♦ Suggest that students use quick sprouting seeds or moss.
- ♦ Use regular dirt instead of potting soil to establish baseline nitrogen, ammonia and phosphate levels before adding the fertilizer or other pollutant.
- ♦ Provide a light source.
- ♦ Snails, worms and insects are appropriate organisms to add to the chamber.

b. Aquatic chamber suggestions:

- ♦ Add a dechlorinator to tap water during set up.
- ♦ Add a biotic conditioner to the water to begin with a healthy, balanced, bacterial population prior to adding animals such as fish and aquatic snails.
- ♦ Add aquatic plants to the water to help maintain healthy dissolved oxygen levels.

c. Decomposition chamber suggestions:

- ♦ Add some rich compost or soil to the bottom of the chamber.
- ♦ Worms, crickets, and other small invertebrates will do well in this chamber.

Allow students to break into groups and design their experiment. They can record their design on the student worksheet. Encourage students to draw labeled diagrams that show what substances will be in which container, and which sensors will be placed in each container. Encourage them to bring in additional items from home on the day they will set up the experiment.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

Note: Students should be experienced using the EcoZone chambers and in developing hypotheses and designing experiments, using a chamber, to test their hypotheses. "Weather in a Terrarium" or "Photosynthesis and Cell Respiration in a Terrarium," or both, should be completed prior to carrying out this experiment.

Suggestions for live organisms

1. Terrestrial chamber: snails, worms and insects
2. Aquatic chamber: aquatic plants, fish, aquatic snails
3. Decomposition chamber: worms, crickets, and other small invertebrates
4. Other types of chambers: students can create other biosystems

Prepare a "pollutant"

1. "Fertilizer pollutant": Dissolve 10 g of solid granulated fertilizer into 1 L of water.

Note: It is suggested that you add the fertilizer as pollutant if you are using the water quality colorimeter to monitor nitrate levels.

2. "Acid rain": Use 1.0 M HCl to represent acid rain.

   To prepare 100 mL of 1.0 M hydrochloric acid solution, adding 16.6 mL of concentrated HCl per 100.0 mL of solution. Pour the concentrated HCl into about 80 mL of water and bring the solution up to 100 mL with water. Do not pour water into the concentrated acid.

Note: For "acid rain," you can substitute household white vinegar if you do not have 1 M HCL.

3. Industrial or home runoff: Detergent

   To prepare the detergent, mix 10 mL of liquid soap in 100 mL of water.

Instructor Tip: You may want to have students adjust the sample rate of the sensors to record data points once every ten minutes or once every hour, to reduce the number of data points being collected and to prevent the data collection systems memory from becoming filled.
Instructor Tip: In most cases, the ecosystems students design will fail. Lack of sufficient light is one of the most common reasons that plants within the ecosystem die. Position the EcoZone System as close to a natural light source as possible, or have ample artificial light. Consider allowing your students to modify the ecosystem after it is set up to increase the time the ecosystem will sustain itself.

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Consult the manufacturer's material safety data sheets (MSDS) for instructions on handling, storage, and disposing of hydrochloric acid. (You can find these on the Internet.) Keep these instructions available in case of accidents.
- ♦ Do not touch the hydrochloric acid (HCl). Handle the pipet with HCl with extreme care.
- ♦ After completing the lab, wash your hands.
- ♦ Wear safety glasses and lab coats or aprons.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

There are three chambers to the EcoZone System. Each of these chambers can be filled with any abiotic material or living organism you can bring in from home or that your instructor can provide for you.

Discuss with your team the important factors in building an ecosystem. Remember that adding live organisms to these zones means you are responsible for providing them with all of the necessities of life.

Part 1 – Design your experiment

1. Write a brief outline of the procedure you will use to set up the EcoZone chambers and collect data. Include the following information:

a. What are your principle design considerations (what is the goal of your experiment)?

The purpose of this lab is for students to design and sustain a stable ecosystem. In this example the students

1. Monitor the interaction of the abiotic and biotic components of each chamber and the relationship between the 3 chambers. (How does a closed, controlled environment behave?)

2. Monitor the affects of pollutants, such as fertilizers, on water quality— how do fertilizers affect pH, dissolved oxygen, ammonia, phosphate, and nitrate levels?

3. Monitor the affects of fertilizer on plant health, including subsequent oxygen and CO_2 cycling.

b. What are the independent variables? What are the dependent variables? What are you keeping the same? What parameters will you measure?

The independent variable is the fertilizer. The dependent variables are the nitrate, ammonia, and phosphate levels of the water in the aquatic chamber, and the plant health in the terrestrial chamber.

The parameters being measured specifically for the purpose of monitoring the water quality of the aquatic chamber are:

- Nitrate levels, phosphate levels, ammonia levels, dissolved oxygen, pH

The parameters being measured specifically for the purpose of monitoring plant health in the terrestrial chamber, in conjunction with visual data, are:

- Oxygen gas levels, carbon dioxide gas levels

c. What are the biotic and abiotic components you are adding to each chamber?

Terrestrial Chamber

- Biotic components include the small fern and crickets.
- Abiotic components include the soil, outside light sources (lamp and building lights), and a portion of the cotton wick from the aquatic chamber.

Aquatic Chamber

- Biotic components include the Elodea and orange platyfish.
- Abiotic components include the aquarium rocks, deionized water, and a portion of the cotton wick from the terrestrial chamber.

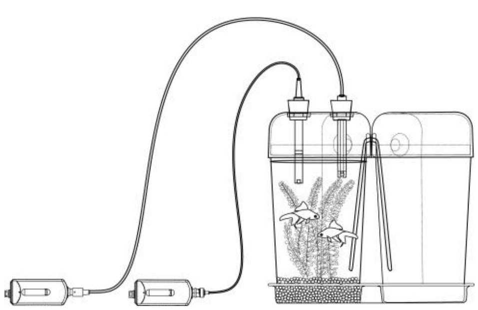
Decomposition Chamber

- Biotic components include moss and lichens.
- Abiotic components include dead sticks and leaves with signs of moss and lichens.

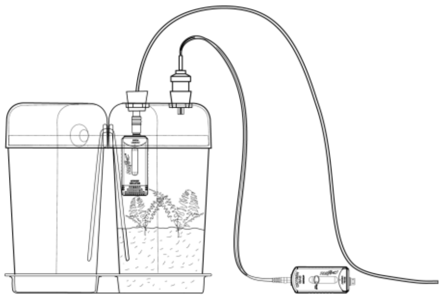
Note: Part of your experiment should determine the effect of the addition of a pollutant.

2. Draw a diagram of the experimental setup you will use. Be sure to label the biotic and abiotic materials in each chamber and the sensor or sensors that will be in each chamber.

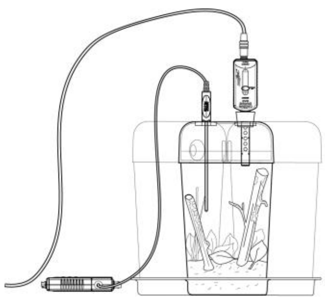
Aquatic chamber



Terrestrial chamber



Decomposition chamber



3. What roles will you and your research team play in creating, monitoring, and analyzing the EcoZone system?

Students can divide the responsibilities for the different aspects of this experiment among the group members.

4. Will the system remain closed? Will you open the system periodically to water plants or feed organisms? How will you account for your influence on the system if it is opened?

Students should plan to leave the system closed for as long as possible to limit any external environmental changes to the ecosystem but should keep in mind that it is their responsibility to provide everything needed for life to thrive in their ecosystem. If students choose to open the system periodically, they should do it as consistently as possible and document each opening. This will allow students to properly analyze their data later.

Part 2 – Set up your experiment and collect data

5. Calibrate sensors that require calibration, according to the instructions provided with the sensor.

Note: Keep the file open that contains this calibration information. The sensor calibration remains with the file that was open when you performed the calibration.

6. Why is it necessary to calibrate sensors?

You need to calibrate the sensors with an external standard so measurements can be reliably compared between groups and when collected at different times or using different sets of equipment. Otherwise, any changes that take place in the EcoZone system are only relative.

7. Add the materials to each chamber.

8. Seal the chambers so they are airtight.

Hint: One way to be sure that the terrarium is airtight is to exhale several times into the empty chamber to raise the CO_2 level of the air in the terrarium relative to the room air. Then seal the terrarium and monitor the CO_2 level for several minutes with a carbon dioxide gas sensor. After the reading stabilizes, the level should not drop. If it does, you probably have a leak. Once you have learned how to make the terrarium airtight, use this procedure in your investigations.

9. Insert the sensors and begin collecting data. Collect data for at least 24 hours. Your instructor may want you to monitor data for an extended period of time.

Note: For longer investigations, you may need to decrease the sampling rate of the sensors. Choose a time interval that will provide adequate information while limiting the number of data points collected to a practical quantity. �(5.1) For example, if you choose to monitor the terrarium for 24 hours, you might set the sampling rate to 1 sample every 10 minutes. Or if you choose to monitor for a week, you might set the sampling rate to 1 sample every 30 minutes.

Note: Take detailed notes about the status of your chambers, including the live organisms, daily. Do not wait for an organism to begin dying to intervene – you can manipulate the chambers as you see fit during the experiment as long as it is properly documented.

Part 3 – Add a pollutant and monitor data

10. After a minimum of 24 hours of data collection, add the pollutant provided by your instructor to at least one of the chambers.

11. Why do you need to wait 24 hours before adding a variable?

Waiting for 24 hours before adding or changing any variables ensures that there is a control to compare changes to after the addition of that variable. For example, if you add fertilizer to the terrestrial chamber, the control data will provide a baseline for nitrate readings and plant health so you can detect changes as the fertilizer begins to affect the chambers.

12. What type of pollutant did you add to your system? What chamber did you add the pollutant to?

Many students will likely choose to use fertilizer, as runoff from yards and parks is common and familiar. Fertilizer should be added to the terrestrial chamber. Simulated acid rain will likely be added to the aquatic chamber and detergent may be added to the terrestrial chamber. In general, no pollutants will be added to the decomposition chamber.

13. What effect do you think the pollution will have on the measurements being recorded in each chamber?

Adding fertilizer to the terrestrial chamber will cause any plants in that chamber to grow more rapidly but may potentially kill any organisms with wide exposure to the ground water. The plant itself may die if the nitrogen concentration rises too high. In turn, the polluted water will wick to the aquatic chamber and cause a decrease in water quality.

14. Why is the substance you added to the chamber considered a pollutant?

Fertilizers and detergent are considered pollutants in water systems because if too much phosphorus and nitrate (found in fertilizer) enter a body of water, the result can be an overabundance of plant growth, commonly seen as an “algal bloom.” Later these abundant plants die off and cause rapid eutrophication.

Acid rain causes acidification of lakes and streams. It also reduces crop productivity and forest growth rates and can accelerate the rate at which "heavy" metals, such as lead and mercury, and nutrient cations (such as Mg^{2+} and K^{+}) leach from soils, rocks, and water body sediments.

Data Analysis

1. Record any changes made to your experimental design, or any time the system was opened to the external environment

In this example there was no change to the experimental design and the chamber was opened only after the pollutant was introduced.

2. Create a table below that displays data you feel is relevant for others to know about the experiment *before* the pollutant was added. Below the table, add comments regarding the conditions in the chambers throughout the course of the experiment.

Measurements before adding pollution

Parameters Measured	Initial Measurement	Measurements After 24 Hours
Nitrate	0.00 mg/L	0.19 mg/L
Ammonia	0.00 mg/L	0.10 mg/L
Phosphate	0.09 mg/L	5.89 mg/L
CO_2	3277 ppm	11738 ppm
pH	7.37	7.23
Relative Humidity	66%	87%

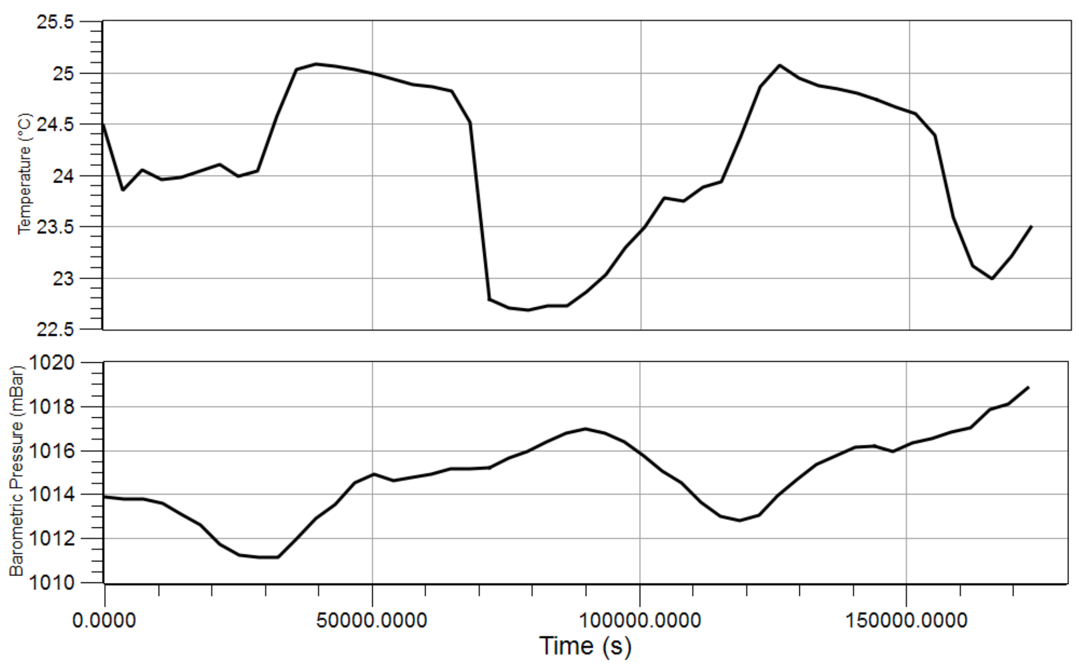
It was noted that the percent oxygen concentration remained fairly stable throughout the experiment. Also, temperature and barometric pressure appear to be cyclic, and will be shown in a graph. The system was not opened at all for the 24 hour time period that was recorded. At the end of the time period, there was a large amount of water that had wicked from the aquatic chamber and pooled in the terrestrial chamber, which is probably related to the increased humidity. Also, there was a large spike in phosphates, which is probably related to dissolved minerals from the gravel.

3. Create a table below that displays data you feel is relevant for others to know about the experiment *after* the pollutant was added.

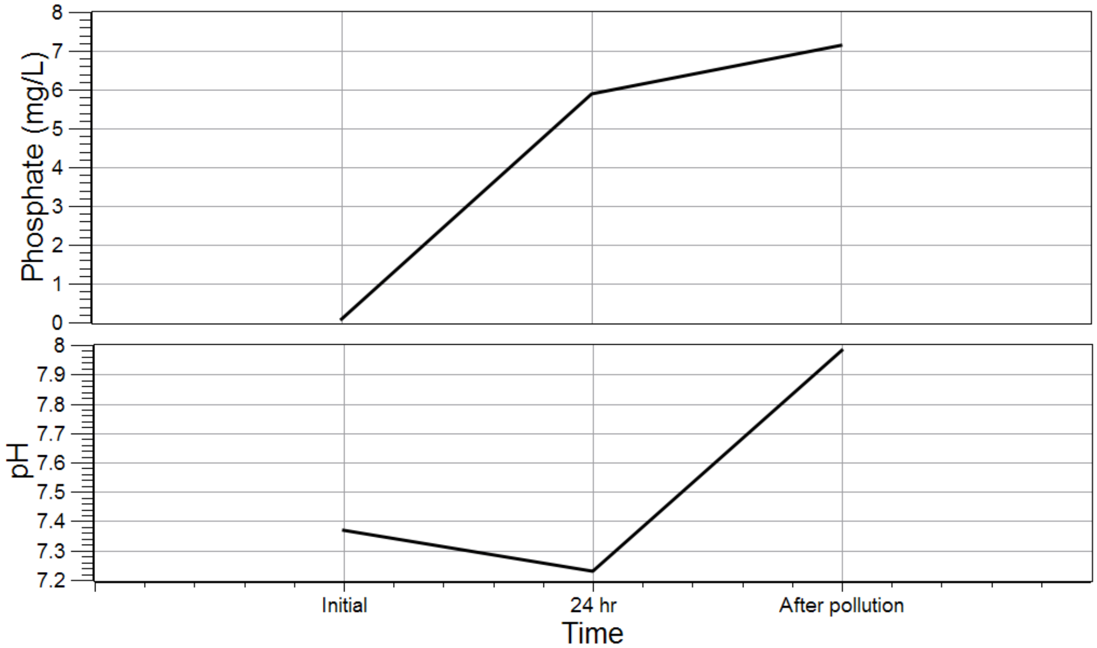
Measurements after adding pollution

Parameters Measured	Initial Values	Measurements After 24 Hours	Measurements After Fertilizer Addition
Nitrate	0.00 mg/L	0.19 mg/L	0.22 mg/L
Ammonia	0.00 mg/L	0.10 mg/L	0.00 mg/L
Phosphate	0.09 mg/L	5.89 mg/L	7.15 mg/L
CO_2	3277 ppm	11738 ppm	11756 ppm
pH	7.37	7.23	7.98
Relative Humidity	66%	87%	89%

4. Graph the set of data that changed the most over the period of data collection prior to adding the pollutant.



5. Graph the set of data that changed the most after the pollutant was added.



Analysis Questions

1. Describe any significant changes you observed in the chambers during the course of the experiment

Answers will vary depending upon the setup and the pollutants added to the system. Assuming students choose the typical decomposition: terrestrial, and aquatic arrangements for the three chambers, and add fertilizer to the system, changes in the nitrate concentration of the water in the aquatic chamber should be observed – particularly watching for an increase in nitrate concentration and possible organism death. Plant health in the terrestrial chamber should increase until the fertilizer concentration is too high.

2. What parameter changed the most prior to adding the pollutant? Explain why you think that factor changed the most.

Answers will vary depending upon the set up. In general, the only significant changes should be in humidity as the water evaporating from the aquatic chamber or wicking into the terrestrial chamber no longer has an open-air source.

3. What parameter changed the most after the pollutant was added? What is the significance of this?

Answers will vary depending upon the pollutant added. In general, pollutants of any type will affect the water and soil quality of the aquatic and terrestrial chambers. In many cases, the decomposition chamber will not be drastically affected until the organisms facilitating plant decay are killed.

4. The pollutant may, or may not, have affected your chambers.

a. If there was a significant change, what further tests would you want to conduct to determine if the pollutant was the sole cause of the change?

Students may suggest setting up an environment WITHOUT living organisms in it to verify that the pollution was the source of any changes.

b. If there was no significant change, what further tests would you want to conduct to determine if the concentration of the pollutant is important?

Students may suggest increasing the amount, or type of pollutant added to the system, or adding it to a different chamber.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Design an additional study to determine how a different pollutant could affect the ecosystem. What pollutant would you use? What changes would you expect to see? How would you measure those changes?

Answers will vary depending upon the original pollutant added to the ecosystem. If HCl is added to simulate acid rain, the ezSample testing kit for chlorine can be used in conjunction with monitoring the pH. If detergent is being added as a pollutant, the phosphate ezSample testing kit can be used.

2. Consider the type of pollutant you added to your system. Where could you find a similar pollution source in a natural environment?

Fertilizers would be found in creeks or lakes close to houses or agricultural areas. For example, houses adjacent to creeks will cause considerable runoff to enter the creek from fertilizers used in the backyard.

Detergents may also enter creeks and lakes from residential areas but are more likely to enter from industrial areas. Acid rain will also pollute creeks, lakes, and ground water and may be caused by a variety of environmental and man-made factors. The major source of nitrogen oxide gas, a cause of acid rain, is nitrogen-bearing fuels such as certain coals and oil. Natural sources of nitrogen oxide gas include volcanoes and biological decay.

3. Agricultural farming typically requires fertilizer to be added to the soil to ensure high quality crops. Rain and runoff wash excess fertilizers into local waterways. Based on your experience, what type of positive and negative consequences could result from this runoff?

Fertilizers applied sparingly and appropriately produce crops that have high yields which means they can feed more people per square acre than low yield crops. Run off into rivers and streams can also supply nutrients to plants in naturally occurring areas, which can provide denser habitat and food sources for native species.

High levels of nitrates and phosphate in water often lead to large, rapid development of aquatic plants, and algal blooms. Eventually the limiting nutrients are consumed by the new growth, and if the fertilizer runoff stops, the algae and plants can die, leading to rapid deoxygenation of the water and eutrophication of the waterway. Fertilizers that run off into natural waterways often end up concentrating nitrate and phosphates to levels that can be toxic to living organisms.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which of the following are considered consumers?

- **A.** Green plants
- **B.** Photosynthetic protists
- **C.** **Parasites associated with plants and animals**
- **D.** Chemosynthetic bacteria

2. Bacteria found in the soil are important in which of the following cycles?

- **A.** The water cycle
- **B.** The carbon cycle
- **C.** **The nitrogen cycle**
- **D.** The phosphorus cycle
- **E.** All of the above

3. The transitional zone found between two adjacent ecosystems is called the:

- **A.** Community
- **B.** Biome
- **C.** **Ecotone**
- **D.** Optimum
- **E.** Zone of tolerance

4. What types of organisms are found in the first trophic level in an ecosystem ?

- **A.** All heterotrophs
- **B.** Carnivores
- **C.** Herbivores
- **D.** **All autotrophs**
- **E.** A and B

5. Which of the following is not a natural process that occurs in ecosystems?

- **A.** **Production of pollutants**
- **B.** Erosion control and topsoil building
- **C.** The control of the earth’s climate
- **D.** Maintaining of biogeochemical cycles
- **E.** Regulation of global carbon dioxide

6. Ecosystems are comprised of which of the following components:

- **A.** Living organisms only
- **B.** Non-living structures in the environment only
- **C.** **Both biotic and abiotic factors**
- **D.** Flora and fauna
- **E.** Fauna only

Extended Inquiry Suggestions

Revise the system. In many cases, the organisms within the ecosystems will die over the course of a two-week experiment. Ask students to compare the various ecosystems that were built and revise their own ecosystem to better support life.

Set up a single chamber to observe and measure the life cycle of an organism. For example leave the chamber open with cut pieces of fruit. Once you see fruit files on the fruit, close and seal the chamber. Include any sensors you see as appropriate (for example, temperature, humidity, oxygen and carbon dioxide gas). Observe the files over a two week period. The females in your trap will lay eggs, and in a few days the eggs will hatch. Watch for the different stages – eggs, larvae, pupae, fruit fly. The entire life cycle is only about 2 weeks. After two weeks consider using your fruit fly colony to feed a predator species like a spider.

Model existing Biomes: Create the conditions that model specific biomes within a single ecochamber. For example, create a desert biome which includes the plants, animals, and environment of a desert. Monitor the conditions that are present in a specific desert (a tropical desert versus a temperate desert).

Model the same ecosystem with different conditions. Build the same ecosystem in two different chambers and put them in separate environments. For example, build two decomposition ecosystems and put one in warm dark conditions, and the other in cold light conditions.

Have students research large-scale ecosystem modeling projects like the Biosphere Project. Have them discuss why it is so difficult to build, measure and maintain a balanced ecosystem.

Population

19. Human Population Dynamics

Objectives

Students examine the relationships between life expectancy, infant mortality rate, fertility rate, illiteracy rate, per capita income, and population growth. They use this information to:

- Analyze current and future problems related to population dynamics in various countries.
- Estimate the future world population.

Procedural Overview

Students analyze global data about population growth and the factors that influence it using databases in My World™ GIS. Additionally, students:

- Prepare scatter plots and assess correlations
- Use key indicators of population changes, formulas, and the spreadsheet automatic fill capability to create a spreadsheet showing predicted increases in world population

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and experiment	45 minutes
♦ Lab experiment	45 minutes

Materials and Equipment

For each student or group:

- Computer with My World GIS™ installed
- Spreadsheet program such as Microsoft Excel®
- Project file: Population Dynamics.m3vz

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Populations of organisms increase at rapid rates if adequate resources exist and if there is an absence of disease or predators. Limits to population growth include limited resources and other factors.
- How to create equations for filling in cells in a spreadsheet program; how to use the automatic fill feature in a spreadsheet program.
- How to create an equation to calculate a percentage increase.

- Scatter plots are used by researchers to look for correlations. A correlation is a relationship between the data, which can suggest that one event might affect another event. Correlations can be strong or weak, and positive or negative. Alternatively, a scatter plot might show that there is no correlation between two parameters.

- The correlation coefficient (*r*) of a line of best fit gives information about the strength and direction of a linear correlation. Some relationships demonstrate linear correlations, while others are models of a different type, such as logarithmic or polynomial.

Related Labs in This Guide

Labs conceptually related to this one include:

- Survivorship and Mortality Curves: Cemetery Dynamics

Using My World GIS

Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

- Opening a project file �(12.1.1)

- Opening a table �(12.4.1)

- Using the Zoom In Tool �(12.4.3)

- Using the Statistics Tool �(12.4.8)

- Opening the Analysis window �(12.5)

- Creating a scatter plot �(12.6)

Background

Factors Affecting Population Growth

Population changes occur in countries for several reasons. Children are born, or people move in from other countries, adding to the population. People die or move out of the country, decreasing the population.

The number of children born depends on, among other factors, a population's fertility rate. Fertility refers to the capability of reproduction. Specifically, the fertility rate refers to the number of children born per thousand women in a year. Rates are used so you can compare large and small countries directly. Mortality rate refers to the number of deaths in a population. Mortality rates are also used to make comparisons between large and small countries. Migration refers to those who immigrate (move into) or emigrate (move out of a particular country). Net migration is the number of immigrants minus emigrants.

Earth's Rapid Rise in Population

Earth's population has been growing for the last 10,000 years, but until about 200 years ago, the population was less than 1 billion people. For the past 200 years, the world population has skyrocketed to more than 6 billion people. If the population continues to grow at its current rate — approximately 1.4% annually — Earth's population will double in 49 years.

Increases in population size can cause a variety of societal problems. These problems affect sanitation, housing, disease control, and food supply, to name just a few.

Malthus' Theory

The theory that only factors affecting mortality (disease, famine, pollution, or war) would control the total population was developed in 1798 by an English demographer and political economist named Thomas Malthus. In his publication, *Essay on the Principle of Population,* he states that human population inevitably grows faster than the available food supply, resulting in increases in events such as war, disease, political instability, and famine, which check the growth in population.

Malthus believed these were inevitable ways of controlling the population, and Malthus' theory has been used on many occasions to help countries justify inaction to end famines, disease outbreaks, or wars. Malthus' theory has been revised in recent times to argue that in undeveloped and developing countries, where the food supply is already insufficient and birth rates are high, the population will most certainly exceed the food supply.

Before Malthus, countries had regarded high fertility rates as an economic advantage because it increased the number of workers available to the economy. Malthus, however, convinced most economists that even though high fertility rates might increase the gross output, it tended to reduce output per capita.

Population Patterns

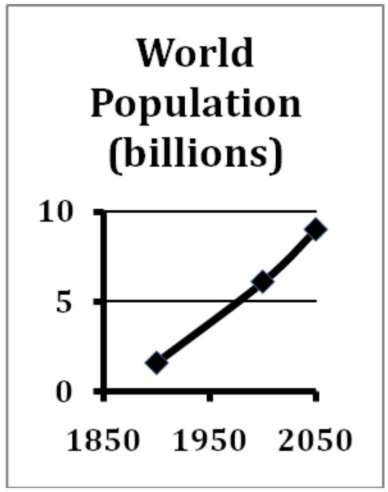
Developing countries, where HIV, AIDS, and tropical diseases are widespread and access to medicines is limited or nonexistent have some of the lowest life expectancies in recorded history. High mortality rates are expected to continue over the next 50 years in these regions. The average life expectancy for a Botswana national, where AIDS is prevalent, is only 36 years. In the least developed countries in the world, where birth and death rates are very high, the average number of children born to one woman (the total fertility rate) is 5.4, compared to only 1.5 in developed countries.

In this experiment, three types of patterns emerge during the study of population dynamics:

- Patterns that apply to poor, undeveloped countries that seem to follow Malthusian predictions,
- Patterns that apply to developing countries that have not become fully industrialized that begin to deviate from Malthusian predictions, and
- Patterns that apply to fully industrialized countries that are contradictory to Malthusian predictions.

Pre-Lab Discussion and Experiment

Present the following information: The world's population has grown more over the past century than it ever has before — from 1.6 billion in 1900 to more than 6.1 billion people in 2000 — and is projected to reach 9 billion people by 2050.



Plot these points on a graph for student viewing: 1900: 1.6 billion people; 2000: 6.1 billion people; 2050: 9 billion people (projected).

Point out that according to the United Nations, the rate of population growth worldwide is currently about 1.4%.

Ask students:

"How can a 1.4% population growth rate result in such a huge increase in population in less than 50 years?" ***Answer:*** **compounded growth.**

Demonstrate what is meant by compounded growth. Open a spreadsheet program for student viewing. Set it up with the following columns:

Setting up the population growth spreadsheet

	A	B	C	D
1	Year	Population (n)	Population Growth Rate (per yr)	Population Growth (n per yr)
2	2005	6,416,196,974	0.014	89,826,758
3	2006	6,506,023,732	0.014	91,084,332
4				

Ask the students to verify these numbers, given the initial population and growth rate. Point out that the growth rate is compounded, meaning the results from the previous year are added to the total for the next year on which the growth is determined.

Next, for cells B3 and D3, insert the formula required to obtain the numbers shown in cell B3 and D3 as follows:

B3 = B2 + D2

D3 = B3 * C3

Make sure the students understand that rather than typing the number into the cell, you have substituted a formula used to produce that number, and the software program generates the number.

Now, ask students to guess what the population will be in 2050, given the assumption of a growth rate of 1.4% annually.

Answer: Almost 12 billion people.

Use the software's automatic fill function to calculate the population through 2050. The table should look similar to the following:

Simulated spreadsheet for years 2040 to 2050 using formulas and automatic fill capabilities

A	B	C	D
2040	10,437,731,311	0.014	146,128,238
2041	10,583,859,549	0.014	148,174,034
2042	10,732,033,583	0.014	150,248,470
2043	10,882,282,053	0.014	152,351,949
2044	11,034,634,002	0.014	154,484,876
2045	11,189,118,878	0.014	156,647,664
2046	11,345,766,542	0.014	158,840,732
2047	11,504,607,274	0.014	161,064,502
2048	11,665,671,775	0.014	163,319,405
2049	11,828,991,180	0.014	165,605,877
2050	11,994,597,057	0.014	167,924,359

So, given an annual growth rate of 1.4%, the world population will reach about 12.0 billion by 2050, based on the population in 2005.

Note: Point out to students that you can also calculate the doubling time by dividing 69 by the growth rate. The doubling time at a growth rate of 1.4% is 49.28 years.

However, experts expect the growth rate to decrease such that the world population will reach only about 9 billion by 2050.

Ask students: "What factors might change to slow the rate of world population growth?" Brainstorm ideas and record them for student viewing.

Review scatter plots and correlations with students. Point out that the population curve you just created for them is a scatter plot of World Population versus Year.

Scatter plots are used by researchers to look for correlations. A correlation is a relationship between the data, which can suggest that one event might affect another event. Alternatively, a positive correlation might indicate that both parameters are positively affected by a third factor.

Lab Preparation

Although this experiment requires no specific lab preparation, allow 10 minutes to assemble the materials needed to conduct the lab.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

Set Up

1. Open the Population Dynamics project file (Population Dynamics.m3vz). �(12.1.1) The following layers are in the Layer List:

- ***U.S. States*** – displays an outline representing all 50 states.
- ***Countries (with Demographic Trends)*** – displays an outline of all world countries with a large subset of appended demographic data.

2. Highlight the Countries (with Demographic Trends) layer.

3. Open the data table for this layer. �(12.4.1)

4. Sort the Population (2005) data in descending order. �(12.4.1.1)

5. Record the 10 most populous countries in Table 1.

Table 1: The 10 most populous countries

Population Rank	Country	Land Area Rank
1	China	5
2	India	8
3	United States	4
4	Indonesia	17
5	Brazil	6
6	Pakistan	35
7	Bangladesh	97
8	Russian Federation	2
9	Nigeria	34
10	Japan	62

6. Sort the Area data in descending order. �(12.4.1.1)

7. Find the countries listed in Table 1 and record their land area rank in Table 1. (While this is not an analytical comparison, these numbers are easier to work with than area and population.)

Data Analysis

1. Does the population of a country depend on its size? Explain in terms of population density.

The population does not depend on the size of the country. The largest country, the Russian Federation, ranks 8th in population, whereas one of the smallest countries, Bangladesh, which ranks 97th in size, ranks 6th in population. This means that Russia has a much lower population density than Bangladesh.

2. Open the Analysis window. �(12.5)

3. For the Countries (with Demographic Trends) layer, create a scatter plot of Life Expectancy (1995–2000) versus GDP Per Capita (1999). �(12.6)

4. Discuss the pattern shown on the scatter plot and its implications in terms of the relationship between income and life expectancy.

For people who live in countries with an average annual per capita income of less than $2,500 (US$), life expectancy is much lower than in countries with higher per capita income. There are wide variations between countries, ranging from about 35 to about 70 years of expected life. Therefore, in this selection of countries, other factors must be important and vary among countries in determining life expectancy.

For countries with average per capita income ranging from $2,500 to about $20,000, there is a gradual increase of life expectancy from about 70 years to about 77 years as per capita income increases. For countries with per capita incomes higher than $20,000, there does not seem to be an associated increase in life expectancy, and there is even an appearance that in countries with the highest per capita levels, life expectancy might decline slightly.

5. From the Analysis window, create a scatter plot of Infant Mortality (1995–2000) versus GDP Per Capita (1999). �(12.6)

6. Discuss the pattern shown on the scatter plot and its implications in terms of the relationship with income and life expectancy.

The pattern for infant mortality looks like the mirror image of the pattern for life expectancy, with very high and highly variable infant mortality rates for countries having per capita incomes of less than $2,500. Infant mortality rates decrease in countries having per capita incomes from $2,500 to $20,000, and no further decrease in infant morality rates in countries having per capita incomes of $20,000 or more.

7. Would you predict a strong correlation between life expectancy and infant mortality? Check your answer in My World GIS and discuss the result.

Students should predict a strong negative correlation between life expectancy and infant mortality. That is, the less infant mortality there is, the greater the life expectancy. When students check this in My World GIS by creating a scatter plot of Life Expectancy (1995 to 2000) with Infant Mortality (1995 to 2000), they will find a correlation coefficient of -0.95, a strong negative correlation. For correlation of these parameters, a negative linear trend is a good model.

8. Close all open scatter plots.

9. Use the Statistics Tool to view the statistical data for the Countries (with Demographic Trends) layer. �(12.4.8) Complete Table 2 using the median values for this data.

Note: Record values rounded to 1 decimal place.

Table 2: Key indicators of population dynamics—historical and projected (median values)

	Recent History		**Projected**		
	1995–2000	2000–2005	2010–2015	2020–2025	2045–2050
Fertility Rate*	3.0	2.7	2.3	2.1	1.9
Infant Mortality**	31.5	27.3	20.4	15.5	9.15
Life Expectancy (years)	68.6	70.2	72.6	74.5	78.3
Population Growth (annual %)	1.6	1.4	1.2	0.9	0.3

*number of births per woman
**number of deaths during the first year after birth per 1000 births

10. Discuss the interrelationships of these trends (fertility rate, infant mortality, life expectancy, and population growth) in the recent past and as projected for the future.

Recently, the fertility rate and infant mortality rate have been decreasing. This decline is projected to continue through 2050. Partly as a result, the trend for life expectancy has been increasing and is projected to increase through 2050. The annual percent growth in global population has decreased recently and is projected to decrease through 2050, although population will still be increasing in 2050. The decrease in fertility rates must, therefore, more than offset the decrease in infant mortality rates so that a slowing of population growth can occur.

11. In a spreadsheet program, use the global population in 2005 and the median population growth rates in Table 2 to estimate the global population in 2025 and 2050. Describe how you set up the spreadsheet.

Note: This exercise is similar to the one you did with your instructor, except that you will use both current and projected population growth rates rather than just the current growth rate.

In their spreadsheets, students should make a column for the years 2005 through 2050, a column for the historical or estimated median Population Growth, and a column of calculated values. For each year, students will calculate the projected population based on the population of the previous year and growth percent for that year. This calculation will be made according to the following formula:

Global population for the next year =
Global population for the last year + (Global population for the last year % Percent population growth for that year).

Students should set this formula up in the spreadsheet program for the first calculation and then use the spreadsheet software's automatic fill function to complete the remaining calculations. For each year, students should enter the appropriate projected growth rate as shown in Table 2.

Projected growth rate and population students should have on their spreadsheets

Year	Projected Global Population Growth	Global Population	Year	Projected Global Population Growth	Global Population
2005	0.014	6,416,196,974	2028	0.009	8,325,338,835
2006	0.014	6,506,023,732	2029	0.009	8,400,266,885
2007	0.014	6,597,108,064	2030	0.009	8,475,869,287
2008	0.014	6,689,467,577	2031	0.009	8,552,152,111
2009	0.014	6,783,120,123	2032	0.009	8,629,121,480
2010	0.012	6,878,083,805	2033	0.009	8,706,783,573
2011	0.012	6,960,620,810	2034	0.009	8,785,144,625
2012	0.012	7,044,148,260	2035	0.009	8,864,210,927
2013	0.012	7,128,678,039	2036	0.009	8,943,988,825
2014	0.012	7,214,222,176	2037	0.009	9,024,484,724
2015	0.012	7,300,792,842	2038	0.009	9,105,705,087
2016	0.012	7,388,402,356	2039	0.009	9,187,656,433
2017	0.012	7,477,063,184	2040	0.009	9,270,345,341
2018	0.012	7,566,787,942	2041	0.009	9,353,778,449
2019	0.012	7,657,589,398	2042	0.009	9,437,962,455
2020	0.009	7,749,480,470	2043	0.009	9,522,904,117
2021	0.009	7,819,225,795	2044	0.009	9,608,610,254
2022	0.009	7,889,598,827	2045	0.003	9,695,087,746
2023	0.009	7,960,605,216	2046	0.003	9,724,173,009
2024	0.009	8,032,250,663	2047	0.003	9,753,345,528
2025	0.009	8,104,540,919	2048	0.003	9,782,605,565
2026	0.009	8,177,481,787	2049	0.003	9,811,953,382
2027	0.009	8,251,079,123	2050	0.003	9,841,389,242

a. What is the calculated population for 2025 and 2050?

Using these data and assumptions, the projected global population in 2025 will be about 8,100,000,000 and in 2050 will be about 9,800,000,000.

12. What are some limitations of these estimates for calculating the future population?

These estimates rely on the accuracy of the projected rate of population growth. However, many factors could alter the annual rate of population growth. Widespread famine and disease could lower population growth rates. Greater-than-expected reductions in fertility rates could decrease growth rates. On the other hand, lower-than-expected decreases in fertility rates or higher-than-expected decreases in infant mortality rates, in combination with the absence of widespread famine, disease, or war, could increase annual growth rates.

13. Open the Analysis window. �(12.5)

14. Create a scatter plot to explore the relationship between illiteracy and fertility rates. �(12.6)

15. What do the scatter plots of illiteracy rate versus fertility rate show?

There is a positive correlation between illiteracy rates and fertility rates. That means that generally, the higher the rate of illiteracy, the higher the fertility rate.

16. Close the open scatter plot.

17. Use the Zoom In Tool to zoom in on Africa, and view many different parameters by changing the fill color. �(12.4.3) Observe the data shown on the map for each parameter.

18. What are some current and future problems related to population on the African continent?

Large portions of Africa have very high fertility rates, very high infant mortality rates, very high illiteracy rates, very large numbers of individuals who are in reproductive years or younger, and a strong potential for high population growth. At the same time, there is very low per capita income and low percentages of urban population.

Unless the fertility rate can be lowered significantly and the rate of food production increased significantly in the very near future, the potential exists for widespread famine in the future. Barriers to lowering the fertility rate include the high illiteracy rate, low per capita income, and the predominance of rural living.

Synthesis Questions

Use available resources to help you answer the following questions.

Malthus' Theory

The theory that only factors affecting mortality (disease, famine, pollution, or war) would control the total population was developed in 1798 by an English demographer and political economist named Thomas Malthus. In his publication, *Essay on the Principle of Population,* he states that human population inevitably grows faster than the available food supply, resulting in increases in events such as war, disease, political instability, and famine, which check the growth in population.

Malthus believed these were inevitable ways of controlling the population, and Malthus' theory has been used on many occasions to help countries justify inaction to end famines, disease outbreaks, or wars. Malthus' theory has been revised in recent times to argue that in undeveloped and developing countries, where the food supply is already insufficient and birth rates are high, the population will most certainly exceed the food supply.

Malthus argued that as wages increase within an economy, the birth rate increases while the death rate decreases. He reasoned that high incomes allowed people to have sufficient means to raise their children, thus resulting in a greater desire to have more children, which increases the population. In addition, high incomes also allow people to afford proper medical care to fight off potentially harmful diseases, thus decreasing the death rate.

As a result, Malthus claimed that wage increases cause the population to grow as the birth rate increases and the death rate decreases. He further argued that as the supply of labor increases, then, with the increased population growth and a constant labor demand, the wages earned would decrease eventually to a subsistence level, where the birth rate equals the death rate, resulting in no growth in population.

1. Give examples of regions in the world in which the population dynamics presently resemble those described in Malthus' theories. Which regions of the world do not follow the predictions arising from Malthus' theories?

In the poorest countries in Africa, the population dynamics seem to resemble those predicted by Malthus. That is, there is rapid population growth because of high fertility rates that cannot be supported by the available food supply, resulting in famine, disease, high infant mortality, and political instability that produces wars. In the industrialized nations having high per capita income, the population dynamics do not show the patterns predicted by Malthus' theories. In these countries, population growth has slowed and in some instances, population is even declining, because of sharply lower fertility rates.

2. Discuss the role of the recent advancements in agriculture that have enabled the production of crops with increased yields (known as the Green Revolution) on population dynamics.

The increased yields possible through using the techniques of modern agriculture have resulted in avoiding widespread famine in India and other countries with rapidly expanding populations that have successfully adopted these techniques.

3. What are some of the ecological problems presented by using modern agricultural methods that were not problems with more traditional methods of farming?

The methods used to improve crop yields require the use of increasing amounts of fertilizers and pesticides, which enter the environment and cause ecological imbalances. Modern agricultural methods are much less biodiverse than traditional methods, resulting in more vulnerability to plant diseases and predators.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. A population that is dominated by pre-reproductive individuals is likely to

- **A.** Decrease in population size.
- **B. Increase in population size.**
- **C.** Remain stable in population size.
- **D.** Decrease in post-reproductive ages.
- **E.** Decrease in reproductive ages.

2. Which population profile best describes a developing country?

- **A.** The population profile shows a low fertility rate.
- **B.** The profile shows a decline of the older population and a reduction in the number of children and young people.
- **C. The population profile shows a high fertility rate.**
- **D.** The population profile has a small base.
- **E.** The profile shows a decrease in the number of children and young people.

3. If the fertility rate of a developing country is reduced by 5%, the population would

- **A.** Continue to grow for a few years, and then decline.
- **B.** Continue to grow for many decades but gradually stabilize.
- **C. Continue to grow until a much higher reduction of fertility takes place.**
- **D.** Begin to decrease immediately.
- **E.** None of the above.

4. Factors that greatly constitute environmental resistance to human population growth in developing countries include

- **A.** War.
- **B.** Famine.
- **C.** Disease.
- **D. All of the above.**
- **E.** None of the above.

5. Compared with people in developing countries, people in developed countries

- **A.** Have the same biotic potential.
- **B.** Have lower fertility rates.
- **C.** Have a higher standard of living.
- **D.** Have greater access to education.
- **E. All of the above.**

6. Population change can be determined by which of the following equations?

- **A. Population change = (births + immigration) – (deaths + emigration)**
- **B.** Population change = (births + deaths) – (immigration + emigration)
- **C.** Population change = (births + deaths) + (immigrations + emigration)
- **D.** Population change = (births + deaths) – (immigrations – emigration)
- **E.** Population change = (births – immigration) + (deaths – emigration)

Extended Inquiry Suggestions

Ask students to research the controversy surrounding the methods used in the "Green Revolution" technologies. Is this technology sustainable for the long term? What are barriers to its use in certain parts of the world? Will this approach to agriculture be successful in staving off famine in the future?

Ask students to research the efforts that are being made worldwide to reduce fertility rates. Are these efforts considered successful? Which strategies seem to work? What are some of the barriers to achieving this goal?

20. Survivorship and Mortality Curves: Cemetery Dynamics

Objectives

Cemeteries in long-established communities can give meaningful information about the life spans of people in the area and how these have changed over time. In this lab, students:

- Collect data as a team using a standardized protocol
- Analyze data for historical survivorship trends
- Find out how survivorship has changed in their community over the years
- Differentiate between a survivorship curve and a mortality curve

Procedural Overview

Students gain experience in geospatial analysis by conducting the following activities:

- Taking a "snapshot" of local life-span data using a standardized protocol to examine and record information from headstones in a cemetery
- Importing this data into My World GIS™ and analyzing it for historical survivorship trends
- Comparing survivorship and mortality curves

Time Requirement

♦ Preparation time	15 minutes (plus time required to organize and conduct a field trip to a cemetery)
♦ Pre-lab discussion and experiment	45 minutes
♦ Lab experiment	Two 90-minute sessions (including one field trip)

Materials and Equipment

For each student or group:

- Mobile data collection system
- Global positioning system (GPS) position sensor
- Computer with a spreadsheet program and My World GIS™ software installed
- Map of the cemetery
- Blank data tables[1]

[1]For instructions on creating blank data tables refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Populations of organisms increase at rapid rates if adequate resources exist and there is an absence of disease or predators. Limits to population growth include limited resources and other factors.
- How to create equations for filling in cells in a spreadsheet program; how to use the auto-fill feature in a spreadsheet program.
- How to create an equation to calculate a percentage increase.
- Scatter plots are used by researchers to look for correlations. A correlation is a relationship between the data, which can suggest that one event may affect another event. Correlations can be strong or weak, and positive or negative. Alternatively, a scatter plot may show that there is no correlation between two parameters.
- The correlation coefficient *r* of a line of best fit gives information about the strength and direction of a linear correlation. Some relationships exhibit linear correlations, while others fit models of a different type, such as logarithmic or polynomial.
- A mathematical model uses rules and relationships to describe and predict events in the real world.

Related Labs in This Guide

Labs conceptually related to this one include:

- Human Population Dynamics
- Biodiversity and Invasive Species
- Biodiversity and Native Species

Using Your Data Collection System and My World GIS

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

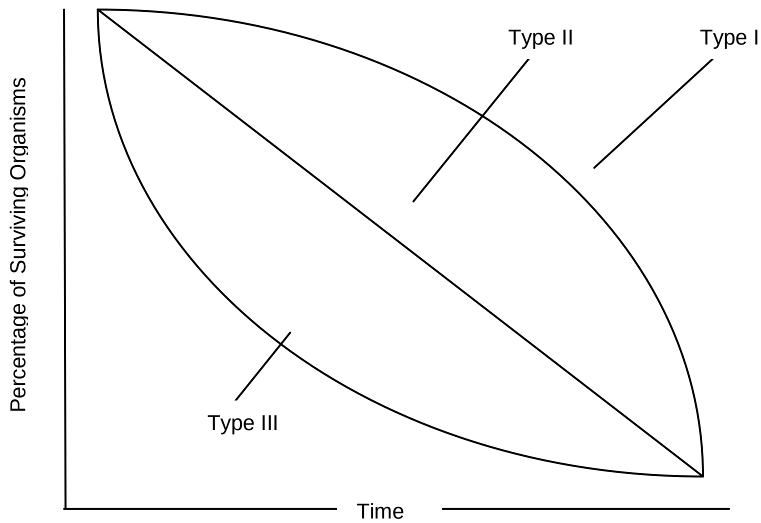
- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Monitoring live data without recording �(6.1)
- Launching My World GIS �(12.1)

- Importing a data file into the Data Library �(12.1.2)
- Importing a data file or map from the Internet �(12.1.3)
- Adding a layer to the Layer List �(12.2.1)
- Arranging layers �(12.2.2)
- Deleting a layer from the Layer List �(12.2.3)
- Hiding and showing a layer �(12.2.4)
- Showing or hiding data selections �(12.3.2)
- Changing the color of a data selection �(12.3.3)
- Opening a table �(12.4.1)
- Displaying a histogram �(12.4.2)
- Using the Zoom In and Zoom Out Tools �(12.4.3)
- Opening the Analysis window �(12.5)
- Selecting records from a layer by value �(12.5.1)
- Creating a scatter plot �(12.6)

Background

Survivorship is the probability of newborn individuals of a species living to a particular age. Survivorship curves are graphs showing the number of surviving members of a particular group followed from birth. This group is known as a cohort. There are three types of survivorship curves:

- Type I survivorship curves represent species, such as large mammals, with a low death rate (high survivorship rate) of their young and long life expectancy. Humans in developed countries are a good example of a species with a Type I survivorship curve.
- Type II survivorship curves represent species that have a relatively constant death rate, such as small mammals and birds.
- Type III survivorship curves represent species with a high death rate early in life, such as fish and most invertebrates. Individuals that survive the first quarter of their life span usually have a long life expectancy.



Typical survivorship graphs for differing populations can be found in reference material. A survivorship curve is the best-fit curve of a scatter plot of the percentage of a population that survives versus age or percentage of the maximum life span, whereas a mortality curve is the best-fit line of a scatter plot of the number of individuals that have died versus the total number of individuals in that population.

Patterns of survivorship for humans have varied through the ages and differ even today for different human populations worldwide. While the Type I pattern is typical of humans in economically developed countries, human populations in undeveloped countries have some Type II survivorship characteristics, as did most human populations prior to the industrial revolution.

Pre-Lab Discussion and Experiment

Ask students to read related material about birth and death rates, limits on population growth, and population growth in the past.

If possible, perform the "Human Population Dynamics" experiment before performing this lab. Discuss survivorship curves and compare survivorship curves of different population types. Miller's *Living in the Environment* textbook, 15th edition, describes the survivorship curves as Late Loss (Type 1), Constant Loss (Type 2), and Early Loss (Type 3).

Discuss age graphs and typical patterns for developing and industrialized countries.

Work with students to set up a standardized protocol for their study so their measurements and observations can be compared with each other (see example in the Sample Data section).

Assign sections of the cemetery to individual students or groups. Ask them to mark these on their maps.

Discuss etiquette expected during the visit to the cemetery. Remind students to be respectful while in the cemetery and avoid stepping on graves and flowers or interfering with funeral services and maintenance activities.

Pre-Lab Homework Assignment

1. Explain how a survivorship curve differs from a mortality curve.

A survivorship curve shows the number of the members of a cohort surviving over the life span of the cohort, whereas a mortality curve shows the cumulative number of deaths in a cohort over the life span of the cohort. The plots of these graphs are mirror images of each other.

2. Think about the data you would need to create a survivorship curve from data found in cemeteries. Outline the types of data you will need to collect, the number of data points, and the types of computations you will need to make with the data.

You would need to record the year people were born and the year they died. You should plan to take at least 6 data points. The more points you can take, the better your data set will be. Then you would need to calculate their age at death (in years). To compare earlier times to more current times, you would need to group people into cohorts by year of birth. You would sort these cohorts by year of death and make a parameter of the number still living when an individual dies and another parameter of cumulative number dead when the individual dies. You would then need to convert these two parameters into percentages of the total cohort.

3. Do you think the trends in survivorship curves will change among cohorts that lived in the past centuries versus those that lived in the most recent century? Explain.

Answers will vary depending upon the student's prediction. Usually, students predict that survivorship curves in recent history will look like Type I, but survivorship curves from earlier times will have more early deaths and fewer people living to close to their life spans.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Find a suitable cemetery, preferably one within walking distance, and arrange the necessary permissions to bring your class to the cemetery on a field trip. Arrange for transportation, parental permissions, and other standard preparations for a field trip.
2. Make sure the mobile data collection devices are fully charged.
3. Create a blank data table, based on Table 1, and create copies for students to fill in.

Note: This experiment is an advanced use of My World GIS. It would be best to complete several labs that develop skills using My World GIS, such as the "Human Population Dynamics" and "Acid Rain" activities, before attempting to perform this lab.

Safety

Follow your normal outdoor class procedures.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual and the My World GIS Tech Tips file. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Set Up

Note: In the pre-lab experiment, you will have established with the class how many data points are necessary for your study as well as how and where you will collect them.

1. At the cemetery, start a new experiment on your data collection system. �(1.2)

2. Connect the GPS position sensor to the data collection system. �(2.1)

Note: Be sure the GPS position sensor is in the ready mode before noting the values.

Collect Data

3. Monitor live data without recording. �(6.1) At each gravestone, find the latitude and longitude of the grave site, and record those measurements to 6 decimal points in Table 1.

Latitude (to 6 Decimal Places)	Longitude (to 6 Decimal Places)	Name of Deceased	Year of Birth	Year of Death
41.218369	-75.952935	Richard Coyle	1887	1974
41.218421	-75.952961	May Green	1887	1982
41.216743	-75.952122	Robert Brennen	1888	1891
41.217180	-75.955400	Rowland Owens	1917	1993
41.216850	-75.955500	Richard Pratt	1903	1993
41.217140	-75.955600	Patricia Bell	1916	1993

4. Record in Table 1 the name of the deceased, year of birth, and year of death for each gravestone.

Note: The names are recorded so the full data set can be checked for duplicate records.

5. Continue to record the latitude, longitude, name, year of birth, and year of death until you have collected the necessary number of data points.

6. Return to the classroom with your gravestone data and enter your data into a spreadsheet program, being sure to follow the data format and headings that have been established by your class for this experiment.

Note: The best way to handle this data is to create a master data file on one computer where everyone inputs their information.

Note: Double-check the data to be sure you have entered it properly. Especially important is proper entry of the longitude and latitude numbers because errors will result in erroneous placement of the data on the map within My World GIS.

7. Save the data file as a comma- or tab-delimited file to the location specified by your instructor.

8. Open the composite data file containing the complete class set of data in your spreadsheet program.

9. In your spreadsheet, calculate new columns as follows:

a. COHORT: Sort the data by BIRTHYEAR (increasing values). Then create a new column named COHORT to define birth eras and assign each record a number according to the cohort grouping your class has decided upon (for example, all births between before 1849 are assigned the number 1, all births between 1850 and 1899 are assigned the number 2, and so on.

b. AGE_AT_DEATH: DEATHYEAR – BIRTHYEAR.

c. NUMBER_DECEASED (sorted by COHORT and DEATHYEAR): Sort the data by COHORT and secondarily by DEATHYEAR (increasing values). Then create NUMBER_DECEASED (by COHORT and DEATHYEAR) and fill it with an increasing number within each cohort ranging from 1 through however many people were in each cohort. When starting a new cohort, start counting from 1 again.

d. TOTAL_COHORT: total number of people in the cohort

e. NUMBER_SURVIVING (sorted by COHORT and DEATHYEAR): number left in the cohort at the time of death of the individual. To create this column, subtract 1 from the number in the TOTAL_COHORT column and then decrease by 1 in each subsequent row.

f. PERCENT_SURVIVING: (NUMBER_SURVIVING ÷ TOTAL_COHORT) × 100

g. PERCENT_DECEASED: (NUMBER_DECEASED) ÷ TOTAL_COHORT) × 100

Hint: Use your spreadsheet's automatic fill functions to fill in the cells with the desired data.

Table 2: Composite spreadsheet sample data

LATITUDE	LONGITUDE	LASTNAME	BIRTHYEAR	DEATHYEAR	AGE_AT_DEATH	COHORT	NUMBER_DECEASED (By COHORT and DEATHYEAR)	TOTAL_COHORT	NUMBER_SURVIVING	PERCENT_SURVIVING	PERCENT_DECEASED
41.215901	-75.951701	Ste	1770	1796	26	1	1	137	136	99.27	0.73
41.215903	-75.951709	Moo	1762	1798	36	1	2	137	135	98.54	1.46
41.215905	-75.951703	Inm	1718	1804	86	1	3	137	134	97.81	2.19
41.215907	-75.951704	Inm	1758	1804	46	1	4	137	133	97.08	2.92
41.215909	-75.951715	Pel	1794	1804	100	1	5	137	132	96.35	3.65
41.215911	-75.951706	Inm	1788	1807	19	1	6	137	131	95.62	4.38
41.215915	-75.951713	Inm	1721	1809	88	1	7	137	130	94.89	5.11
41.215913	-75.951704	Fis	1726	1809	83	1	8	137	129	94.16	5.84
41.215917	-75.951709	Kei	1738	1811	73	1	9	137	128	93.43	6.57

10. Save your comma- or tab-delimited file to the location specified by your instructor.

Data Analysis

Part 1: Importing composite data and constructing the My World GIS environment

1. Launch My World GIS �(12.1) and import your composite class data set into the Data Library. �(12.1.2)

2. Add the following layers to the Layer List �(12.2.1):

- ♦ The cemetery data that you collected
- ♦ From the United States Data Library, the U.S. States layer

Note: If you live outside the United States, you will need to substitute the Countries data set from the World Library.

- ♦ The USGS Digital Ortho-Quadrangles layer �(12.1.3)

Note: If you live outside the United States, you will need to import an aerial map from another source, such as Google Maps.

Part 2: Creating and visualizing cohorts based on birth year

3. Highlight your class's data. Zoom in to the area where you collected your data using the Zoom to Active Layer too. �(12.4.4)

4. Create a data selection by value for each birth era (cohort). Name each new selection (for example, COHORT 1).

5. Show the COHORT 1 selection. �(12..3.2)

Hint: If necessary, change the highlight color to distinguish the selection on the map. �(12.3.3)

Part 3: Using histograms and scatter plots to analyze data by cohort

6. Display the histogram for each of the following: �(12.4.2)

- ♦ BIRTHYEAR
- ♦ DEATHYEAR
- ♦ AGE_AT_DEATH

7. From the information on the AGE_AT_DEATH histogram window, record the following data in Table 3: number of values (n), minimum (Min), maximum (Max), mean, median, and mode.

Table 3: Summary statistics by cohort

		AGE_AT_DEATH (years)					
	COHORT	**n**	**Min**	**Max**	**Mean**	**Median**	**Mode**
1	BIRTHYEAR before 1800	44	19	105	60	66	NA*
2	BIRTHYEAR from 1800 to 1850	93	2	97	60	68	67
3	BIRTHYEAR from 1850 to 1900	766	0	102	66.6	70	66
4	BIRTHYEAR from 1900 to 1990	359	0	95	59	64	75

NA* = No mode exists--all values were unique

8. Repeat the previous two steps for the remainder of the birth era selections.

9. Do you see any patterns in the data mapped by birth year, death year, and age at death?

Students may see that certain areas of the cemetery were used during different time periods. If so, the year of death would show the clearest pattern of usage of the cemetery. If the cemetery shows a clear pattern of usage, students may see a difference in the pattern of age at death, with the age of death being generally younger in the very old areas of the cemetery, or in areas of the cemetery that were used during war time.

10. Do you see any patterns in the data listed in Tables 3?

The mean, median, and mode for age of death may be lower in the earlier birth eras. In the latest birth era, the mean, median, and mode may be deflected downwards because many of the people who might be expected to be included in the sample are not yet deceased.

During wartime periods or periods of disease epidemics, an increased number of people may have died in childhood or early adulthood. The data may show a decreased incidence of infant mortality in the later birth eras.

11. Open the Analysis window �(12.5) and create a scatter plot for the entire data set of PERCENT_SURVIVING versus AGE_AT_DEATH. �(12.6)

12. Compare your scatter plot with the curves on the graph of the model of survivorship types presented in a reference book. Which type does your data resemble?

Students should see that their scatter plot data follows a pattern similar to the Type I survivorship curve. A best-fit curve drawn on their scatter plot would show a line with a curve similar to that of the line on the survivorship modeling graph shown in reference material.

13. How is the graph of your data different from the modeled data? What do you think accounts for these differences.

Student data might be less clear than the modeled data. Instead of a smooth curved line, their data points will be spread out, with outliers here and there. Students may note that their examination of the histograms for AGE_OF_DEATH revealed that, unlike the model, a few people died in infancy, a few as children and teenagers, and some as young and middle-aged adults. This may be particularly true in the earlier birth eras, but it will also hold true throughout the data set.

In contrast, the survivorship curve in the model suggests that very few people die before old age. Another difference between the graphs is that the parameters shown on the model are not the same as the parameters on the scatter plot. Students should point out that while the parameters are somewhat different, the result, a survivorship curve, is the same.

14. Create a scatter plot for the entire data set of AGE_AT_DEATH and PERCENT_SURVIVING for each of the additional three birth eras. �(12.6)

15. Do you see any difference in the patterns of scatter plots for the different birth eras? If so, what accounts for these differences?

Students might find that the plots for the earliest birth era look less like the modeled Type I survivorship curve and have a tendency to look like a Type II survivorship curve. If this is the case, students should mention the greater number of people dying in infancy, childhood, or as young adults. Students might also mention the lack of modern medical services or the possibility of wars or plagues as being responsible factors.

Part 4: Comparing scatter plots of cumulative mortality and survivorship

16. Create a scatter plot of the cumulative mortality of the entire data set by graphing AGE_AT_DEATH versus PERCENT DECEASED. �(12.6)

17. How does the cumulative mortality scatter plot compare with the survivorship scatter plot?

The cumulative mortality scatter plot is the mirror image of the survivorship scatter plot.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Describe some of the limitations in the design of the Cemetery Dynamics experiment in creating a survivorship curve for a community. In light of these limitations, how might the analysis of cemetery data prove useful?

To create a survivorship curve from data collected from a cemetery that accurately reflects a given population, the following factors would need to be true:

- All individuals who died in the population were interred in the cemetery.
- All individuals who were interred in the cemetery had grave markers with accurate dates of birth and death.
- No one moved in or out of the area during the test period.
- The birth era being studied ends at least 100 years (maximum expected life span for the vast majority of individuals) before the date of data collection.

These four conditions were not met in the Cemetery Dynamics experiment. Thus the data and analysis gives some information about survivorship trends, but any conclusions arising from the analysis would need to be substantiated using other means, such as examining county vital statistics archives to collect the data for further analysis.

The indications derived from the Cemetery Dynamics experiment could serve as the basis of hypotheses that could be tested using more thorough data collection procedures.

2. Devise a procedure to calculate the infant mortality rate by birth era. Perform the calculations, and compare the infant mortality rates of each birth era. What are some limitations to interpretation of this calculation?

First, the term infant must be defined. In this example, infant is defined as AGE_OF_DEATH is less than 2.

Second, a selection must be created for each birth era for all records with AGE_OF_DEATH less than 2.

A table must then be created with the following column headings: Number deceased with AGE_OF_DEATH less than or equal to 2, Number in COHORT, ratio of columns 1 to 2. The ratio represents the infant mortality rate (or number of infant deaths per 100 people in the population).

The comparison shows a difference in infant mortality rates, and these differences should be ranked.

The most important limitation of this calculation is that to be valid, all incidents of infant mortality would need to have been represented by a grave marker, which might not be the case. Furthermore, a statistical test would need to be applied to determine whether these differences represent a statistically significant difference between the birth eras.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. The percentage of the members of a population surviving at different ages can be represented by a(n)

- **A.** Age-structure curve.
- **B.** Exponential curve.
- **C.** Mortality rate curve.
- **D.** Intrinsic growth curve.
- **E.** **Survivorship curve.**

2. Factors that constitute important environmental resistance to human populations manifesting Type I survivorship curves in developing countries include:

- **A.** War.
- **B.** Famine.
- **C.** Disease.
- **D.** **All of the above.**
- **E.** None of the above.

3. Data required to generate a survivorship curve for a population in a given birth era include:

- **A.** Year of birth.
- **B.** Year of death.
- **C.** Total number of individuals in the population.
- **D.** Age at death.
- **E.** **All of the above.**
- **F.** Only B, C, and D.

Extended Inquiry Suggestions

Create survivorship curves using historical birth and death data located in the county government archives. Describe the reasons for any differences that might be seen between the cemetery data and the data on record in the county archives.

Map a second cemetery in your area and compare the results with the first cemetery.

Consult newspaper archives to identify factors that might have accounted for any increases in early mortality found in the historical data.

Consider pooling data from other lab sessions or even different years. Assign a portion of the graveyard that has not been previously mapped and continue to add additional data to the master data set. A more complete data set will yield better analysis results.

Energy Resources and Consumption

21. Energy Content of Food

Objectives

Students investigate and compare the energy content of energy-rich substances (foods) to determine:

- How much energy is stored in some common food items
- What type of food contains the most concentrated amounts of energy

Procedural Overview

Students measure the energy released from different types of foods by oxidative combustion (burning) through energy transfer into water in a closed container (calorimeter). From this they

- Calculate the amount of heat released from the food item based on the change in temperature of the water in the calorimeter
- Calculate the total amount of energy stored in each piece of food

Time Requirement

♦ Preparation time	15 to 60 minutes (shopping may be required)
♦ Pre-lab discussion and experiment	45 minutes
♦ Lab experiment	75 minutes (less if testing fewer items or if items are divided among groups)

Materials and Equipment

For each student or group:

- Mobile data collection system
- Temperature sensor
- Fast-response temperature probe
- Electronic balance
- Large base and support rod, rod and clamp
- Graduated cylinder, 100 mL
- One-hole rubber stopper (4), ~1 1/2" top diameter
- Aluminum pie pan (4)
- Marking pen
- Plastic straw
- Food sample[1] (4)
- Wooden matches or starter wand
- Paperclip, large (5)
- Aluminum soda can (4)
- Water, 200 mL
- Tape
- Cardboard box, large[2]

[1]Use a small marshmallow, a piece of popped popcorn, a peanut, and a cashew.

[2]If no ventilated hood is available indoors, a box serves as a wind break for burning food samples outdoors.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Food provides molecules that serve as fuel and building material for all organisms.
- ♦ Thermal energy is transferred by the collisions of atoms.
- ♦ Thermal energy transfers from warmer objects to cooler ones.
- ♦ Energy appears in different forms and can be transformed within a system.
- ♦ Whenever energy appears in one place, it must have disappeared from another.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Cellular Respiration and the Carbon Cycle
- ♦ Photosynthesis and Primary Productivity
- ♦ Investigating Specific Heat

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to your data collection system �(2.1)
- ♦ Starting and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Showing and hiding data runs in a graph �(7.1.7)
- ♦ Naming a data run �(8.2)
- ♦ Finding the values of a point in a graph �(9.1)
- ♦ Saving your experiment �(11.1)

Background

The entire food web depends on the primary productivity of autotrophs. Plants, for instance, consume much of the energy they capture by photosynthesis. They also store some of this energy in large energy-storage molecules. These are formed into energy-rich substances known as food. Other organisms eat this food to supply themselves with energy.

Living organisms convert this chemical energy to a chemical form that they can use for their life processes. This complex series of chemical reactions is known collectively as cellular respiration. The aerobic form of cellular respiration (which consumes oxygen gas) is summarized as follows:

$$C_6H_{12}O_6 + 6O_2 + 30ADP + 30Pi \rightarrow 6CO_2 + 6H_2O + 30ATP$$

The entire process of energy transfer during cellular respiration is tightly controlled by cellular enzymes. This efficient process results in a minimum amount of energy being released as heat. The chemical energy from the food is primarily stored in ATP molecules, which can be used by organisms for their life processes.

This same energy can be released from the food by the process of oxidative combustion, also known as burning. That is, energy-rich molecules containing carbon plus oxygen yield carbon dioxide plus water plus a lot of heat.

Combustion is similar to aerobic cellular respiration in that it releases chemical energy from food molecules. However, it differs from cellular respiration in that it requires a high temperature to initiate it. Such burning is wildly uncontrolled, causing all the energy to be lost as heat.

The amount of energy stored in food is measured in terms of calories. One calorie is equal to the amount of heat energy required to increase 1 gram (g) of water by 1 degree Celsius (°C). One calorie equals 4.186 joules (J), another unit used to measure energy.

How can we determine how much energy is stored in food? Theoretically, the amount of thermal energy from burning food equals the amount of thermal energy transferred to water. This statement assumes that no energy is lost to the surrounding environment. The following equation describes this concept:

$$Q = m \times c \times \Delta T$$

- Q is thermal energy (J)
- m is mass of water (g)
- c is specific heat of water (4.186 J/g °C)
- ΔT is the change in temperature of the water (°C)

Once Q is known, the energy in the food can be expressed as calories; Q (in Joules) divided by 4.186 Joules/calorie converts the energy from joules to calories.

The energy in food is commonly expressed in terms of kilocalories (1000 calories). A kilocalorie is also known as a large Calorie (a Calorie with an upper case “C”). Thus, declaring that an average adult man needs 2000 Calories of food each day means that he needs 2,000,000 calories. Gram calories, or small calories, are terms for calories with a lower case “c”.

Pre-Lab Discussion and Experiment

Engage students by holding a contest called "Guess How Many Calories."

1. After announcing the contest, make distinctions about calories.

- A calorie (lower case "c") is also known as a small calorie. It equals the amount of heat energy required to increase 1 gram (g) of water by 1 degree Celsius (°C). This equals 4.186 joules (J).
- A Calorie (upper case "C") is also known as a large calorie or a kilocalorie, which is 1000 small calories (lower case "c"). A Calorie (large calorie) is what people mean by the calories they are eating or avoiding. For instance, 200 calories in an "energy bar" means 200 kilocalories or two hundred thousand calories. Commonly, people may not pay attention to the distinction between the upper case and lower case "c" in the word calorie.

2. Show students one of each food sample they will use in the lab: a small marshmallow, a piece of popped popcorn, a peanut, and a cashew.

3. Ask students to write their guesses about how many Calories (kilocalories) are stored in each of these pieces of food.

4. Tell them that at the end of the lab, they will compare their guesses with the lab results. For each food, the smallest difference between the guesses and the lab results wins.

5. Draw a diagram of the experiment setup, and then ask the students the following questions.

a. Describe how the energy released from the burning of the food will be transferred to the calorimeter. Use the terms oxidative combustion, radiation, and conduction in your answer.

The burning (oxidative combustion) of the food releases heat energy that is primarily radiated upwards to the aluminum can. The can absorbs the radiated heat energy and transfers it to the water by conduction. The heat energy is distributed throughout the water by convection.

b. Do you expect all of the energy from the burning food to be transferred into the calorimeter? Why or why not.

No. Some of the heat energy will be lost to the air through radiation and not transferred to the aluminum can. Since the aluminum can is a highly efficient conductor of heat, some of the heat will radiate into the surrounding air in addition to transferring to the water in the can.

c. What parameter will be measured to quantify the amount of energy that is transferred?

The parameter that will be measured is the temperature of the water.

6. Introduce students to the formula $Q = m \times c \times \Delta T$ they will use to calculate the amount of energy transferred to the water in the calorimeter. (Refer to the Background information.)

7. Demonstrate how to convert energy in terms of *Q* (joules) to energy in terms of calories.

Divide Q by 4.186 joules/calorie.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Shop for the food items.
2. Pop some popcorn.
3. Have students bring in clean, empty aluminum soda cans.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Use appropriate caution with burning and hot materials, such as matches, starter wands, and foods.
- Conduct the lab in a well-ventilated area, preferably outside or under a ventilated hood.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Preparation

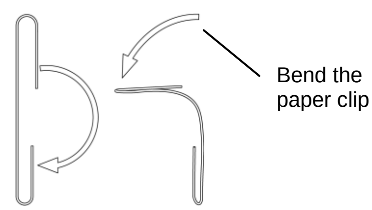
Set Up

1. Start a new experiment on the data collection system. � (1.2)

2. Connect the fast-response temperature sensor to the data collection system. � (2.1)

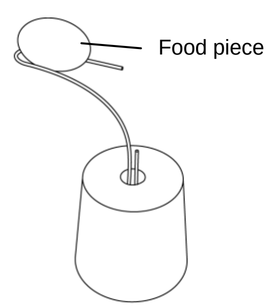
3. Display data on the graph to show Temperature versus Time. � (7.1.1)

4. Label each of four aluminum soda cans with one of the following: marshmallow, popcorn, peanut, and cashew.



5. Open a large paper clip, and bend the top half so it is perpendicular to the bottom half.

Note*:* Bend the paper clip over the side of a piece of cardboard or cover of a hard-cover book. The paper clip should form a flat platform to hold the food piece.



6. Insert one end of the paper clip into a one-hole rubber stopper as shown in the illustration.

7. Make three more paper clip platforms and insert each one in a rubber stopper.

Note: For the following instructions, use the balance to determine mass, and use Table 1 in the Data Analysis section when instructed to record data.

8. Determine the mass of each empty aluminum can, and record the data in Table 1.

9. Pour 50 mL of water into each can.

10. Determine the mass of each can plus water, and record the data in Table 1.

11. Determine the mass of each sample of food, and record the data in Table 1.

12. For each food sample, put a paper clip, rubber stopper and the sample of food into a pie pan.

13. Determine the mass for each set of a paper clip, a rubber stopper, a sample of food, and a pie pan, and record the data in Table 1.

14. Make a hanger for the soda can by bending open another paper clip.

15. Tape a plastic straw to the cord just above the bulb of the quick-response temperature probe.

Note: The straw taped to the sensor cord helps prevent the sensor from touching the can. This helps assure accurate measurements.

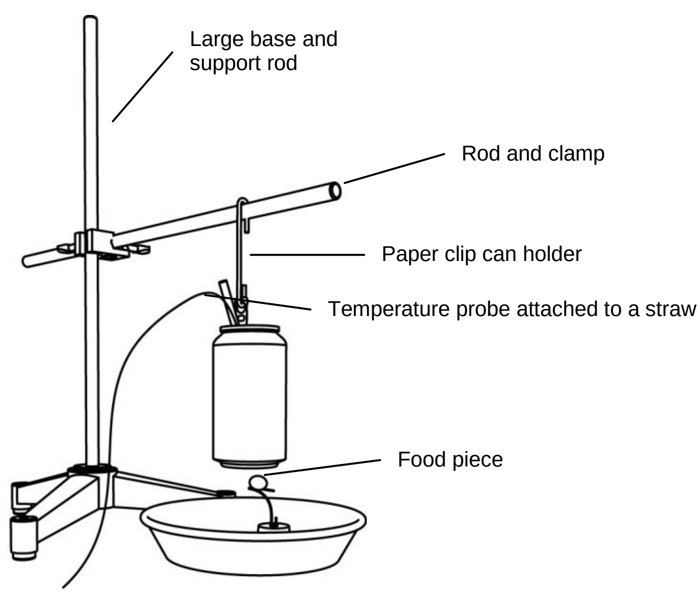
16. Take the setup to a ventilated hood inside or, alternatively, use a cardboard box outside as a wind break.

Note: The setup includes the data collection system, temperature sensor with a straw taped to the cord, and four sets of food samples with a paper clip and rubber stopper in a pie pan.

Part 2 – Measure the energy content of the marshmallow

17. Hang a soda can to the rod with the paper clip, and adjust the height of the rod stand so the bottom of the can is about one centimeter above the food sample on the paper clip platform in the pie pan.

Equipment setup



Note: Testing this adjustment before proceeding helps assure that the flame of the burning food sample will directly heat the can of water.

18. Hang the soda can labeled “marshmallow” on the rod with a paper clip.

19. Insert the straw taped to the sensor cord into the water, and tape the cord to the can so that the end of the probe does not touch the bottom or sides of the can.

20. Put the paper clip and rubber stopper in a pie pan close to the aluminum can, but not directly under it, and place the marshmallow on the paper clip platform.

Collect Data

CAUTION: Keep hair, clothing, and other items away from open flames.

Note: Whether indoors or outdoors, minimize air circulation when the food is burning. This helps assure that the flame stays lit and remains in contact with the bottom of the aluminum can. You can use a large cardboard box set on its side with the lid flaps extended to shelter the burning food from air movement. If the day is windy, consider postponing the experiment until a day when the winds are calm.

21. Start data recording. �(6.2)

22. Adjust the scale of the graph to show all data. �(7.1.2)

23. Using the wooden match or starter wand, begin burning the food sample.

24. Adjust the rod with the hanging soda can so the bottom of the soda can is directly over the burning food sample on the paper clip above the pie pan as shown in the equipment setup graphic.

25. Immediately after the food sample stops burning, gently twirl the can to stir the water with the probe still in it.

26. Stop recording data when the temperature stops rising, which may be about 30 seconds after the food sample stops burning. �(6.2)

27. Name the data run “Marshmallow”. �(8.2)

28. Remove the sensor from the soda can, and take the hanging soda can off the paper clip hanger.

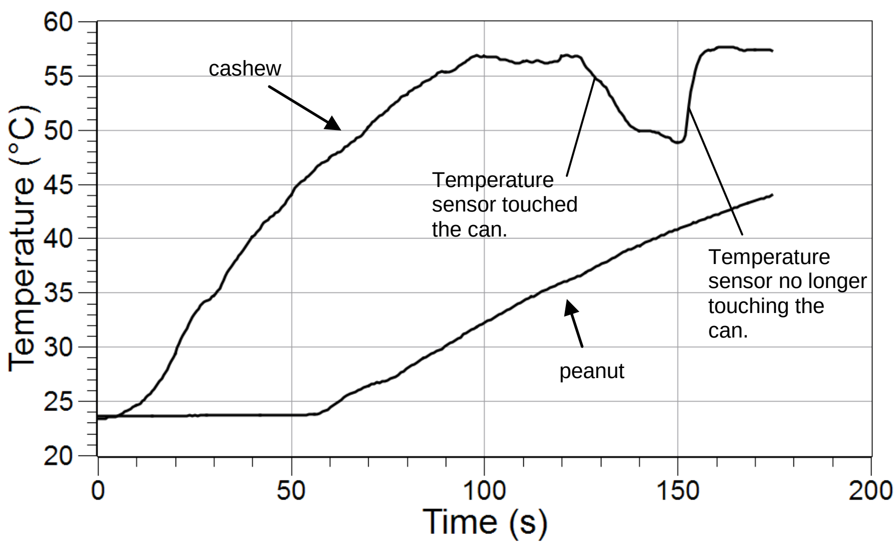
Part 3 – Popcorn, peanut, and cashew

29. Repeat the steps in Part 2 for the popcorn, the peanut, and the cashew.

30. Save your experiment �(11.1) and clean up according to your instructor's instructions.

Sample Data

This graph shows the temperature of the water in the calorimeter while food samples (peanut and cashew) are burning.



Data Analysis

For each food sample, many of the rows in Table 1 were filled in while completing the steps in the Procedure section. The following instructions help you calculate the remaining rows.

1. Display your run named "Marshmallow" on a graph of Temperature versus Time. �(7.1.7) Adjust the scale of the graph to show all data. �(7.1.2)

2. Find the initial and final temperatures �(9.1) and record these values in Table 1.

3. Repeat this procedure for your other three data runs.

4. For each food trial, determine the following and record the values in Table 1:

a. mass of the water

b. change in mass of the food sample after burning

c. change in temperature of the water

d. heat Q (in joules) transferred to the water ($Q = m \% c \% \Delta T$)

e. the energy content (calories) of the burned food sample in terms of calories, that is, the portion of the heat that was transferred to the water, which is equal to Q/(4.186 calories/joule)

f. energy (Calories) per gram of food burned

g. total energy (Calories) contained in the food piece

Table 1: Mass, temperature, and energy data for food samples

Item	Marsh-mallow	Popcorn	Peanut	Cashew
Mass of empty can (g)	48.0	48.4	15.6	14.9
Mass of can + water (g)	98.0	98.3	63.6	62.1
Mass of water (g)	50.0	49.9	48.0	47.2
Mass of food sample (g)	0.5	0.3	1.1	1.7
Before burning, mass of food sample + clip + rubber stopper + pie pan (g)	7.7	7.4	32.4	31.8
After burning, mass of food sample + clip + rubber stopper + pie pan (g)	7.3	7.2	31.9	31.3
Change in mass of food sample (g)	0.4	0.2	0.5	0.5
Water temperature before burning (°C)	22.8	23.3	23.6	23.6
Water temperature after burning (°C)	24.2	30.7	47.3	57.5
Change in temperature, ΔT (°C)	1.4	7.4	23.7	33.9
Heat Q transferred to the water (joule)	293	1546	4762	6698
Energy content of burned food (calorie), Q/(4.186 calories/joule)	70	369	1138	1600
(Large) Calories/gram of food sample	0.2	1.8	2.3	3.2
Total Calories in food sample (Calorie)	0.1	0.6	2.5	5.4

Analysis Questions

1. According to the United States Department of Agriculture (USDA), there are about 5.9 Calories in 1 gram of peanuts. What percentage of this accepted value was measured in your calorimeter?

Answers will vary, but in this example, the calorimeter captured 39% of the total energy in the peanut:

(2.3 measured Calories/gram ÷ 5.9 USDA Calories/gram) X 100 = 39%

2. Assume you had similar percentage for the other food items. What would be the accepted value for the other food samples?

For this example data:

- Marshmallow: 0.2 ÷ 0.39 = 0.5 Calories/gram
- Popped popcorn: 1.8 ÷ 0.39 = 4.6 Calories/gram
- Peanut: 2.3 ÷ 0.39 = 5.9 Calories/gram
- Cashew: 3.2 ÷ 0.39 = 8.2 Calories/gram

3. Compare your predictions with your data.

Answers will vary, but students should mention predicted and actual findings of the food samples with the highest and lowest number of Calories.

4. For the contest, add the total (adjusted) Calories from the four samples. Add this total to the total of every experiment in the class. Divide this grand total by the number of experiments in the class to calculate the average number of Calories for these four samples. The guess that came closest to this average wins the contest.

For this example, the total number of Calories contained in the 4 food pieces is 19.2 Calories.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Carbohydrates and proteins contain 4 Calories/gram, whereas fats contain 9 Calories/gram. From this information, what can you say about the composition of the 4 food items you tested?

To answer this question, the calculated value of Calorie/gram must be corrected for the calculated efficiency of the calorimeter (39% in this example). For this example, the corrected values would be the following:

Marshmallow = 0.2 ÷ 0.39 = 0.5 Calories/gram

Popped popcorn = 1.8 ÷ 0.39 = 4.6 Calories/gram

Peanut = 2.3 ÷ 0.39 = 5.9 Calories/gram

Cashew = 3.2 ÷ 0.39 = 8.2 Calories/gram

An answer based on results like the one in this example would be something like the following: Based on the equivalent reference of Calories per gram, marshmallows probably have no fat. Popcorn has some fat. Peanuts have more fat than popcorn. Cashews have the most fat. There is no way from this experiment to make any comparison of carbohydrates versus protein since they contain the same Calories per gram.

2. What happened to the heat that was not captured in this calorimeter?

Some of it was transferred directly to the surrounding air by radiation. Since the aluminum can is a highly efficient conductor, most of the heat that did not transfer to the water radiated into the air.

3. What happened to the mass that was lost during burning?

During combustion (oxidation) of the carbohydrates and fats, the carbon, oxygen, and hydrogen in these molecules, together with the oxygen gas, were recombined into carbon dioxide and water vapor and released into the air. A small amount of unburned carbon was also released into the air in the form of smoke.

4. Conduct research on the process using bomb calorimetry that is usually used to determine the caloric content of food. Describe the process.

In a bomb calorimeter, electrical energy is used to ignite the food piece. The calorimeter is pressurized with excess pure oxygen. The energy released by the combustion of the food raises the temperature of the steel bomb, its contents, and the surrounding water jacket. The temperature change in the water is then precisely measured. This temperature rise, along with a bomb factor (which is dependent on the heat capacity of the metal bomb parts) is used to calculate the energy produced by the fuel burnt. A small correction is made to account for the electrical energy input and the burning fuse.

5. Discuss the role of plants in the energy cycle of living organisms. Why is the productivity of plants of concern to other organisms?

The process of converting CO_2 and water into energy-rich organic molecules is called primary production. Autotrophs, through the process of photosynthesis, are the most important primary producers in any food web. Most other organisms in food webs depend on the primary productivity of plants. Primary consumers eat plants or their fruits and seeds, as the source of their food energy, while secondary consumers eat primary consumers for their food energy.

6. Discuss the similarities and differences of aerobic cellular respiration and oxidative combustion (burning).

During both aerobic cellular respiration and oxidative combustion, energy-rich organic molecules are converted to CO_2 and water with the release of energy. Both involve oxidation that requires oxygen. However, oxidative combustion is an uncontrolled process. The energy is released rapidly as heat directly into the environment. In contrast, aerobic cellular respiration is a highly controlled process. It occurs more slowly in multiple biochemical steps. The energy released is captured in chemical bonds in ATP molecules. These ATP molecules can then fuel biosynthetic reactions in a living cell.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. A calorie is defined in terms of a certain amount of what?

- **A.** Food
- **B.** Weight in milligrams
- **C.** **Heat**
- **D.** Fat
- **E.** Carbohydrate

2. Which foods have the greatest density of calories?

- **A.** Carbohydrates
- **B.** Sugars
- **C.** Starches
- **D.** **Fats**
- **E.** Proteins

3. When foods are burned by combustion or oxidized during cellular respiration, in what form is the mass lost to the environment?

- **A.** Energy
- **B.** Carbon dioxide
- **C.** Water vapor
- **D.** Oxygen gas
- **E.** **Both B and C**

Extended Inquiry Suggestions

Challenge students to design and test calorimeters that are more efficient in capturing the energy released during the combustion of foods.

22. Global Resources and Energy Consumption

Objectives

Students determine the present state of the global energy resource economy and the use of alternative forms of energy based on global production and consumption. To do this, they:

- Analyze resource data to determine the global distribution and use of energy resources.
- Explore connections between fossil fuel production and consumption.
- Examine alternative energy use and its relationship to the use of fossil fuels.

Procedural Overview

In this experiment, students analyze global energy resource data for fossil fuels and renewable sources. Students look at the energy production and consumption of each resource and:

- Use My World GIS to determine which countries have the greatest quantity of resources
- Explore the relationship between a country's production and consumption of energy resources
- Contrast the data for individual countries with data calculated per capita
- Identify countries that use alternative energy sources and compare that to its use of fossil fuels

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	40 minutes

Materials and Equipment

For each student or group:

- Computer with My World GIS™ installed
- Computer with an Internet connection
- Project file: Global Resources and Energy Consumption.m3vz

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Sources of global energy, including coal, oil, electricity, natural gas, and renewable resources
- ♦ Members of OPEC, OECD, and the post-Soviet states and why they are important to the international resources market
- ♦ Basic trends of supply and demand and their affect on the economy and ecology

Related Labs in This Guide

There are no other labs related to this lab.

Using My world GIS

Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

- ♦ Opening a project file �(12.1.1)
- ♦ Showing or hiding data selections �(12.3.2)
- ♦ Changing the fill color of a layer in the layer list �(12.3.5)
- ♦ Opening a table �(12.4.1)
- ♦ Sorting the data in a table �(12.4.1.1)
- ♦ Editing the appearance of a layer �(12.2.5)
- ♦ Using the Zoom In and Zoom Out Tool �(12.4.3)
- ♦ Using the Zoom to Active Layer Tool �(12.4.4)
- ♦ Using the Pointer Tool �(12.4.6)
- ♦ Adding a field to a layer by math operation �(12.5.4)

Background

World Energy Consumption

In 2004, the total world energy consumption was estimated to be 15 terawatts, with 86.5% of that energy from the burning of fossil fuels. The world's energy resources are abundant. Petroleum has become the most widely used form of energy, with coal following as a close second. However, neither of these resources, unfortunately, is renewable.

Due to the Industrial Revolution, when the world's manual-based labor was replaced with machinery and engines, consumption of energy resources (primarily fossil fuels) began to grow. In the 20th century in particular—from the 1920's through the 1970's—the use of fossil fuels increased twenty-fold as the price of oil steadily dropped. In the mid-70's, oil price shocks occurred when the price of a barrel of oil jumped from 5 dollars to 45 dollars.

During this time, countries attempted to decrease their dependence on oil through the use of coal. Today, while petroleum and coal are the primary sources of energy, environmental concerns are turning producers and consumers to more efficient and "green" forms of energy sources. Photovoltaic cells, for example, are becoming more popular in the face of strict constraints against burning coal and oil.

Renewable Energy Sources

Renewable energy today provides only 7% of the world's total energy and comes in a variety of forms, including hydroelectric, biofuel, wind, solar, and geothermal power. The sun is the world's largest source of renewable energy, dwarfing all other forms of energy combined in the amount of energy it makes available. Hydroelectric power is popular in the largest of the Asian countries, though Canada is the largest producer of hydroelectric power in the world.

Bioethanol, an alternative to gasoline, has increased in production and popularity as gas prices increase around the world. Solar power is the most abundant form of renewable energy that the world possesses, and some scientists believe it would take very little time and money to harness enough energy to wean the world off fossil fuels.

Although there is no widespread consensus as to the status of the world's oil, coal, or natural gas reserves, some experts estimate that oil reserves will be depleted in approximately 35 years, and coal will run out in approximately 200 years. Regardless of when or how, severe economic disturbances will take place when resources begin to run low.

Pre-Lab Discussion and Experiment

Plan to discuss units of measurement for the given data. Consumption, production, and reserve information is given in a variety of units, such as thousand barrels and billion barrels.

Show students various unit equivalents and conversions. For example:

1 barrel = 42 gallons crude oil

42 gallons crude oil = 19.6 gallons refined gasoline

1 metric ton (2205 lb or 1000 kg) = 1.10231 short tons (2000 lb or 907 kg)

(or 1 short ton = 0.907185 metric tons)

1 kilowatt-hour is the amount of electrical energy consumed when 1,000 watts are used for one hour.

Instructor Tip: The amount of usable gasoline obtained from 1 barrel, or 42 gallons, of crude oil is significantly less after refining. Remind students that not all refined oil is used for gasoline. This reduces oil reserves available for fuel even further.

Lab Preparation

These are the appropriate preparations prior to the lab.

1. Be sure students can access the My World GIS program from their computers.

2. Make the project file, Global Resources and Energy Consumption.m3vz, available to students.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

Set Up

1. Open the Global Resources and Energy Consumption project file (Global Resources and Energy Consumption.m3vz). �(12.1.1) The following layers are in the Layer List:

- ***Hydroelectric Power Generation (U.S. 2007)*** – displays hydroelectric power generation (in thousand megawatt-hours) for 2007 in the United States.
- ***Energy Production and Consumption*** – contains multiple layers that display global production or consumption of various resources, including natural gas, oil, electricity, and coal. This layer also includes consumption of hydroelectric power and other renewable energy resources, including geothermal, solar, wind, wood, and waste electric power.
- ***Oil Reserves*** – displays total oil reserves available in the world's countries (in billion barrels) for 2005). This layer does not contain data for tar sands or other such sources of oil.
- ***Oil Reserves of OPEC Nations*** – displays total oil reserves (2005) available in countries associated with the Organization of the Petroleum Exporting Countries (OPEC).
- ***Natural Gas Reserves*** – displays total natural gas reserves available in the world's countries (in trillion cubic feet, for 2004).
- ***Coal Reserves*** – displays total coal reserves available in the world's countries (in short tons, for 2004).
- ***Countries*** – displays an outline of all world countries.

Data Analysis

Part 1 – Coal, oil, and natural gas

Coal producers and consumers

1. Click to highlight the Energy Production and Consumption layer. Open the data table for this layer. �(12.4.1)

2. Arrange the Coal Production column data in descending order. �(12.4.1.1)

3. Which five countries are the largest coal producers?

The top five coal producing countries are China, United States, India, Australia, and Russia.

4. Look at the entire column in the data table that contains the data for coal consumption. Is there a country that is a major producer of coal but not a major consumer?

Indonesia

5. Sort the Coal Consumption column in descending order and list the top 5 coal consumers. �(12.4.1.1)

China, United States, India, Germany, Russia.

6. Examine the coal consumers and coal producers. Is there a country that is a major consumer of coal but not a major producer?

Japan

7 Which of the top 5 coal producers can meet the demand for coal within their own country without importing additional coal from a foreign source?

China, United States, Australia, and Russia produce more coal than they consume. However, India consumes more than it produces.

8. Close the data table, hide the Energy Production and Consumption layer, and show the Coal Reserves layer. �(12.2.4)

9. Highlight the Coal Reserves layer.

10. Looking at the pattern of the map, does anything surprise you? What pattern do you see?

Students may note that the United States has the largest coal reserves. Russia, China, India, and Australia also have large coal reserves, compared to the rest of the world.

11. Open the data table for the Coal Reserves layer and arrange the Coal Reserves column data in descending order. �(12.4.1)

12. Which five countries have the largest reserves of coal?

The United States, Russia, China, India, and Australia.

13. Compare these countries to the greatest producers of coal. Do you see any trend? Are these countries consuming large amounts of coal and producing large amounts of coal for consumption and exportation? Explain your answer.

The five countries with the largest reserves of coal are the same five that produce the largest amounts of coal in the world. What appears to be happening is that these five countries, with the exception of India, are producing only the necessary quantities of coal to cover the consumption needs within their own countries and do not appear to be producing any for export.

14. Calculate the time that it would take for China and the United States to completely consume their respective coal reserves (Hint: Divide total tons by tons consumed per year.)

United States: 267,312 tons/1107.2 tons per year = 241.5 years.

China 126,215 tons/2062.4 tons per year = 61.2 years.

Oil producers and consumers

15. Hide the Coal Reserves layer and show the Oil Reserves layer. �(12.2.4)

16. Looking at the pattern of the map, does anything surprise you? What pattern do you see?

Note: Countries in grey either do not have data available or do not have any appreciable oil reserves.

Students may note that the Middle East, Russia, and Venezuela have larger oil reserves than the rest of the world.

17. Display the histogram for the Oil Reserves layer and select the Oil Reserves field. �(12.4.2) What is the total amount of known oil reserves for all countries?

1215.5 billion barrels.

18. How long, at current consumption rates, will these oil reserves last?

47.56 years

1215.5×10^9 barrels $\div$ 7.88×10^7 barrels/day $=$ 1.5425×10^4 days = 15425 days
15,425 days $\div$ 365 days/year $=$ 42.26 years

19. Close the histogram. Hide the Oil Reserves layer and show the Oil Reserves of OPEC Nations layer. �(12.2.4)

20. Looking at the pattern of the map, does anything surprise you? Where are most of the OPEC nations located?

Students should note that the majority of OPEC nations are located in the Middle East and northern Africa, with some potentially surprising members in central Africa and northern South America.

21. Find the total amount of oil reserves for the OPEC nations.

Table 1: Total OPEC nation oil reserves

Name of OPEC Country	Oil Reserves in Billion Barrels
Algeria	12.3
Angola	9
Ecuador	4.9
Indonesia	4.2
Islamic Republic of Iran	137.5
Iraq	115
Kuwait	101.5
Libyan AJ	41.5
Nigeria	36.2
Qatar	26.9
Saudi Arabia	264.2
United Arab Emirates	97.8
Venezuela	80
TOTAL Oil Reserves:	931

22. What percentage of total proved global oil reserves belongs to the OPEC nations?

Note: "Proved" reserves are estimated quantities that analysis of geologic and engineering data indicates, with reasonable certainty, are recoverable under existing economic and operating conditions.

931 billion barrels/1215.5 billion barrels = 0.766 = 76.6%

23. Hide the OPEC Oil Reserves layer. �(12.2.4)

24. The United States has a small amount of the world's oil resources but consumes a large percentage of the total amount consumed by all nations. Support this fact with data from your project file.

According to the data table for the Oil Reserves layer, the world's known oil reserves total 1,251.5 billion barrels. The United States has only 29.9 billion barrels (2.5%) of known oil reserves.

Total global oil consumption, according to the Oil Consumption histogram of the Energy Consumption and Production layer, is 78,818 thousand barrels per day. Of this total global consumption, the United States consumed about 20,731 thousand barrels per day, approximately 26%.

25. Where does the United States rank, relative to other countries, in the following categories (Hint: Use a data table to find the appropriate rank.)

- United States oil production ___3rd___
- United States oil consumption ___1st___
- United States oil reserves ___11th___

26. Explain the production and consumption patterns of oil in the United States, and how they relate to the country's reserves.

The United States consumes over two times as much oil as it produces each year. In order to meet the needs of the population, the United States imports large quantities of oil from foreign sources. The United States has begun to use more of its oil reserves in order to decrease dependence on foreign oil exporters. However, a number of federally protected areas sit atop these reserves. Drilling in these areas, such as the Arctic National Wildlife Refuge, is currently prohibited, so the amount of oil the United States can use of its reserves is limited and the quantity of this oil cannot be clearly determined.

27. Do you think the United States is in the top ten for *per capita* consumption of oil? Why or why not?

Students are likely to answer that the United States will be among the top 10 and they are likely to suggest that it will be among the highest of those. The United States is the largest consumer of oil in the world, with the 3rd highest population. However, there are a number of countries with very small populations that use a significant amount of oil in relation to their population. Therefore, the per capita consumption of oil in other countries is much higher.

Students will calculate these figures (in the coming steps) and find that the United States is 16th in the list of per capita consumption of oil (15th if Antarctica is excluded because of its lack of a permanent population).

28. In the Analysis window, �(12.5), add a field in the Energy Production and Consumption layer for per capita consumption. �(12.5.4) Create this field by computing the quotient of Oil Consumption divided by Population (2005)/100,000.

Note: Dividing the total population by 100,000 is necessary so the per capita numbers are not too small.

29. Once you have created the field, edit its appearance. �(12.2.5) Change the color interval under “Classify By” from "Equal Interval" to "Natural Breaks."

30. How does the United States compare to other nations in per capita oil consumption?

The United States is 16th in per capita oil consumption. Numbers 2 through15 are all small countries, mostly islands, whose oil consumption in relation to their small populations is very high. There is no permanent population in Antarctica— there is a staff of researchers that ranges from 1000 to 4000 people.

31. What nations have the top 5 per capita consumption of oil (exclude Antarctica because it has no permanent population)?

Virgin Islands, Gibraltar, Netherlands Antilles, Singapore, United Arab Emirates

32. Compare these answers to your earlier prediction. Were you surprised by the result? Why is the oil consumption per capita in a country like Gibraltar so high?

Students will likely be surprised at the results. The oil consumption per capita in Gibraltar may be high due to its shipping trade. It has several hundred ships as part of its merchant marine fleet and is also adjacent to one of the world's busiest shipping lanes, as it is situated at the entrance to the Mediterranean Sea. It may provide fuel as a service to passing ships, as well as for its own.

33. Look at the per capita consumption of Africa. Many countries in Africa have very large populations but very low per capita consumption. Why do you think this is the case?

Much of Africa is still under-developed and oil consumption is limited to large, well-developed cities like Cairo and Johannesburg. Additionally, much of the African population lives in rural towns and villages where access to oil-consuming equipment is limited.

Natural gas producers and consumers

34. Hide the Energy Production and Consumption Layer and show the Natural Gas Reserves layer. �(12.2.4)

35. Looking at the pattern of the map, does anything surprise you? What pattern do you see?

Answers will vary. Students should see that Russia has the largest natural gas reserve, with Iran having the next largest reserve.

36. Open the data table for the Natural Gas Reserves layer and arrange the Natural Gas Reserves column data in descending order. �(12.4.1)

37. Which five countries appear to have the largest reserves of natural gas?

Russia, Iran, Qatar, Saudi Arabia, and the United Arab Emirates hold the largest reserves of natural gas.

38. Compare these countries' natural gas reserves to their natural gas production and consumption using this data table and the data tables for Natural Gas Production and Natural Gas Consumption from the Energy Production and Consumption layer. Do you see any trend? Are these countries producing large amounts of natural gas for consumption and export? Explain your answer.

Except for Iran, all of these countries are producing enough natural gas for their own consumption. Russia and Qatar produced more natural gas than they consumed and may be exporting it.

Part 2 – Global hydroelectric power

39 Close the data tables, hide the Natural Gas Reserves layer, and show the Energy Production and Consumption layer. �(12.4.1)

41. Predict where you think hydroelectric energy is being used. Are these countries in which coal, oil, or natural gas would be available?

Student answers will vary. Students might predict that the countries that are the top consumers of coal, oil, and natural gas (Russia, Canada, United States, and China) are also the largest consumers of hydroelectric power. Some students might predict that the countries using the least amount of oil, natural gas, and coal are the greatest consumers of hydroelectric power. Other students might predict that countries with larger coastlines or waterways are the greatest consumers.

42. Change the fill color to Hydroelectricity Consumption �(12.4.2.4) and open the data table. �(12.4.1)

43. Looking at the pattern of the map, does anything surprise you? What pattern do you see?

Students should observe that Canada, China, Brazil, the United States, and Russia stand out as the greatest consumers of hydroelectric power.

44. Check your predictions. Which five countries are the greatest consumers of hydroelectric power? How does the quantity of these countries' hydroelectric power consumption compare to their consumption of the other resources you have looked at?

Canada, China, Brazil, United States, and Russia are the five greatest consumers of hydroelectric power. Canada did not appear on the lists of top consumers of oil, coal, or natural gas, nor did Brazil, which suggests that these countries are using hydroelectric power as one of their main sources of energy.

45. Since all the countries listed above have very large populations, it is hard to tell how aggressive a country is about using hydroelectric power. Create a "Per Capita Hydroelectricity Use" field in the Energy Production and Consumption layer. Use the same instructions you used for creating the Per Capita Oil Consumption field but use the hydroelectric power consumption field instead. � (12.5.4)

46. What 5 countries have the highest *per capita* hydroelectricity use?

Iceland, Norway, Canada, Paraguay, and Sweden

47. Using data from the Hydroelectricity Consumption and the Electricity Consumption fields, determine how the United States compares to Norway in terms of percentage of electricity that comes from hydroelectricity. Show your calculations.

Norway: $$\frac{\text{107.7 billion kilowatt-hours/year from hydroelectricity}}{\text{112.8 billion kilowatt-hours/year total electricity consumed}} \times 100 = 95.5\%$$

United States: $$\frac{\text{268.4 billion kilowatt-hours/year from hydroelectricity}}{\text{3657.5 billion kilowatt-hours/year total electricity consumed}} \times 100 = 7.3\%$$

48. In the Energy Production and Consumption layer, change the fill color to Renewable Energies Consumption. � (12.2.5)

49. Use the Pointer Tool � (12.4.6) or data table � (12.4.1) to view each country's renewable energy consumption. Compare the five countries with the highest consumption of hydroelectricity to the renewable energy consumption of the same countries.

The five countries with the highest consumption of hydroelectricity are Canada, China, Brazil, United States, and Russia. The five countries with the highest renewable energy consumption are the United States, Germany, Spain, Brazil, and Japan. The United States and Brazil are the only countries within the top five countries with the highest consumption of both hydroelectricity and renewable energies.

50. Are these countries making an effort to consume more renewable resources and reduce their use of fossil fuels? Give an example to justify your answer.

Each of these five countries consumes much less of the other renewable energy sources than of hydroelectric power. However, Brazil and the United States consume more of the other renewable energy resources than China, Russia, or Canada. It does appear that these countries are attempting to use renewable energy sources as a more energy-efficient, and possibly less expensive, way of providing energy for their countries. Brazil, for example, consumes very little coal, natural gas, or oil but ranks third in the consumption of hydroelectricity.

Part 3 – Hydroelectricity in the United States

51. Hide all previous layers, and show the Hydroelectricity Generation (2007) layer. � (12.2.4) Click to highlight this layer.

52. Use the Zoom To Active Layer Tool to zoom in on the United States. �(12.4.3)

53. Which state produced the most hydroelectricity in the United States for 2007?

Washington State was the top producer of hydroelectric power in the United States for 2007.

54. Use the histogram �(12.4.2) or the Statistics Tool �(12.4.8) to calculate the percent of the total hydroelectric power generation in the United States that was contributed by Washington State.

Washington State: 20,857 thousand kilowatt-hours/year

United States: 69,103 thousand kilowatt-hours/year

20,857/69103 = 30.2%

Analysis Questions

1. In general, are larger countries making an effort to reduce their use of fossil fuels and increase their use of cleaner, renewable energy? Explain your answer.

In general, only a few countries are using renewable energy resources. Brazil consumes very little coal, natural gas, or oil but consumes large amounts of hydroelectricity, suggesting that the country is making an effort to use renewable resources rather than fossil fuels. However, other large consumers of fossil fuels are using very few renewable energy resources. Many of these countries also have large reserves of fossil fuels that may be leveraged in several ways if a coal, oil, or natural gas crisis occurs.

2. Use the Pointer Tool to determine how many gallons of gasoline are used every day in the United States (Energy Production and Consumption layer, with the Fill Color set to Oil Consumption). �(12.4.6) **Calculate the number of gallons of refined oil consumed per day from the number of barrels consumed per day.**

9,674,560 gallons of refined gas used each day in the United States:

$$20731.2 \text{ thousand-barrels (crude) per day} \times \frac{1000 \text{ barrels (crude)}}{1 \text{ thousand-barrel (crude)}} \times \frac{19.6 \text{ gallons (refined gas)}}{42 \text{ barrels (crude)}}$$

$$= 9{,}674{,}560.0 \text{ gallons (refined gas) per day}$$

This quantity should surprise students. According to this number, the United States consumes more than 3.5 billion barrels of gasoline every year for transportation, industry, heating, and so on. United States production of oil is not even one third of the required amount to cover the daily consumption rate.

3. Explain the difference between energy consumption or production quantities per country and energy consumption or production quantities per capita. Explain when per capita consumption might be more appropriate.

Consumption or production quantities per country provide information related to an entire country. These quantities do not take into account the size of the country or the population of the country. Energy consumption or production quantities per capita provide information about the energy use per person.

Per capita data may be more appropriate when comparing the consumption of energy of countries. An industrial country with a large population likely uses more energy than one with a small population, so determining the amount of energy consumed per capita provides better insight into the consumption patterns of the people of a country.

Synthesis Question

Use available resources to help you answer the following questions.

1. In what ways does geography play a role in the type of energy resources a country will use? Give examples to support your argument.

There are at least two possible reasons: 1) Indonesia, for example, is much less developed and has a lower dependence on electricity, or 2) because Indonesia is a member of OPEC it has the political impetus and infrastructure to be a strong exporter of fuels. Japan is just the opposite, with a large electricity demand and very few natural resources.

2. If oil reserves become completely depleted, which form of energy do you propose would be best to use in place of oil? Why?

Student answers will vary. Natural gas burns cleaner than fossil fuels, has a later peak date, and costs about half as much as oil. Coal, however, is in much higher abundance than natural gas, and is readily used around the world. Hydroelectricity and other renewable energy sources (such as wind) are the cleanest forms of energy, but because so few countries have the technology in place to produce and use them, they would be costly to implement.

3. Is your energy proposal more economically sound or more environmentally friendly? Use the Internet to perform some research (see several organizations listed below). What do you think is more important?

Energy Information Administration

Union of Concerned Scientists:

Answers will vary. The most economically friendly solution would be coal. The most environmentally friendly solution would be hydroelectric and other renewable energy sources (such as wind). The best combination of the two would be natural gas.

4. The calculated time frames for the United States (241 years) and China (61 years) to completely consume their coal reserves are different than projections made by scientists (300 years). Why?

The calculated time frames do not account for increases or decreases in the efficiency of coal over time. Also, different sources analyze the data differently.

5. Based on the data you have seen, how do you expect the world energy market *in general* to change if resources (oil in particular) begin to run low? If this happens, which countries will be susceptible to the most drastic changes?

In general, if oil resources begin to run low, the market price of oil produced by countries with large reserves will skyrocket. Prices will be driven up even further because those countries with the largest reserves are OPEC countries, which will create a monopoly on the oil industry. In addition, market prices of other resources, such as coal, natural gas, and even renewable energies, will increase due to demand from those countries that will not pay higher oil prices.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Advantages of using natural gas as an energy source include all of the following *except*:

- **A.** Natural gas burns cleaner with lower carbon emissions than oil.
- **B. Natural gas is highly combustible.**
- **C.** Natural gas is cheaper to burn than oil.
- **D.** Natural gas can be transported directly to the user from the source, bypassing refinement processes that oil must undergo.
- **E.** Natural gas is abundant in the United States, making import from foreign countries unnecessary.

2. Which of the following negative environmental impacts are due to the extraction or burning of coal?

- **A.** Burning coal releases sulfur and carbon dioxide into the atmosphere, which can result in acid rain.
- **B.** Mine tailings exposed to water can result in acid mine drainage.
- **C.** Strip mining and mountaintop removal damage the environmental value of the surrounding land and can release coal dust and fly-rock into the air.
- **D.** Coal waste products contain heavy metals, including arsenic, lead, and trace levels of uranium that are extremely dangerous and can result in radioactive contamination.
- **E. All of the above.**

3. Which of the following renewable resources is *not* considered a perpetual resource?

- **A. Geothermal energy**
- **B.** Hydroelectricity
- **C.** Solar radiation
- **D.** Wind
- **E.** Tidal power

4. Biomass is a type of biofuel that depends upon which biogeochemical cycle?

- **A.** Phosphorous cycle
- **B. Carbon cycle**
- **C.** Water cycle
- **D.** Sulfur cycle
- **E.** Nitrogen cycle

5. Extraction of a petroleum substitute from oil shale:

- **A.** Requires more processing and refinery than crude oil.
- **B.** Can result in acid drainage due to the mining process.
- **C.** Is less costly than extraction of conventional fossil fuels.
- **D.** **A and B.**
- **E.** None of the above.

23. Wind Power Development

Objectives

Study the feasibility of harnessing wind power in various locations by using a specific set of energy data. Students will:

♦ Examine the strength of winds that blow across North America.

♦ Compile a list of cities that are good candidates for the development of wind power.

Procedural Overview

Students gain experience conducting the following procedures:

♦ Using a variety of criteria to determine some of the best places in the United States to build a wind farm

♦ Creating a data selection in My World GIS for ideal power class range and using this layer as the master layer from which all other data selections will be defined

♦ Creating a series of crossed data selections using the power class layer to narrow a list of US cities with potential for wind power development

Time Requirement

♦ Preparation time	10 minutes
♦ Pre-lab discussion and experiment	10 minutes
♦ Lab experiment	45 minutes

Materials and Equipment

For each student or group:

♦ Computer with My World GIS™ software installed

♦ Computer with access to the Internet

♦ Project file: Wind Power Development.m3vz

Concepts Students Should Already Know

Students should be familiar with the following concepts:

♦ Wind power classes

♦ The relationship between locale, elevation, and wind speed

Related Labs in This Guide

- ♦ Radiation Energy Transfer
- ♦ Insolation and the Seasons
- ♦ Mapping and Understanding Weather Systems
- ♦ Tracking Weather

Using My World GIS

Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

- ♦ Opening a project file �(12.1.1)
- ♦ Arranging layers �(12.2.2)
- ♦ Hiding or showing a layer �(12.2.4)
- ♦ Opening a table �(12.4.1)
- ♦ Creating a selection from records in a table �(12.4.1.2)
- ♦ Using the Zoom In and Zoom Out Tools �(12.4.3)
- ♦ Using the Pointer Tool �(12.4.6)
- ♦ Opening the Analysis window �(12.5)
- ♦ Selecting records from a layer by value �(12.5.1)
- ♦ Selecting records by crossing two layers �(12.5.2)
- ♦ Selecting records by distance relationship �(12.5.3)

Background

Wind Energy

Wind energy is a form of converted solar energy and is a green renewable resource. The sun heats land and water at different rates during the day and night. As a result of these differences, the atmosphere around the Earth heats and cools at different rates. A large air mass that heats significantly will develop low pressure, as warm air tends to rise. Large air masses that chill over cold bodies of water, polar regions, or mountains develop high pressure as cool air sinks and piles up. When a warm air mass comes close to a cold air mass, the pressure will normalize as air from the high pressure mass rushes toward the low pressure mass of warmer air. The result is wind.

Winds are classified according to their speed. Breezes can range from 5 – 30 mph (6 – 50 km/hr). Around 35 mph (kmh) winds are known as a gale. Storm force winds are greater than 55 mph (88 kmh), with winds stronger than 74 mph being called a hurricane. For wind power, short term strong or gusty winds would not be of value. Sustained winds known as moderate or strong breezes are most useful for wind power production.

Some areas are naturally windy, such as a river valley, which channels air into a narrow topography. Mountains also cause air movement to be predictable; warmed air rises up the windward flank of mountains, cools as it passes over the tops of the mountains, and sinks down the leeward side. Sea coasts are windy because of the differential heating of the land and the water. In general, wherever wind is found, wind trends are gradual. That is, big winds taper off gradually rather than stop abruptly, making wind a reliable source of renewable energy.

Harnessing Wind Energy

Wind energy is harnessed using turbines, bladed structures that capture wind and convert it into electricity. Turbines can be built on farms and mountainsides to provide electricity to nearby towns and cities. The success of the turbines in generating energy depends upon the wind power density of the area, known as wind power class.

Wind power generation is limited by its capacity and availability factors. The capacity factor is defined as the amount of power produced over a given time divided by the power that would have been produced had the turbine operated at maximum output 100% of that time. The availability factor refers to the amount of time that the turbine itself is ready and able to generate power. Wind turbines have a larger availability factor than any other power generation system.

Additionally, the strength of the wind at a given location is rated for the amount of power it can potentially produce based on its average speed and power density. The scale is set by the Department of Energy’s National Renewable Energy Laboratory and is from 1 to 7 (1 is least and 7 is greatest). This is called the wind power class. A rating of around 4 is generally a suitable power class for the development of wind power.

Environmental Concerns

Environmentalists have expressed concern about the damage that large wind turbines can do to the surrounding area, specifically to bird and bat populations. An article in *Nature* magazine stated that wind turbines on average kill only 0.03 birds per year (1 kill per 30 turbines) compared to the 10 million birds killed in the United States by cars alone. (Emma Marris and Daemon Fairless. "Wind Farms' Deadly Reputation Hard to Shift," *Nature*, 10 May 2007.*)* The impact is local and is not severe or pervasive.

Bat populations, however, have been greatly affected by wind turbines. As noted by Merlin Tuttle, President of Bat Conservation International, a study done at one site showed that there were 2092 bats killed at the site with an average of 48 bats per turbine between the spring and fall of one year. (Memo to Wind Energy Production and Wildlife Conservation Planners, January 2004)

Safety Concerns

Safety is another concern related to building wind farms. The turbine's blades run according to the amount of wind that is being captured. When the turbine is taken offline by the operator, a brake slows the blades and the turbine shuts down. When the turbine's brake fails, the blades turn freely. Often, the blades spin at such a rate that they bend and catch the pylon, causing the blades and nacelle to shear from the pylon. Ice can also accumulate on blades and be thrown into surrounding areas (known as ice throws). As a result of these safety concerns, wind farms are usually built away from heavily populated areas.

Pre-Lab Discussion and Experiment

Engage your students by asking the following questions and discussing their answers.

1. What are your experiences with the speed or direction of wind in your area?

Students will mention wind-related events in your town or city, including storms, damage done by winds such as trees blown over or roofing torn away, or in some areas, tornadoes.

2. Where have you noticed consistent wind patterns in your area?

Help students to recall places that seem to be windier than other places nearby. You may want them to think about prevailing wind direction in your town if that is consistent. If you have a large body of water nearby, you can help them recall the way the wind churns up the water and in what direction it tends to blow across the water. All of these discussions should serve to help students visualize the movement of wind as a predictable force in a given area.

3. What makes wind blow stronger? What makes wind blow steadily?

Big changes in atmospheric pressure over a short area or narrow passageways make wind blow stronger, and large, open spaces can make wind blow more steadily.

4. How do we use the wind?

Students will include work and play examples. Play examples include kites and sailboats, or wind surfing. Work examples include wind-powered turbines and windmills.

5. Where on your school grounds are places where the wind blows the strongest?

Answers will vary. Students should note any areas where they have experience strong winds, such as soccer fields, outdoor hallways, or around corners.

6. How fast do winds have to blow to turn a wind turbine?

A moderate breeze of 20 kph (12 mph) will be enough to turn a simple turbine. Students may want to research various wind speeds and the work they can do. Researching information in the Beaufort Scale or the Saffir-Simpson Scale can give them an idea of the power of winds at any given speed.

Case Study (homework assignment or class discussion)

Set up the following scenario: Students assume they are acting as consultants for a large power company that is looking to invest in renewable energy. Students will need to find several areas of the U.S. that are good candidates for wind power development. To develop a proposal, students will assess the resource availability, proximity to infrastructure, population density and environmental impact,

To prepare for this task, have students use available resources to answer the following questions:

7. How big are wind turbines? How small can they be?

The smallest wind turbines that are sometimes used in rural locations are no more than 2 meters tall. The tallest towers are up to 90 meters tall (300 ft).

8. How close should a wind farm be from electrical infrastructure? How far is too far?

Most wind farms should be built **no more than 5 miles** away from FEMA (Federal Emergency Management Agency) power lines. This distance will keep wind farms far enough away from major power lines (to avoid damage), but they will be close enough to the power lines to feed them.

9. How close should a wind farm be to a city to provide power to that city?

Answers will vary. Proximity to power lines is the principle limiting factor for maximum distance. Aesthetics is one of the considerations for minimum distance. There are examples of wind turbines within city limits and located many miles away. This question should be asked to get students thinking about what the visual impacts are of a wind farm.

10. How far away should a wind farm be from a city to ensure the safety of the public?

Wind turbines are relatively safe and even in areas where ice throws are possible a few hundred meters is sufficient for public safety.

11. How far away should a wind farm be from sensitive environments?

Visual, noise, TV/Radio interference, and threats to birds and other living resources have been greatly reduced by modern wind turbine technologies. Wind farms should be located at least 10 miles from major parks to ensure animal protection.

12. How close can wind farms be to highways?

Wind farms should be at least 1.2 times their height from highways.

Instructor Tip: Briefly discuss what a consulting proposal should include. Remind students that, although the original criteria were based largely on their opinion combined with a basic knowledge of wind farms, the proposal is to be in the best interest of the company for whom they work. This is particularly important for students who choose not to recommend any cities for wind power development.

Instructor Tip: This experiment is written to challenge students to think about the social, environmental, and political implications of building a wind power plant. Students may become frustrated with predicting selection parameters with limited information. To minimize the frustration, be prepared to provide students with suitable ranges, and refer them to the National Renewable Energy Laboratory for additional supporting information.

Lab Preparation

These are the materials and equipment to set up prior to the lab:

1. Be sure students can access the My World GIS program from their computers.

2. Make the project file, Wind Power Development.m3vz, available to students.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment (identified by the number following the symbol: "�"). The instructions are on the storage device that accompanies this manual. Choose the My World GIS Tech Tips file. Please make copies of these instructions available for your students.

Set Up

1. Open the Wind Power project file (Wind Power.m3vz). �(12.1.1) The following layers are in the Layer List:

   - ***Major Parks*** – displays the outlines of over 7,000 national parks, national forests, and major state parks in the United States.

   - ***U. S. Cities*** – displays major United States cities.

   - ***NASA Earth Observations (NEO) WMS***– displays a medium resolution blue marble image of the Earth.

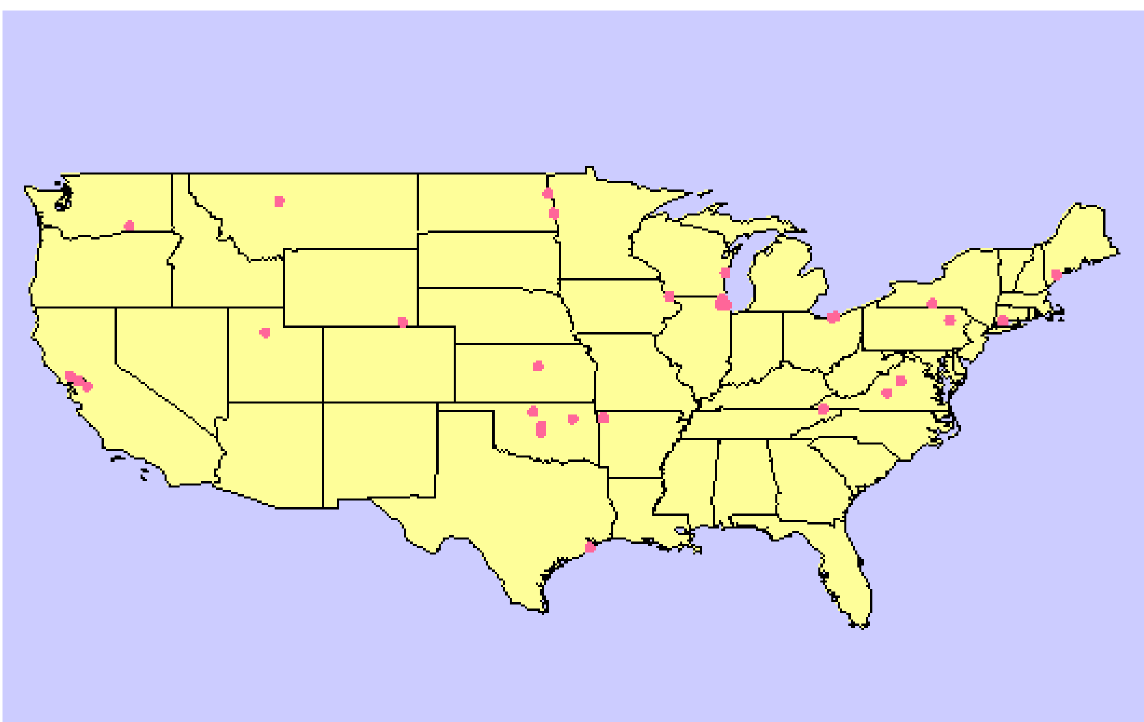
   - ***Major Highways*** – generalized data from the National Highway Planning Network, which includes only the major highway road segments of the original data set and a subset of attributes.

   - ***Power Class*** – sorts the wind power densities into classes for regions in the United States. Wind Power Density is a measure of how much energy is available from the wind at a given site to drive a wind turbine, measured in Watts per square meter.

Wind Power Class	Wind Power Density (W/m^2)	Speed (mi/hr)
1	< 100	< 9.8
2	100–150	9.8–11.5
3	150–200	11.5–12.5
4	200–250	12.5–13.4
5	250–300	13.4–14.3
6	300–400	14.3–15.7
7	> 400	> 15.7

- ***FEMA Powerlines***– displays the Federal Emergency Management Agency (FEMA) map of power lines in the United States
- ***U. S. States*** – displays an outline of all 50 states.
- ***Global Wind Pattern***– displays the prevailing winds over the oceans with a series of arrows that represent the direction of wind flow.

Sample Data



This is a screenshot of cities that will appear at the end of the experiment. Student results may vary.

Data Analysis

1. Notice the direction of the wind at the northwestern edge of North America. In what direction is the wind blowing?

The wind is blowing toward the east.

2. Notice the wind pattern in the North Atlantic. In what direction is the wind blowing?

The wind is blowing toward the east.

3. Assuming that the wind does not stop when it approaches the west coast, what is the direction of the prevailing wind as it moves across North America?

The wind moves from west to east across North America.

4. Does this mean that all the winds we experience in the United States will blow in this direction? Explain your answer.

All winds in the United States will not blow west to east. Winds are influenced by weather conditions and topography, and surface winds may blow in any direction. However, prevailing, high-level winds have a tendency to blow in the same direction at all times.

5. Hide the Continents and Global Wind Pattern layers and show the U.S. States and Power Class layers. �(12.2.4) Highlight the Power Class layer and use the Zoom to Active Layer Tool to zoom into the United States. �(12.4.4)

6. Power class is an important factor in determining whether an area produces sufficient winds to convert to useable power. Use the Pointer Tool to see where the winds are sustainable and strong enough to produce wind powered energy and list those general locations here. �(12.4.6)

Any power class less than 4 will not generate the necessary power to make its building cost effective. Students will notice that mountainous areas have pockets of good strong wind, as well as some places on the Great Plains. Additionally, the wind blows well across the Great Lakes.

7. In the Analysis window, �(12.5) select an ideal power class range by value, for example power class 3 to 7. �(12.5.1) Make this selection a new layer and name it "Ideal Power Class."

8. Hide the original Power Class layer and show the U.S. Cities layer. �(12.2.4) Arrange the Layer List so that the Ideal Power Class layer is below FEMA Powerlines. �(12.2.2)

9. In the Analysis window �(12.5), cross the U.S. Cities and Ideal Power Class layers. � (12.5.2) Do not make this selection a new layer. Accept the default name and click OK.

10. Describe the map as it appears now.

The map shows the ideal power classes where wind power could be developed and it also shows the U.S. cities that are located in those ideal power classes.

11. How far from a power line should your wind farm be located? Explain why you have chosen this distance.

Most wind farms should be built no more than 5 miles away from major power lines and no closer than 0.1 miles. This distance will keep wind farms far enough away from major power lines to avoid damage but will be close enough to power lines to feed them.

12. In the Analysis window, �(12.5) select records from the "US Cities That Cross Ideal Power Class" selection you created in step 9 that are the distance you have specified above from FEMA Power Lines. �(12.5. 3) Do not make this selection a new layer. Accept the default name and click OK.

13. Show the Major Highways layer. �(12.2.4)

14. How far from major highways should your wind farm be? Explain why.

Wind turbines must be built a factor of 1.2 times the height of the turbine from highways to provide proper distance. The smallest turbines, used in rural communities on a minimal scale, are two meters high. Two meters equates to approximately 0.00124 miles. Multiply this number by a factor of 1.2 to compensate for the height of the smallest turbine in use to obtain the minimum distance that a turbine should be built from a highway. This distance is approximately equal to 0.0015 miles, the minimum distance required from the highway.

15. In the Analysis window, �(12.5) select records from the "Within X miles from FEMA Power Lines" selection you just created that are the distance you specified above from Major Highways. �(12.5.3) Do not make this selection a new layer. Accept the default name and click OK.

16. Explain what your map looks like now.

The number of cities has been limited by how far cities within the ideal power classes are from power lines and major highways.

17. How far from major parks should your wind farm be location? Explain why.

Wind farms should be at least 10 miles from major parks. Large parks and national parks are often home to species that are protected, threatened, and sometimes endangered. Wind farms can be a hazard to birds and other wildlife if they are located too close to wildlife habitat.

18. In the Analysis window, �(12.5) select records from the "X Miles From Major Highways" selection that you just created that are the distance you specified above from Major Parks. �(12.5.3) Do not make this selection a new layer. Accept the default name and click OK.

19. You should now have a small set of cities that are good candidates for wind power development. If you have too many cities, repeat previous steps to narrow your search.

20. Open the data table for the final selection of cities. �(12.4.1)

21. Sort the table by population. �(12.4.1.1)

22. Determine a population criterion for your wind farm. What is your approximate population range?

Answers will vary. For the most part, only single turbines can be built in very large cities, but there could be a location nearby for more turbines. Smaller cities (30,000—80,000) are a good choice because a single turbine can supply their power.

23. Click and drag to highlight the cities that fall within your population range. Create a selection from the table. �(12.4.1.2)

24. Show the NASA Earth Observations (NEO) WMS. �(12.2.4) Use the Zoom In and Zoom Out Tools to zoom in to each of your chosen cities and examine the terrain around the city. �(12.4.3)

25. Are any of these cities near mountain ranges? Are they near coasts or plains? Why is this important? Should you eliminate any of these cities?

Cities near coasts receive steady, reliable wind, often at a reasonable power class. Cities near coastlines that are often affected by hurricanes should be eliminated. Cities in the plains states should be chosen carefully because these are often affected by tornadoes. Valley and mountain cities receive fairly steady and reliable breezes.

26. Print your map, and list the cities you have selected for the development of wind power.

If students use the exact information provided in the responses for this experiment, prospective sites in the United States, when equalized for population and poor location could include the following cities.

- Grand Forks, North Dakota
- Great Falls, Montana
- Fargo, North Dakota
- Moorhead, Minnesota
- Kennewick, Washington
- Sheboygan, Wisconsin
- Portland, Maine
- Dubuque, Iowa
- Waukegan, Illinois
- Highland Park, Illinois
- Buffalo Grove, Illinois
- Northbrook, Illinois
- Arlington Heights, Illinois
- Elmira, New York
- Tracy, Callifornia
- Pittsburg, California
- Vallejo and Napa, California
- Lancaster, California
- Ammarillo, Texas
- Cheyenne, Wyoming
- Wilkes-Barre, Pennsylvania

Analysis Questions

1. Visit the home page of the American Wind Energy Association's website. At the bottom of the screen, click the Projects (Wind Energy US) link. How do your proposed sites compare to existing wind farms and projects under construction?

For the most part, the cities listed in the Data Analysis section are in states that are already heavily implementing wind power, such as California.

2. You have relied on multiple criteria to help you determine a potential site for wind power development. Which criteria are the most important when selecting a potential development site? How did you determine that these criteria are more important than others?

All of these criteria are important when coming to a decision. Aside from environmental friendliness and cost effectiveness, the location of the FEMA power lines is probably the most important criteria. Without the proper power lines available to feed power to a city (no matter how large or small) the wind farm will be useless.

3. The power classes throughout the Great Plains were very good for wind power development, yet relatively no cities were selected for development as your search progressed. Why was this region eliminated?

The majority of the plains states are largely in undesirable power classes. Students should notice that their ideal power class layer has eliminated large portions of the Great Plains, leaving predominantly North and South Dakota. Additionally, the FEMA power lines layer does not cover large swaths of some plains states, and thus, My World eliminated these areas.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What are some cost considerations that impact the siting of wind farms?

Land costs will be more expensive just outside of urban and suburban cities, while rural land costs will be much lower. It is important for students to realize that cheaper land that is further away from the town it is providing power for means extra transmission expenses. Federal and State governments provide varying amounts of assistance through tax credits for wind power production. Although wind velocities are greater at higher altitudes, the cost of constructing a wind tower increases dramatically as the height increases. The cost of raw materials for wind turbines also influences the cost of wind energy.

2. What is a capacity factor, and what are some issues that affect the capacity factor of a wind farm?

The capacity factor of a power plant is the ratio of the actual output of a power plant over a period of time to its output if it had operated at full capacity.

For wind power, three issues are primarily involved in the capacity factor: maintenance issues, the cost of alternative power, and the availability of wind. If wind turbines are down for maintenance, they can't produce power. If the cost of alternative power is cheaper than wind power, no one will buy the wind power. If the wind isn't blowing, a wind turbine can't produce power.

3. There was a recent suggestion to install a wind farm on the shallow ocean shelf off the south tip of Cape Cod. Discuss the pros and cons of this location.

A good wind farm needs steady strong winds, which would be present off the coast of Cape Cod. However, this is also a bird flyway and has occasional hurricanes. Additionally, offshore wind farms should be built more than 10 km offshore to avoid interfering with bat populations. The main factor against this location was the idea that wind farms spoil the view. Preserving the view is often the main argument against placement of most wind farms today.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. The benefits of wind power include:

- **A.** Wind is a renewable resource.
- **B.** Wind is an inherently green form of energy.
- **C.** Wind reduces strain on fossil fuel resources.
- **D.** Wind reduces greenhouse gas emissions when replacing fossil fuel use.
- **E. All of the above.**

2. All of the following affect the location of wind farms *except*:

- **A.** Proximity to power lines.
- **B.** Proximity to major parks.
- **C. Proximity to other types of power plants.**
- **D.** Proximity to highways.
- **E.** Proximity to urban areas.

3. Wind farms can interfere with:

- **A.** Radar.
- **B.** Radio and TV signals.
- **C.** Cell-phone signals.
- **D. A and B.**
- **E.** None of the above.

4. In which of the following areas would wind farms likely be located?

- **A.** Some coastal regions not affected by hurricanes
- **B.** Mountainous regions
- **C.** The Great Plains
- **D.** Mountain valleys
- **E. A, B, and D.**

5. If a given turbine produces 110,000 Megawatts of power at a time when its maximum output could have been 150,000 Megawatts, what is its capacity factor?

- **A.** 136%
- **B. 73%**
- **C.** 40,000
- **D.** 0.73%
- **E.** None of the above

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Answers section.

1. Wind energy is a form of converted **solar** energy and is a green **renewable** resource. The sun heats land and water at different rates during the day and night. As a result of these differences, the atmosphere around the Earth heats and cools differently. Warm air tends to **rise**, and cool air rushes in to replace it. The result is wind.

2. Wind trends are gradual. That is, big winds will taper off gradually rather than stop abruptly, making wind a reliable source of renewable energy. Wind energy is harnessed using **turbines**, large bladed structures that capture wind and convert it into **electricity**. Turbines can be built on farms and mountainsides to provide electricity to nearby towns and cities and depend upon the wind power density of the area, known as **wind class**. Wind power generation is limited by its **capacity factor**. The capacity factor is defined as the amount of power produced over a given time divided by the power that would have been produced had the turbine operated at **maximum output** 100% of that time. Generation is also limited by the **availability factor**, which refers to the amount of time that the turbine itself is ready and able to generate power. Wind turbines have a **larger** availability factor than any other power plant.

Extended Inquiry Suggestions

You may want your students to write a proposal for the power company, recommending a location for a wind farm. Include the power class of the city or cities that are recommended, discuss the proximity to infrastructure (both electrical industry and city), population density of the surrounding area, and environmental impact. Discuss the cost of the land and the costs of construction and transmission of the wind farm. If they think they have only poor choices for investment (economically, environmentally, ethically, and so on), they should explain their reasoning.

Pollution

24. Monitoring Water Quality

Objectives

Students monitor the quality of a natural body of water in several locations to determine how water quality changes in response to changes in environmental factors. They also:

- Make measurements that can be reliably compared to measurements made with different equipment or at other times, or both

Procedural Overview

Students gain experience conducting the following procedures:

- Calibrating electronic sensors
- Measuring parameters of water quality and interpreting the results
- Comparing the results of measuring water quality factors in situ with measurements of water samples removed from the source

Time Requirement

Preparation time	First water quality monitoring field trip: several hours; otherwise, 1 hour
Pre-lab discussion and experiment	45 minutes
Lab experiment	90 minutes

Materials and Equipment

For each student or group:

- Mobile data collection system
- Water quality sensor
- Turbidity sensor
- Weather/anemometer sensor
- GPS sensor (optional)
- Sensor extension cable
- Sensor user guides with calibration instructions and tables
- Chemical test kit (optional)
- Buffer solution, pH 4, 25 mL[1]
- Buffer solution, pH 10, 25 mL[1]
- Wide-mouth sampling jar or small plastic bucket with a handle
- Long-handled sampling device[2]
- Duct tape and scissors
- Wash bottle containing distilled or deionized water
- Wading boots (optional)

[1]Used for pH sensor calibration.

[2]Available commercially, or can be made from a tree-pruning pole. Refer to the Lab Preparation section for details.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Renewable and non-renewable resources
- Waste material disposal
- Cations and anions
- Conductivity
- Cell function and pH
- Measuring pH
- Measuring turbidity

Related Labs in This Guide

Labs conceptually related to this one include:

- Determining Soil Quality
- Water Treatment

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting a new experiment on the data collection system �(1.2)
- Connecting a sensor to the data collection system �(2.1)
- Calibrating a dissolved oxygen sensor �(3.3)
- Calibrating a pH sensor �(3.6)
- Calibrating a turbidity sensor �(3.7)
- Setting up a conductivity sensor for a particular range �(4.2)
- Monitoring live data without recording �(6.1)
- Starting and stopping data recording �(6.2)

- Displaying data in a graph [7.1.1]

- Finding the values of a point in a graph [9.1]

Background

Water quality is the suitability of water for a given use. Water in a natural ecosystem has to have the right balance of dissolved oxygen, nutrients, temperature, pH, salts, and light penetration to sustain a healthy aquatic ecosystem. Drinking water must have acceptable levels of contaminants to be deemed safe. Treated wastewater must also be of acceptable quality before it is released into the environment.

Natural bodies of water have many chemical and physical characteristics that can vary from one location to another. Water quality indicators can fluctuate depending on the characteristics of the surrounding watershed as well as from varying weather conditions. Water quality at a given point in a stream or river reflects the effects of upstream activities. We can measure different aspects of water quality at different locations to assess the health of a natural body of water and to locate possible sources of pollution.

The World Health Organization publishes guidelines for water quality worldwide. These are available in full text on the Internet. For the United States, standards for the water quality of natural bodies of water supportive of aquatic organisms are specified by the US Environmental Protection Agency (EPA) in their Red Book and Gold Book, the full text of which is available on the Internet. The US EPA also publishes Primary and Secondary Drinking Water Standards, available on the Internet. These specify the maximum lawful level of contaminants in the United States for drinking water supplied by municipal water treatment facilities and are good references to have on hand.

Pre-Lab Discussion and Experiment

Engage students by presenting information about a local body of water that has been in the news due to water quality issues. This could be a fish kill that occurred because of accelerated (cultural) eutrophication or due to low water levels in the summertime. Or it could be an industrial accident that caused a point-source pollution crisis. Work on a local dam can cause water quality problems that affect fish and other aquatic organisms. A local beach may have been closed for a part of the summer due to elevated levels of pathogenic bacteria.

If no local news related to water quality is available, choose an example from other parts of the country, or even worldwide. Alternatively, there may be a good example of a successful water quality cleanup project. An Internet search will produce a number of good options.

1. Brainstorm with students regarding a suitable local body of water to monitor. One that is within walking distance would be ideal.

Instructor Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment.

Continue the discussion by asking students these questions:

2. How is water quality monitored?

Water quality is monitored using sensors and chemical tests that have been calibrated to external references and give reliable, repeatable measurements.

3. How can we ensure that measurements are accurate and can be compared with each other over time?

Measuring instruments must be calibrated to external standards, and standard sampling and testing techniques must be used.

Demonstrate the correct techniques for calibrating the dissolved oxygen, pH, and turbidity sensors.

Point out that water samples should be obtained away from the shoreline and below the surface of the water.

Ask students:

4. Why is it important to take measurements from samples obtained away from the shoreline?

It is important to take measurements away from the shoreline to avoid contamination by mud or other materials that might reduce the accuracy of measurements.

Demonstrate proper sampling technique with your sampling equipment (see the Lab Preparation section).

Instructor Tip: The *Water Quality Field Guide*, published by PASCO scientific, is a thorough and concise reference that can help add meaning to your water quality measurements.

Instructor Tip: Consider doing additional field work to maximize the value of the field trip. For example, part of the day could be used to do the "Biodiversity and Invasive Species" or "Biodiversity and Native Species" activities, or both. These additional investigations would give a more complete picture of the watershed of your natural body of water.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Plan how students are to obtain water samples away from the shoreline and below the surface of the water. If they use a wide-mouth sampling jar, they will need to dip it into the water. Wading boots would be useful in this case.

   Special sampling devices are made specifically for this purpose; they are generally cylinders with closable ends, weights, and attached to long ropes.

   Alternatively, use a long pole (such as a telescoping tree-pruning pole) with a device (such as duct tape) on the end to hold a sensor extension cable, plastic water bottle, or bucket. You can make these poles with supplies from the local hardware store, or you can order them ready-made from companies specializing in such gear.

   For beginning studies, the homemade equipment works well. More advanced studies may require specially made equipment.

2. Think through the requirements for your field trip, including safety considerations and necessary permissions needed.

   You should visit the site beforehand and note safety issues to alert your students to.

   Prepare the instructions for student behavior at the testing site based on this survey.

Instructor Tip: Point out hazards you noticed during your survey of the site.

Instructor Tip: Require students to use a buddy system and specify the procedure to use in case of trouble.

3. The following is a checklist of equipment you may choose to take, depending on the nature of the field trip:

- Water sampling device
- Field microscope
  Digital camera or camcorder
- Binoculars
- Seine or kick nets for collecting macro invertebrates
- Ice chest and ice (for storing collected water samples)
- Rain gear
- Wading boots
- Plastic sample storage bottles with caps (for samples to be brought back to the school lab for testing)
- Water bottles for collecting samples
- Extra clothing if contact with water is anticipated
- Non-perishable snacks
- Sunscreen
- Mosquito repellent
- First aid kit with a pocket knife and snake bite kit

4. The following are tips for increasing the success of the field trip.

- Establish a base to bring samples back to for testing and analyzing.
- If samples can be brought back to the school lab, do so.
- For multiple outings, develop a packing routine.
- Establish a clean-up routine for coming off the field.
- Use a GPS sensor to enable mapping of data (data can be uploaded into My World GIS™ back at school).
- Emphasize the need to develop a story, that is, a description of the water quality based on the surrounding environment. Encourage collaboration between student pairs or groups.
- Measure other aspects of the environment such as temperature, humidity, barometer, rainfall, wind, insolation, light intensity, and challenge students to incorporate these findings into the overall story.

5. Consider bringing samples back to the classroom to analyze for pollutants using colorimetric chemical test kits. If you plan to do this, be sure to take extra sampling bottles and an ice chest. Alternatively, take test kits to the site and set up a lab area to complete the analyses there.

Safety

Add these important safety precautions to your normal outdoor class procedures:

- Practice appropriate caution around bodies of water, steep terrain, and harmful plants or animals. Point out hazards you observe at the site.
- Use a buddy system and follow the established procedure in case of trouble.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Work with your instructor to find a good place to take your measurements.

Set Up

1. Start a new experiment on the data collection system. �(1.2)

2. Connect the weather/anemometer sensor to the data collection system. �(2.1)

3. Monitor live data without recording. �(6.1)

4. Determine the current barometric pressure and record below:

Barometric pressure:______________.

5. Why is it necessary to determine the barometric pressure?

The barometric pressure is needed to calibrate the dissolved oxygen sensor. The amount of dissolved oxygen that can be held in water depends on the barometric pressure and the temperature of the water. The greater the air pressure, the more dissolved oxygen water can contain.

6. Connect the water quality sensor, using a sensor extension cable, to the data collection system. �(2.1)

7. Make sure the conductivity sensor is adjusted to measure the quality of fresh (not salt) water. �(4.2)

8. Calibrate the dissolved oxygen sensor. �(3.3)

Note: Determine the 100% saturation point for the dissolved oxygen sensor with the sensor's storage bottle submerged in the water you plan to monitor.

9. Why is it important to calibrate the dissolved oxygen sensor at the same temperature as the water you are testing?

The amount of dissolved oxygen (mg/L) that can be held in water depends on the barometric pressure and the temperature of the water. The calibration should be related directly to the test temperature and air pressure conditions.

10. Use pH 4 and pH 10 buffer solutions to calibrate the pH sensor. �(3.6)

11. Why is it necessary to calibrate the pH, dissolved oxygen, and turbidity sensors?

You need to calibrate the pH, dissolved oxygen, and turbidity sensors with an external standard so measurements can be reliably compared between groups and when collected at different times or using different sets of equipment.

Note: Keep the file open that contains this calibration information. The sensor calibration remains with the file that was open when you performed the calibration.

12. Use duct tape to secure the data collection system and the sensor cables to the extension pole so the probes dangle from the end of the pole.

Collect Data – In situ

13. Start data recording, �(6.2) and gently lower the probes into the water at least 1 meter from the shoreline and to at least 1/3 meter below the surface of the water. If the water is stagnant, gently move the sensors back and forth for 1 minute.

CAUTION: Do not let the data collection system get wet!

14. Carefully remove the probes from the water, return them to the shore, and stop data recording. �(6.2)

Write the run number here ____________ .

15. Remove the sensors and recording device from the extension pole.

Collect Data – From a water sample

16. Use duct tape to attach a clean bucket or other container to the end of the extension pole.

17. Collect a sample of water from approximately the same spot that you just monitored with the sensors.

18. Test the quality of the water in the bucket (measure the temperature, pH, conductivity, and dissolved oxygen) using the same procedure used for the in situ sample.

Record the run number here ____________ .

19. Calibrate the turbidity sensor. �(3.7)

20. Stir the water in the bucket and measure the turbidity of the water.

Record the run number here ____________ .

21. Record the turbidity in Table 1.

22. (Optional) Test other water quality parameters as indicated by your instructor, using the water in the bucket as your sample.

23. (Optional) Record the GPS coordinates.

24. Find another site to monitor the water quality (Site 2), repeating the data collection procedure above.

Data Analysis

1. Show your first data run in a graph. �(7.1.1)

2. Complete Table 1 as follows:

a. Use the graph tools to identify the value of each parameter that best represents the measured parameter. �(9.1)

Note: This is a value in the area of the graph where the measurements have stabilized.

b. Record these values in Table 1.

c. Repeat this process for your second data run.

Table 1: Water quality measurements from two locations

Test	Temperature (°C)	pH	Conductivity (µS/cm)	Dissolved Oxygen (mg/L)	Turbidity (NTU)
Site 1: In situ	22.7	8.0	637	0.8	
Site 1: Sample	22.4	8.0	646	1.9	7.5
Site 2: In situ	22.7	7.7	806	0.9	
Site 1: Sample	22.3	7.7	813	3.1	4.5

3. Describe the first test site. (For example, note the presence and types of surrounding vegetation, shade or full sun, signs of soil erosion, presence or absence of insects or other animals, and evidence of point-source pollution.)

Answers will vary. In this example, the test site was a small, slow-running, shallow creek flowing through a field. There was a mixture of shade and sun surrounding the creek. The vegetation surrounding the creek and in the creek was fairly dense, composed of bushes, grasses, and trees. The creek showed signs of accelerated eutrophication, including lots of algae growing on the surface water; weeds and reeds growing in the water; and a green, slightly turbid color.

When we sampled the water, we pulled up a lot of dead vegetation. There were a lot of tadpoles and frogs, dragon flies, and flies present. We saw 4 river otters swimming by. We did not see any fish. There did not seem to be erosion of the soil. The field next to the stream was very dry, largely comprising grasses, bushes, and thistles. We saw squirrels, woodpeckers, and ants in this area.

4. Describe the second test site.

Answers will vary. For this example, Site 2 was a little upstream from Site 1. There seemed to be more dead vegetation in the water, and the water seemed shallower. Otherwise, it looked similar to Site 1.

Analysis Questions

1. Was there a sizable difference between measurements made in situ and measurements of the water sample? Do you think it is worth the effort to take measurements in situ?

Answers will vary. For this example, we saw a big difference in the dissolved oxygen level between the in situ measurement made about 1/2 meter under water compared with the sample we collected. The in situ samples had much lower dissolved oxygen concentrations. We think the in situ measurements were more accurate, reflecting the almost anoxic conditions of this creek that was clearly in a state of accelerated eutrophication.

The higher levels of dissolved oxygen in the bucket sample could have occurred because air mixed with the sample during the collection process and while sitting in the bucket before we could measure it. Also, the temperature measurement was somewhat lower for the measurements of the sample, and again, we thought the in situ measurements were more representative of the creek. So we would conclude that it is worth the effort to take measurements in situ.

2. What do you think could be responsible for any differences you found between sites?

Answers will vary. For this example, the main difference between our sites occurred in the conductivity. We did not see any obvious reason for it, like point-source pollution. However, there seemed to be a lot of decaying vegetation on the bottom of the creek, and that could have been contributing dissolved solids to the water.

3. Dissolved oxygen levels below 3 mg/L indicate low water quality for many aquatic animals. Do you think the water you tested had enough dissolved oxygen to support most aquatic animals? Explain.

Answers will vary. For this example, the water we tested did not contain enough dissolved oxygen to support fish and many other aquatic animals that cannot gather oxygen from the air. The mean dissolved oxygen level for our two sites was 0.85 mg/L, which is a very low concentration.

4. Dissolved oxygen levels above 9 mg/L indicate accelerated eutrophication and low water quality, due to rapid algae growth in nutrient-dense, warm water. These algal blooms are usually followed by very low dissolved oxygen levels. The algae die and are decomposed by bacteria, which consume the dissolved oxygen during aerobic cellular respiration. Does the body of water you investigated show evidence of accelerated eutrophication? Explain.

Answers will vary. For this example, there were multiple signs of accelerated eutrophication that had progressed to the point where bacteria were decomposing the algae and plants. Some of the evidence included the low dissolved oxygen levels, the presence of dead vegetation on the bottom of the creek, and the abundance of algae and weeds growing in and on the creek.

5. Does the body of water show signs of acid rain or other acid deposition? Explain.

Answers will vary. For this example, there was no sign of acid deposition, since the pH at both sites was greater than 7.

6. Conductivity is a measure of salts dissolved in the water. Conductivity levels above 200 to 300 µS/cm in a fresh-water surface body of water may indicate pollution by runoff from cities or agricultural regions. Does the body of water you investigated show signs of pollution? If so, what do you think might be contributing to this pollution?

Answers will vary. For this example, there was evidence of pollution from runoff, since the conductivity levels were relatively high (between 600 and 800 µS/cm) and there were signs of accelerated eutrophication.

7. In the United States, turbidity levels higher than 1 nephelometric turbidity unit (NTU) in drinking water are unlawful, and the World Health Organization recommends levels lower than 1 NTU for drinking water. If the body of water you investigated served as a drinking water source, would the water have to be filtered to remove suspended solids? Explain.

Answers will vary. For this example: to be used as drinking water, this water would have to be filtered to remove suspended solids, since turbidity levels were between 4.5 and 7.5 NTU.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Design an additional study to determine levels of pollutants in the body of water you tested. Use the evidence you collected in the field study to identify 3 additional tests you think would be useful to conduct, and explain why you picked these.

Answers will vary. For this example, we think it would be interesting to look at nutrient pollutants, including nitrates, phosphorous, and potassium. We chose these tests because the evidence from the test site—low dissolved oxygen measurements and a lot of algae and vegetation growing on and in the creek—suggests that these pollutants may be present at high levels, causing accelerated eutrophication.

2. Design a water quality monitoring process to test whether point-source pollution is significantly affecting the body of water you investigated. If this body of water does not have an obvious point source for pollution, create a hypothetical one.

(Examples of point-source pollution include heat from power plants; nitrogen-, phosphorous-, and phosphate-containing effluent from agricultural sources or runoff from cities; salt-containing effluent; and treated or untreated sewage.)

Answers will vary. For this example, the creek we monitored runs through an industrial area just before it gets to the monitored sites. We would pick two or three pollutants that we found at high levels at our site. We would go to a site on the creek upstream before it gets to the industrial area and, using the same techniques, monitor levels at that point. We would include the GPS coordinates with our data.

Based on our findings there, we would move further up or down the creek and repeat the testing procedure to see if we could find a specific point where levels rose sharply. If such a point was found, we would evaluate the adjacent watershed to determine whether we could identify a point source for the pollution.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Which of the following statements is true?

- **A.** A watershed delivers runoff, sediment, and dissolved substances into the body of water.
- **B.** A coastal delta is an example of a watershed.
- **C.** A watershed is the land area bordering a body of water
- **D. Both A and C are true.**
- **E.** A, B, and C are true.

2. Point-source pollution:

- **A.** Can usually be identified within a given area
- **B.** Is dispersed and difficult to identify
- **C.** Is more easily controlled than non-point-source pollution
- **D. A and C**
- **E.** A, B, and C

3. Fish kills can be caused by:

- **A.** Decreased dissolved oxygen levels due to decomposition of sewage by bacteria
- **B.** Decreased dissolved oxygen levels due to high summer temperatures
- **C.** Excessive cultural (or accelerated) eutrophication, in which plant matter is decomposed by bacteria
- **D.** A and C
- **E. A, B, and C**

4. Nitrates, potassium, and phosphorous found in plant fertilizers are considered water pollutants because they:

- **A.** Directly reduce the dissolved oxygen in water
- **B.** Form toxic compounds in water
- **C. Cause increased algae growth rates**
- **D.** Are harmful to fish and humans
- **E.** None of the above

5. Cultural (or accelerated) eutrophication can be caused by:

- **A.** Plant nutrients found in fertilizers
- **B.** Organic wastes from waste treatment facilities
- **C.** Human recreational activities such as swimming or boating
- **D. A and B**
- **E.** All of the above

6. Bodies of water that are eutrophic or hypereutrophic typically exhibit:

- **A.** High turbidity
- **B.** High nutrient levels
- **C.** Low turbidity
- **D.** A low level of primary productivity
- **E.** **A and B**

Extended Inquiry Suggestions

Have students collect samples of water at your test sites. Keep them on ice and take them back to school. Analyze them for levels of pollutants you suspect may be present. Use colorimetric chemical test kits or do a biological oxygen demand study, or both. Relate the results to the characteristics of the watershed.

Conduct water quality monitoring field trips several times during the year and examine seasonal differences in water quality and in the watershed.

Have students record the GPS coordinates for their test sites and create a database of those measurements. Import this database into My World GIS, which helps students visualize the measurements spatially. This way they can see relationships of their data with elements of the watershed. (Refer to the "Biodiversity of Invasive Species" experiment for details on creating, importing, and visualizing databases in My World GIS.)

25. Toxicology Using Yeast

Objectives

Students demonstrate how yeast cells can serve as simple models to assess chemical hazards. They also:

- Evaluate the role of pH in toxicity
- Evaluate the role of cell culture in toxicology studies

Procedural Overview

Students determine the relative toxicity of half-strength bleach and full-strength vinegar using a yeast cell culture system. They gain experience completing the following procedures:

- Conducting toxicology studies of yeast cell cultures in a closed system, measuring the carbon dioxide gas level as the indicator of toxicity, and correlating pH with toxicity
- Extrapolating the median effective dose (ED_{50}) for half-strength bleach and full-strength vinegar from experimental data

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and experiment	15 minutes
♦ Lab experiment	90 minutes or two 45-minute sessions

Materials and Equipment

For each student or group:

- Data collection system
- CO_2 sensor
- pH sensor
- Sensor extension cable
- EcoChamber
- Magnetic stir plate and stir bar
- Beaker, 100-mL (for vinegar)
- Beaker, glass, 2-L
- Graduated cylinder, 25-mL or 10-mL
- Graduated cylinder, 1-L or 500-mL
- Erlenmeyer flask, 125-mL (for bleach)
- Rubber stopper for Erlenmeyer flask
- Stirring rod
- Rapid-rise activated baker's yeast, 7-g packet
- Sugar, 100 g
- White vinegar, 50 mL
- Household bleach, half-strength, 50 mL
- Water, 1 L

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- Basic biochemistry of cellular respiration
- The role of closed systems in evaluating change
- Most cells function best within a narrow range of acidity
- pH is a logarithmic measurement of the concentration of hydrogen ions in water. ($\text{pH} = -\log_{10}[\text{H}^+]$)
- pH measurements can range from 0 through 14. The lower the value, the higher the concentration of hydrogen ions.
- pH can be a measure of acidity, with values below 7 becoming increasingly acidic as the value approaches 0. Therefore, the lower the pH, the higher the concentration of hydrogen ions and the higher the acidity.
- A pH of 7 is neutral—neither acidic nor basic.
- pH values greater than 7 are considered basic. Practically speaking, a pH of 6 to 8 is considered to be in the neutral zone.
- Standard deviation is a simple measure of the variability of a data set.

Related Labs in This Guide

Prerequisites:

- Yeast Respiration

Labs conceptually related to this one include:

- Air Pollution and Acid Rain

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- Starting your experiment on the data collection system �(1.2)
- Connecting multiple sensors to the data collection system �(2.2)
- Starting and stopping data recording �(6.2)
- Adjusting the scale of a graph �(7.1.2)

- Displaying multiple graphs simultaneously �(7.1.11)
- Naming a data run �(8.2)
- Finding the value of a point on a graph �(9.1)
- Viewing statistics of data �(9.4)
- Find the slope and intercept of a best-fit line �(9.6)
- Saving your experiment �(11.1)

Background

Toxicologists must concern themselves with the degree of toxicity—that is, the capacity to cause harm or death to living organisms—that exists for chemicals in the environment. Their studies must consider the dose (the amount of the substance that organisms are likely to be exposed to). They must also consider the genetic makeup of a species that might cause it to be sensitive to damage by a given chemical.

Toxicologists must select organisms for toxicity testing that are genetically similar to the organisms they want to protect from toxic chemical effects. Because of ethical considerations, substitutes for the organism of concern are often needed. Organisms further down in phylogeny that, nevertheless, have critical genetic characteristics similar to those of humans, are preferred test subjects.

Yeasts are good candidates for toxicology screening tests because 1) they are easy to grow, 2) they are relatively simple single-celled organisms yet are eukaryotic, 3) they have many metabolic processes that also occur in humans and other organisms further up in phylogeny, and 4) they have a known genetic code.

Pre-Lab Discussion and Experiment

Engage your students by examining a Material Safety Data Sheet (MSDS) of sodium fluoride, a toxic chemical that might be familiar to them and one they might encounter in their everyday lives. Sodium fluoride is a chemical that is sometimes added to drinking water at low levels to increase its fluoride content.

Note: MSDS documents are available on the Web in PDF format. They are easily found using a Google search. Students might not be aware that such information is freely available.

Note: You may find a bottle of sodium fluoride in your chemistry storage area to use as a visual aid.

Examine the MSDS for toxicity study information. For sodium fluoride, environmental toxicity data is listed in terms of lethal dose (LD_{50}). The LD_{50} for a goat and wild bird are listed.

Engage students in the following questions and discussion items:

1. Based on the LD_{50} information given for sodium fluoride, find the mass of sodium fluoride that would be expected to kill 50% of rats weighing 500 g.

The LD_{50} of sodium fluoride for a rat is 52 mg/kg. Therefore, 26 milligrams would be required to kill 50% of the rats weighing 500 g (52 mg/kg x 0.5 kg = 26 mg).

2. Discuss the ethical issues of testing the toxicity of substances. What would be the advantages of finding cell-culture systems that could produce toxicity information that could be directly applied to humans?

Conduct a brainstorming session to identify the criteria that such a test system would need to satisfy.

Instructor Tip: Accept all answers and write ideas on the board or overhead projector to remain displayed during the experiment.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Prepare 2 liters of a 1:1 household bleach:water solution (equal parts of bleach and water).
2. For each group, pour a 60-mL aliquot of the half-strength bleach solution into a 125-mL Erlenmeyer flask.

Note: Put stoppers in the Erlenmeyer flasks to minimize the amount of chlorine that vaporizes from the solution.

Safety

Add these important safety precautions to your normal laboratory procedures:

- If the room is not well-ventilated, handle open containers of bleach and bleach solutions under a ventilated hood.
- Wear safety glasses and a lab coat.
- Have running water or an eyewash station in close proximity.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Part 1 – Prepare the yeast culture

Set Up

1. Start a new experiment on the data collection system. �(1.2)

2. Connect the CO_2 sensor and the pH sensor to the data collection system to record pH and CO_2 gas simultaneously. �(2.2)

3. Display pH on the y-axis of a graph and CO_2 gas on the y-axis of another graph; show Time on the x-axes of these graphs. �(7.1.11)

4. Heat 1 L of water and 100 g of sugar in a 2-L beaker to about 40 °C on a hot plate.

5. Remove the beaker from the hot plate and turn off the heat.

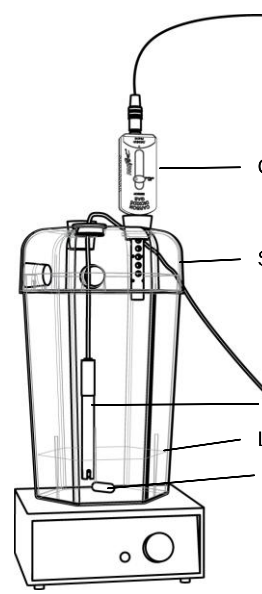
6. Add a package of activated yeast, and stir thoroughly.

7. Allow the mixture to activate for 15 minutes, stirring occasionally.

Note: The formation of bubbles indicates the yeast is activating.

Part 2 –Test the toxicity of vinegar

Set Up



8. Set up the EcoChamber to measure pH and CO_2 gas simultaneously, as follows:

- **a.** Place a stir bar in the chamber and set it on a magnetic stirrer.
- **b.** Make sure the end of the pH probe is about 1 cm above the bottom of the chamber.
- **c.** Arrange the CO_2 gas sensor so the end is completely inside the container, but will not get wet.
- **d.** Using the graduated cylinder, measure and pour 500 mL of the yeast cell culture solution into the chamber and seal it airtight.
- **e.** Turn on the magnetic stirrer.

Collect Data

Important! Record data continuously until you have added all 50 mL of vinegar.

9. Start data recording. �(6.2) Adjust the scale of the graph so the data fills the screen. �(7.1.2)

10. Measure 10 mL of vinegar using the graduated cylinder while data is recording.

11. After recording data for 3 minutes, remove the stopper from a port at the top of the chamber and add the 10 mL of vinegar. Replace the stopper.

Note: Do not stop recording data!

12. Record data for 3 additional minutes and again add 10 mL of vinegar.

Note: Do not stop recording data!

13. Repeat this procedure until a total of 50 mL of vinegar has been added.

14. Record data for 3 additional minutes.

15. Stop recording data. �(6.2)

16. Name the data run appropriately. �(8.2)

17. Discard the yeast solution as instructed by your instructor, and rinse the chamber and pH sensor.

18. Predict which will be more toxic to the yeast cells—half-strength bleach or full-strength vinegar? Explain your reasoning.

Answers will be either half-strength bleach or full-strength vinegar. Students may think an acidic solution is more harmful than a basic one, or vice versa; or that half-strength bleach may not be as strong as full-strength vinegar.

19. Why are you measuring the CO_2 gas concentration?

Carbon dioxide gas is being used as an indicator of cellular respiration by the yeast cells. Reduction in the rate of CO_2 gas production should indicate a reduced level of cellular respiration, indicating toxic stress on the yeast cells.

20. Why are you measuring the pH of the solution?

Vinegar is acidic, and so the acidity of the solution can be correlated with the toxicity of the dose of vinegar. Also, the effect of bleach on the pH of the yeast solution can be investigated and compared with the results of the vinegar trial.

Part 3 – Test the toxicity of half-strength bleach

Set Up

21. Set up the EcoChamber to measure pH and CO_2 gas simultaneously, as follows:

- **a.** Place a stir bar in the chamber and set it on a magnetic stirrer.
- **b.** Make sure the end of the pH probe is about 1 cm above the bottom of the chamber.
- **c.** Arrange the CO_2 gas sensor so the end is completely inside the container, but will not get wet.
- **d.** Using the graduated cylinder, measure and pour 500 mL of the yeast cell culture solution into the chamber and seal it airtight.
- **e.** Turn on the magnetic stirrer.

Collect Data

Important! You should record data continuously until you have added all 50 mL of half-strength bleach.

22. Start data recording. �(6.2) Adjust the scale of the graph so the data fills the screen. �(7.1.2)

23. Measure 10 mL of half-strength bleach using the graduated cylinder while data is recording.

24. After recording data for 3 minutes, remove the stopper from a port at the top of the chamber and add the 10 mL of vinegar. Replace the stopper.

Note: Do not stop recording data!

25. Record data for 3 additional minutes and again add 10 mL of half-strength bleach.

Note: Do not stop recording data!

26. Repeat this procedure until a total of 50 mL of half-strength bleach has been added.

27. Record data for 3 additional minutes.

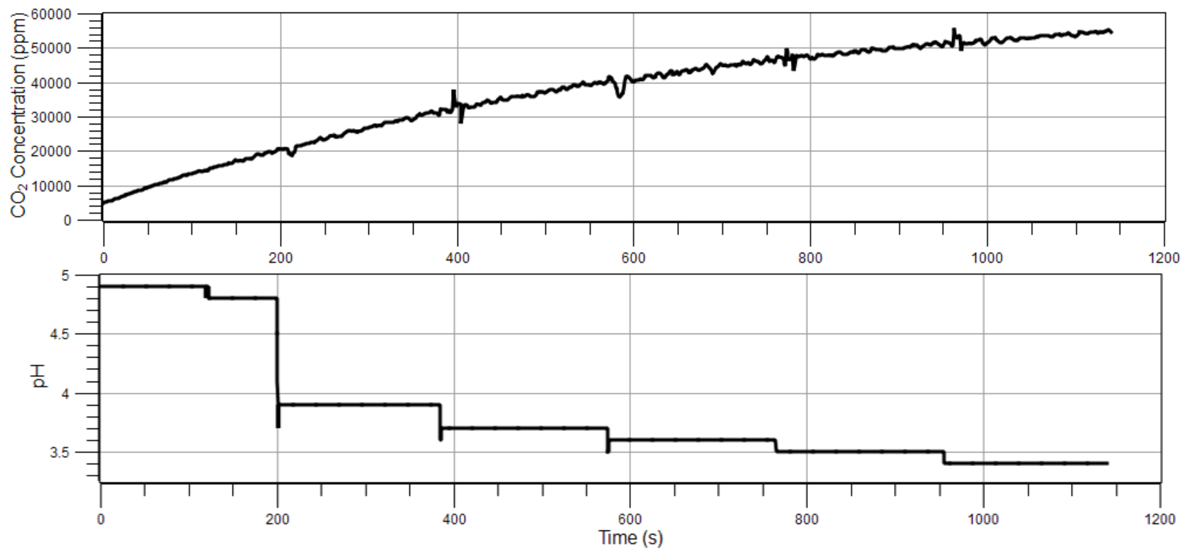
28. Stop recording data. �(6.2)

29. Name the data run appropriately. �(8.2)

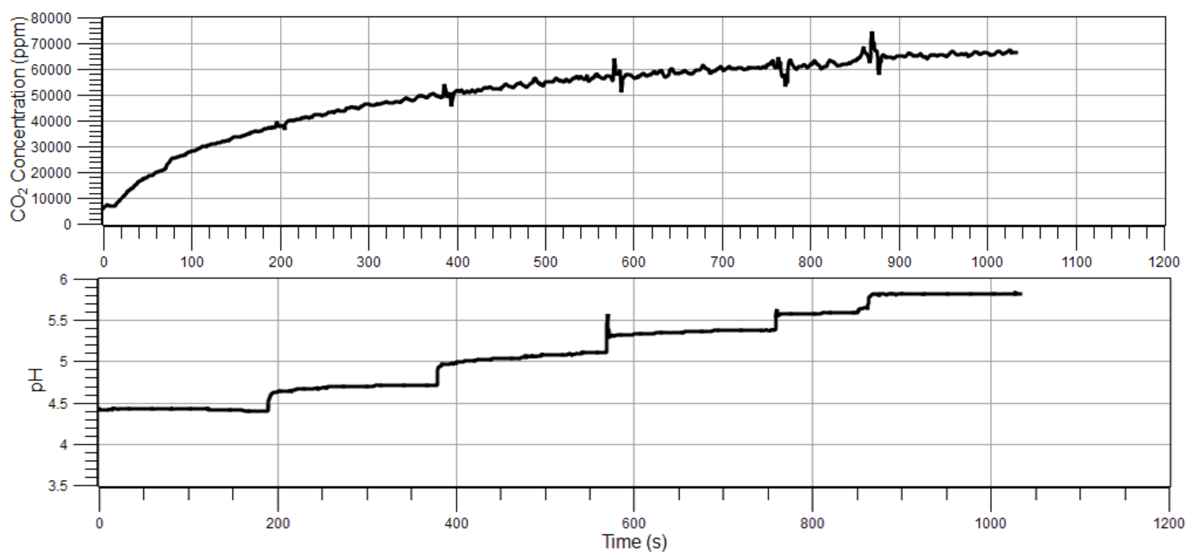
30. Discard the yeast solution as instructed by your instructor, and rinse the chamber and pH sensor.

31. Save your experiment and clean up according to your instructor's instructions. �(11.1)

Sample Data



Effect of full-strength household vinegar on CO_2 gas concentrations and pH of a yeast cell culture system



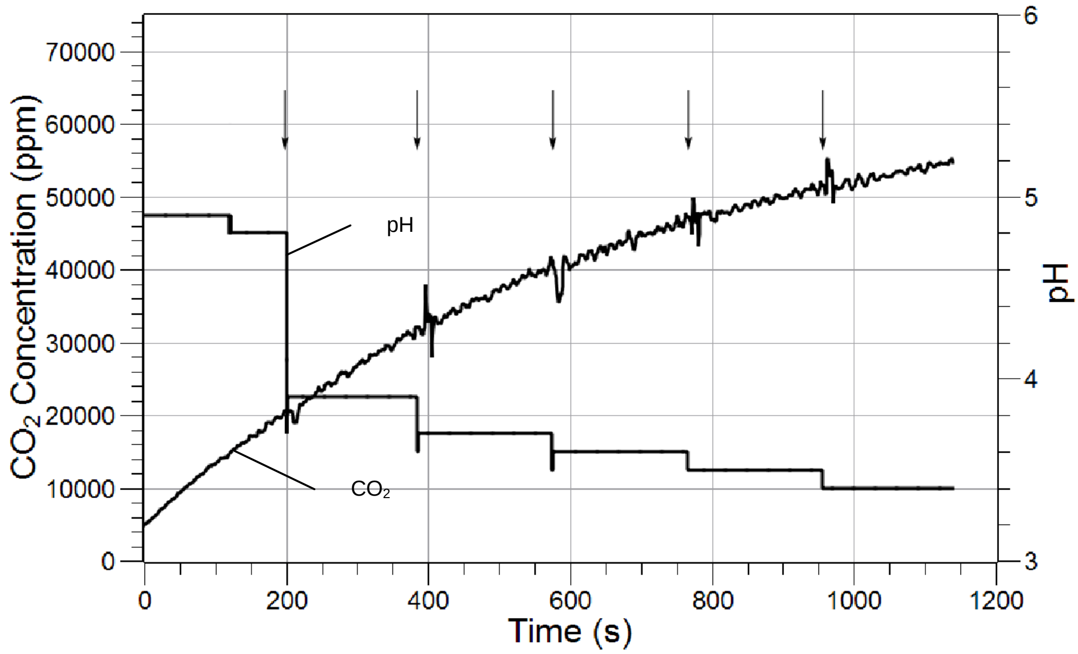
Effect of half-strength household bleach on CO_2 gas concentrations and pH of a yeast cell culture system

Data Analysis

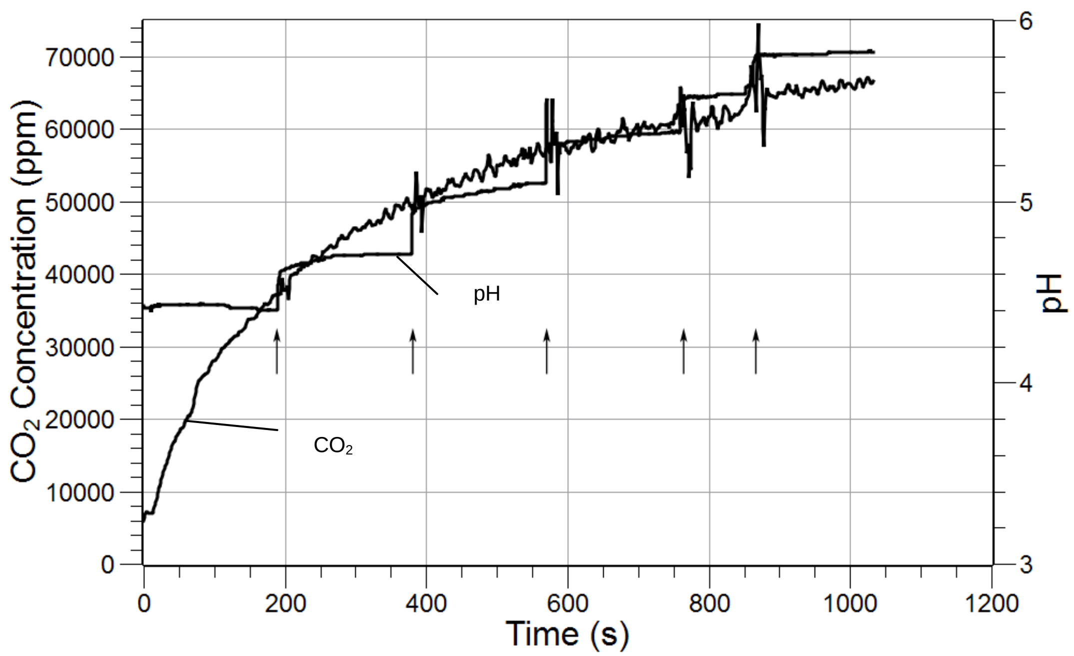
1. Display the dependent variable on the y-axis of a graph and time on the x-axis for both measurements (pH and CO_2 gas concentration) for each toxin. �(7.1.11)

2. Adjust the scale of the graph so the data fills the screen. �(7.1.2)

3. Sketch the graphs on the blank graphs. Sketch one graph for the vinegar trial and one graph for the half-strength bleach trial. Indicate the appropriate scale on the axes. Indicate the points at which the toxins were added to the system.



Effect on CO_2 concentration and pH of adding aliquots of full-strength vinegar



Effect on CO_2 concentration and pH of adding aliquots of half-strength bleach

4. Use graph tools to find the value of data points to complete Table 1. �(9.1)

Hint: To find the rate of CO_2 production (parts per million/second) for selected regions of the CO_2 data plot, use the linear fit tool to determine the slope of a best-fit line. �(9.6) To find the pH value for selected regions of the pH plot, use the statistics tool to find the mean value. �(9.4)

Table 1: Enter the rate of production of CO_2 gas and the pH change for each of the toxins

	Rate of production of CO_2 gas (ppm/s)						**pH**					
Toxin (total volume added)	**0 mL**	**10 mL**	**20 mL**	**30 mL**	**40 mL**	**50 mL**	**0 mL**	**10 mL**	**20 mL**	**30 mL**	**40 mL**	**50 mL**
White Vinegar	76	64	46	35	25	20	4.9	3.9	3.7	3.6	3.5	3.4
Bleach: water 1:1	144	59	37	20	14	11	4.4	4.7	5.0	5.4	5.6	5.8

5. Toxicologists often report the strength of a toxin in terms of LD_{50} or ED_{50}. Which of these terms is most appropriate for the results of this experiment? Explain.

Note: The LD_{50} is the dose of a substance at which 50% of the organisms are killed—that is, the lethal dose for 50% of exposed organisms. In many cases, the end point of interest is a sublethal effect, such as affecting the ability to reproduce or inhibiting metabolism. In these cases, the strength of a toxin is reported in terms of ED_{50}—that is, the effective dose causing 50% inhibition.

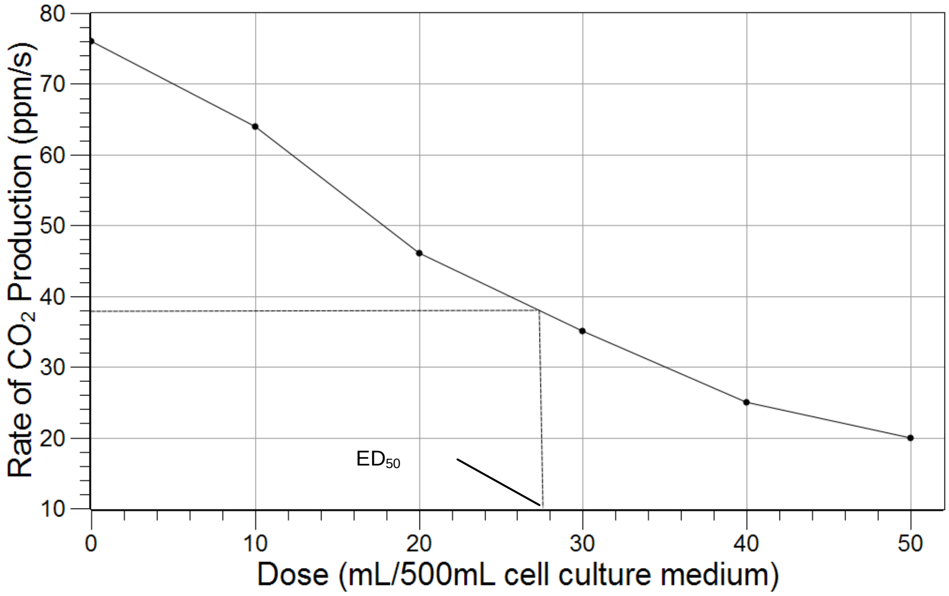
To evaluate the relative toxicity of substances using this yeast cell culture, the best measure would be the ED_{50}. This is because it is impossible to know in this experimental design whether the yeast cells are dead or whether they are just temporarily inhibited.

6. Use your data to extrapolate the ED_{50} of the half-strength bleach solution and the full-strength vinegar solution. To do this:

a. Plot the rate of CO_2 gas production versus the dose administered (mL toxin solution/500 mL).

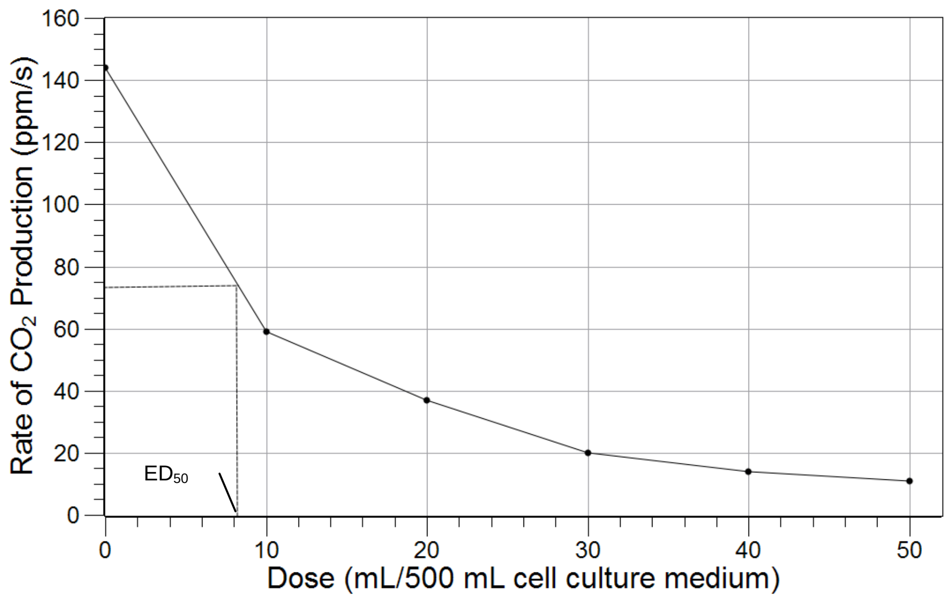
b. Then connect the points and use this curve to extrapolate the volume of toxin (mL toxin/500 mL yeast culture) required to reduce the rate of CO_2 gas production in half (ED_{50}).

c. Adjust the dose calculation to terms of mL toxin/L yeast culture.



The ED_{50} of full-strength vinegar is **56 mL/L**

Toxicity of full-strength vinegar



The ED_{50} of half-strength bleach is **16 mL/L**

Toxicity of half-strength bleach

ED_{50} of full-strength vinegar: ___56 mL/L___

ED_{50} of half-strength bleach: ___16 mL/L___

Answers will vary. For this example, the ED_{50} of half-strength bleach is 16 mL/L of yeast culture medium, and the ED_{50} of full-strength vinegar is 56 mL/L yeast culture medium.

7. Using the ED50 values as indices of toxicity, how does the toxicity of bleach compare to the toxicology of vinegar?

For this example, the ratio of toxicity of half-strength bleach to full-strength vinegar, as expressed in terms of ED_{50}, was 56:16. Using the ED_{50} values as indices of toxicity, half-strength bleach was 56/16 or 3.5 times more toxic than full-strength vinegar. That would mean that full-strength bleach is 3.5 x 2 = 7 times more toxic for yeast cells than full-strength vinegar.

Analysis Questions

1. What is the independent variable in this experiment?

The independent variable in this experiment is the toxin being tested.

2. What are the dependent variables?

The dependent variables are the rate of CO_2 gas production and the pH of the solution.

3. What are the controlled variables in this experiment?

The controlled variables are the volume of yeast cell culture added to the EcoChamber, the volume of vinegar and half-strength bleach added to the yeast culture, and the time between the additions of the toxins.

4. How do the data compare with your prediction?

Students should mention the relative response of yeast cells to toxins and should identify which toxin they predicted would be strongest and which actually was strongest.

5. What does the rate of CO_2 gas production indicate regarding the yeast culture? Explain why the rate of CO_2 gas production by a yeast culture can be used as an indicator of the toxicity of an added substance.

Yeast cells produce CO_2 gas during cellular respiration. Therefore, the production of CO_2 is an indicator that the yeast cells are metabolically active. A toxic substance would inhibit the metabolism of yeast, or perhaps even kill the yeast. In the presence of a toxic substance, their cellular respiration would be reduced, resulting in a decreased rate of CO_2 production.

6. Why do you think pH was measured in this experiment? What was the relationship of pH to toxicity? Was a large change in pH necessary for a toxic effect to occur?

pH was measured to correlate the pH of the yeast cell culture to the rate of cellular respiration. Cells function in a limited range of pH, therefore, lowering pH should inhibit cell function. However, a change in pH is not the only mechanism that can cause cells to reduce the rate of cellular respiration. The evidence from this experiment shows that bleach was more toxic than vinegar and raised the pH slightly, rather than lowering it.

7. For the best interpretation of the data, what additional test should be run with this assessment? Explain.

A control trial with water as the independent variable should be run to support the assumption that there is a constant rate of CO_2 production by the yeast culture. If students have performed the Yeast Respiration lab before performing this lab, they can use the evidence from that experiment to support this assumption. If time permits, consider performing this control trial.

Synthesis Questions

Use available resources to help you answer the following questions.

1. Determine the mean and standard deviation (SD) of the ED_{50} data obtained from the several trials conducted in your class. Compare the results of your trial to that of your classmates. Discuss possible reasons for the variations seen. Which value do you think is closest to the true value?

Answers will vary according to class results. Possible sources of experimental variation include variation in the number of active yeast cells in the cell culture and variations in measuring accuracy. Generally, the mean is the value that is closest to the true value, given enough trials. In general, from a large number of trials, the true mean is highly likely to fall within the range of the mean ± 2SD.

2. In what ways are yeast cells good subjects for toxicity studies?

Yeast cells are good subjects for toxicity studies because they are eukaryotic cells, so they are more like cells of organisms higher in phylogeny than bacteria are. Baker's yeast cells are easy to grow, and they are not pathogenic. Yeasts have many metabolic pathways that are like those of humans, and their genetic code is largely known.

3. What are some limitations of using yeast cells as subjects for toxicity studies?

Yeasts are single cells, so they do not have many of the complex mechanisms for detoxifying chemicals that exist in humans. Yeast reproduction has almost no characteristics that are similar to humans. Yeasts do not have differentiated cells and tissues, such as neurons and brains, that could be uniquely affected by a toxin.

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. The toxicity of a substance depends on

- **A.** Genetic makeup or sensitivity of the organism
- **B.** Frequency of exposure
- **C.** Ability of the body to detoxify
- **D.** The amount or dose
- **E. All of the above**

2. An LD_{50} is a determination of

- **A.** The amount of a toxin required to inhibit growth by 50%
- **B.** The amount of a toxin required to inhibit reproduction by 50%
- **C. The amount of a toxin required to kill 50% of a population**
- **D.** The lethal dose of a chemical after 50 days of exposure

3. An ED_{50} is a determination of

- **A.** The amount of a toxin required to inhibit growth by 50%
- **B.** The amount of a toxin required to inhibit reproduction by 50%
- **C.** The amount of a toxin required kill 50% of a population
- **D.** The lethal dose of a chemical after 50 days of exposure
- **E. Both A and B could apply**

4. Yeast cells can be useful in toxicology studies because

- **A.** They are eukaryotic.
- **B.** They have many metabolic pathways that are similar to those of humans.
- **C.** They are easy to grow.
- **D.** Their genetic code is largely mapped.
- **E. All of the above.**

5. Which of the following characteristics of baker's yeast is *not* a limitation in using yeast cells for toxicology studies?

- **A.** They have some metabolic pathways that are not found in humans.
- **B. They are not pathogenic.**
- **C.** They do not have similar detoxification mechanisms compared with those of humans.
- **D.** They are single-cellular organisms.
- **E.** They reproduce differently than humans.

6. In this experiment, the rate of CO_2 gas production was used as an indicator of toxicity to yeast cells because

- **A. It indicates the relative amount of cellular respiration by actively growing yeast cells.**
- **B.** CO_2 is consumed by yeast cells during aerobic cellular respiration.
- **C.** Yeast cells release CO_2 gas when they die.
- **D.** The toxin reacts to substances in the yeast cells to produce CO_2 gas.
- **E.** A and D are correct.
- **F.** None of the above.

Extended Inquiry Suggestions

Toxicologists have identified two basic models of dose-response curves for toxicity: those with no threshold and those with a threshold. Toxins that have no threshold are ones that are toxic at any level. Toxins that have a threshold are ones that are not toxic until a certain threshold of dose is achieved. Refer to available resources for examples of these models. Which model seems to apply to the toxicity of bleach for yeast cells? Which model seems to apply to the toxicity of vinegar for yeast cells?

Design additional trials using smaller doses of the toxins to determine whether bleach or vinegar have a threshold effect and the level of that threshold effect. What is the relationship of pH of the yeast cell culture to any threshold you discover?

Research the toxicity of sodium hypochlorite (active ingredient in bleach) and acid. Ask students to report on some possible mechanisms by which these toxins inhibit the rate of cellular respiration in yeast cells.

26. Air Pollution and Acid Rain

Objectives

In this experiment, students investigate chemical reactions that are important in the formation of acid rain to better understand the relationship between certain types of man-made (anthropogenic) emissions and problems arising from acid rain. During this investigation, students:

- Determine the effect of different anthropogenic gases on the pH of water
- Discuss the effect of changes in the pH of water on the environment

Procedural Overview

Students gain experience conducting the following procedures:

- Learning the chemical reactions involved in generating three types of gases (CO_2, SO_2, and NO_2) that are common anthropogenic emissions
- Measuring the effect of CO_2, SO_2, and NO_2 on the pH of water using a pH sensor
- Analyzing the chemical reactions that lower the pH of rain

Time Requirement

♦ Preparation time	15 minutes
♦ Pre-lab discussion and experiment	30 minutes
♦ Lab experiment	50 minutes

Materials and Equipment

For each student or group:

- Data collection system
- pH sensor
- Erlenmeyer flask, 50-mL
- 1-hole rubber stopper for flask
- Beaker, 40-mL
- Graduated pipet, 4-mL and pipet bulb
- Glass tubing for rubber stopper
- Flexible Teflon® tubing to fit glass tubing, 20 cm
- Graduated cylinder, 50- or 100-mL
- Sodium bicarbonate ($NaHCO_3$), 5 g
- Sodium bisulfite ($NaHSO_3$), 5 g
- Sodium nitrite ($NaNO_2$), 5 g
- 1 M HCl (15 mL)[1]
- Water or deionized water, 1 L
- Wash bottle containing distilled or deionized water

[1] To formulate using 6 M HCl, refer to the Lab Preparation section.

Concepts Students Should Already Know

Students should be familiar with the following concepts:

- ♦ Most cells function best within a narrow range of acidity.
- ♦ pH is a logarithmic measurement of the concentration of hydrogen ions in water. ($pH = -\log_{10}[H^+]$)
- ♦ pH measurements can range from 0 through 14. The lower the value, the higher the concentration of hydrogen ions.
- ♦ pH can be a measure of acidity, with values below 7 becoming increasingly acidic as the value approaches 0. Therefore, the lower the pH, the higher the concentration of hydrogen ions and the higher the acidity.
- ♦ A pH of 7 is neutral—neither acidic nor basic.
- ♦ pH values greater than 7 are considered basic. Practically speaking, a pH of 6 to 8 is considered to be in the neutral zone.

Related Labs in This Guide

Labs conceptually related to this one include:

- ♦ Acid Deposition and Natural Water Bodies
- ♦ Determining Soil Quality
- ♦ Monitoring Water Quality

Using Your Data Collection System

Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

- ♦ Starting a new experiment on the data collection system �(1.2)
- ♦ Connecting a sensor to your data collection system �(2.1)
- ♦ Start and stopping data recording �(6.2)
- ♦ Displaying data in a graph �(7.1.1)
- ♦ Adjusting the scale of a graph �(7.1.2)
- ♦ Naming a data run �(8.2)

- Viewing statistics of data �(9.4)

- Saving your experiment �(11.1)

Background

The Creation of Acid Rain

Acid rain is rain, or any other form of precipitation that is acidic. As this acidic water flows over and through the ground, it affects a variety of plants and animals. The strength of these effects depends on many factors, including: 1) the acidity of the water, 2) the chemistry and buffering capacity of the soils involved, and 3) the types of fish, trees, and other living things that rely on the water.

Scientists discovered that sulfur dioxide (SO_2) and nitrogen oxides (including nitric oxide, (NO), nitrogen dioxide (NO_2), and nitrous oxide (N_2O), collectively known as NO_x, are the primary causes of acid rain. Acid rain results when these gases react in the atmosphere with water, oxygen, and other airborne chemicals to form various acidic compounds.

Sulfur dioxide and nitrogen oxides go through several complex pathways of chemical reactions in the atmosphere before they become the acids found in acid rain. One of the most important pathways involves the oxidation of sulfur dioxide (SO_2) to sulfur trioxide (SO_3) by ozone (O_3). Ultraviolet energy of sunlight increases the rate of most of these reactions by degrading ozone to oxygen gas (O_2) and an oxygen radical (O^-) that is a highly reactive oxidizer. The sulfur trioxide then reacts with water vapor to form sulfuric acid. These reactions are shown as follows:

$$2SO_2 + 2O^- \rightarrow 2SO_3$$

$$SO_3 + H_2O \rightarrow H_2SO_4$$

Dust or ice particles can transport this sulfuric acid through the atmosphere to settle on the ground as dry acid deposition. The sulfuric acid can also dissolve in rain or fog and settle on the ground as wet acid deposition. Scientists believe that sulfuric acid is primarily responsible for the formation of acid rain.

Sulfur dioxide also readily dissolves in water, producing bisulfite and hydrogen ions. Students will explore this reaction of sulfur dioxide in this lab experiment.

In the United States, about two-thirds of all SO_2 and one-quarter of all NO_x comes from electric power generation that relies on burning fossil fuels such as coal. Other sources include automobile exhaust, furnaces, paper pulp production, and metal smelters.

Carbon dioxide is also a source gas for acid rain. It produces a relatively weak acid, but still should be considered a source due to increased use of fossil fuels.

The Effects of Acid Rain

The effects of acid rain are widespread. Acid rain causes acidification of lakes and streams. It damages trees at high elevations, such as red spruce trees above 600 meters, damages sensitive forest soils, and accelerates the decay of building materials (such as limestone and marble), metals (such as bronze) and automotive paint and other coatings. The stressful and sometimes deadly fluctuations in water systems due to acid rain cause aquatic life to experience chemical “shock” effects. For example, as the pH drops to 5.5, plankton, certain insects, and crustaceans begin to die and trout eggs do not hatch well.

Acid rain reduces crop productivity and forest growth rates while accelerating the rate at which "heavy" metals, such as lead and mercury, and nutrient cations (such as Mg^{2+} and K^{+}) leach from soils, rocks, and water body sediments. Scientists believe that acid rain causes increased concentrations of methylmercury in bodies of water—methylmercury is a neurotoxic molecule that accumulates in fish tissues and can cause birth defects in populations that ingest high concentrations of affected fish.

Pre-Lab Discussion and Experiment

Engage your students by having them research adverse effects of acid rain worldwide. Brainstorm for a variety of examples and record them for class viewing. If local examples can be found, these are excellent for focusing and stimulating interest.

Point out that anthropogenic emissions are responsible for some of the acidity in the atmosphere that results in acid rain. Tell students they will be generating some of these gases and testing their effect on the pH of water.

Review the chemical reactions that produce the gases you will be studying:

Sodium bicarbonate + hydrochloric acid + water → sodium ion + chloride ion + water + carbon dioxide gas:

$$NaHCO_3(s) + HCl(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l) + CO_2(g)$$

Sodium bisulfite + hydrochloric acid + water → sodium ion + chloride ion + water + sulfur dioxide gas:

$$NaHSO_3(s) + HCl(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l) + SO_2(g)$$

Sodium nitrite + hydrochloric acid + water → sodium ion + chloride ion + water + sulfur dioxide gas:

$$NaNO_2(s) + HCl(aq) \rightarrow Na^+(aq) + Cl^-(aq) + H_2O(l) + NO_2(g)$$

If necessary, review the pH scale and how it is determined.

Lab Preparation

These are the materials and equipment to set up prior to the lab.

1. Prepare the 1.0 M hydrochloric acid solution by adding 16.6 mL of 6 M HCl per 100.0 mL of solution. Pour the concentrated HCl into about 80 mL of water, bring the solution up to 100 mL with water, and pour 15 mL into a beaker for each group.

Note: Do not pour water into the concentrated acid.

Instructor Tips: Use tap water unless the water in your area has a high level of dissolved solids, which can produce a significant buffering action. This is the case for some well water, for example. The pH of distilled and deionized water is highly susceptible to large changes as a result of minute contaminants.

Because the pH measurements in this experiment are relative to measurements within this lab, the factory calibration is sufficient.

If your classroom does not have a vented hood, student groups or the instructor can generate the SO_2 and NO_2 under the vented hood in the chemistry lab. It is safe for students to generate the CO_2 at their workbenches in the classroom. Each group can then present its results to the class for analysis.

For students generating CO_2 at their workbench, you can substitute household white vinegar if you don't have 1M HCL.

Safety

Add these important safety precautions to your normal laboratory procedures:

- Consult the manufacturer's material safety data sheets (MSDS) for instructions on handling, storage, and disposing of hydrochloric acid, sodium bisulfite, and sodium nitrite. (You can find these on the Internet.) Keep these instructions available in case of accidents.
- Students creating sulfur dioxide and nitrogen dioxide should work under a vented hood.
- Do not touch the hydrochloric acid (HCl). Handle the pipet with HCl with extreme care.
- Do not remove the rubber stopper from the Erlenmeyer flask once the reaction has started.
- After completing the lab, wash your hands.
- Wear safety glasses and lab coats or aprons.

Procedure with Inquiry

Note: Students use the following technical procedures in this experiment. The instructions for them (identified by the number following the symbol: "�") are on the storage device that accompanies this manual. Choose the file that corresponds to your PASCO data collection system. Please make copies of these instructions available for your students.

Create gas generators, and measure pH

You will create CO_2, NO_2, and SO_2, as follows:

Mix sodium bicarbonate ($NaHCO_3$) with hydrochloric acid (HCl) to produce carbon dioxide gas (CO_2).
Mix sodium nitrite ($NaNO_2$) with hydrochloric acid (HCl) to produce nitrogen dioxide (NO_2).
Mix sodium bisulfite ($NaHSO_3$) with hydrochloric acid (HCl) to produce sulfur dioxide gas (SO_2).

1. Make predictions: What do you think will happen to the pH of the water when you dissolve these gases in it? Which gas will produce the largest change in pH?

Answers will vary according to student predictions. Answers should include the prediction about the gas that will create the largest change in pH.

Part 1 – Making carbon dioxide (CO_2) gas and measuring its effect on the pH of water

Set Up

2. Start a new experiment on the data collection system. �(1.2)

3. Connect the pH sensor to the data collection system. �(2.1)

4. Display pH on the y-axis of a graph with time on the x-axis. �(7.1.1) (7.1.2)

5. Measure 20.0 mL of water using the graduated cylinder.

6. Pour the water into the 40-mL beaker.

7. Thoroughly rinse the pH electrode with distilled water.

8. Place the rinsed pH electrode in the beaker.

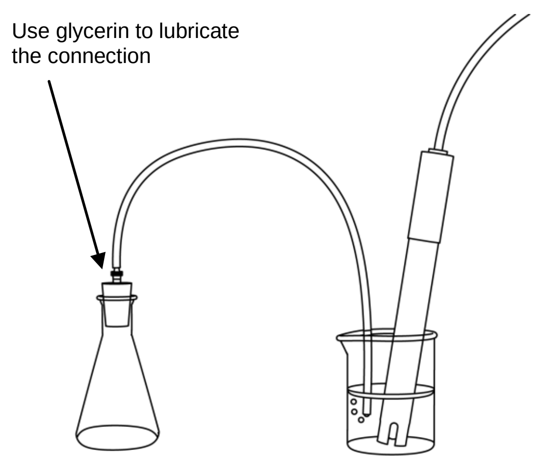
9. Obtain a sample of powdered sodium bicarbonate ($NaHCO_3$) from the instructor.

10. Measure 5 grams of $NaHCO_3$

11. Place the measured $NaHCO_3$ in the Erlenmeyer flask.

12. Assemble the stopper, glass tubing or barbed connector, and flexible tubing.

Note: If necessary, use glycerin to lubricate the connection so that the connector or glass tubing is well seated in the rubber stopper



13. Pipet 4 mL of 1.0 M hydrochloric acid (HCl) into the Erlenmeyer flask, and immediately stopper the flask.

CAUTION: Hydrochloric acid is a strong acid. Handle with care. Flush any spillage with a lot of water.

Collect Data

14. Place the free end of the flexible tubing in the water in the beaker, and immediately start recording data. �(6.2)

15. Record data for about 200 seconds (until the change in pH stops or stabilizes), and then stop recording. �(6.2)

16. Name your run to reflect the sample type. �(8.2)

17. Dispose of the contents of the flask and beaker as directed by your instructor.

18. Rinse the beaker, flask, and tubing with water.

Part 2 – Making sulfur dioxide (SO_2) gas and measuring its effect on the pH of water

19. Repeat the steps in Part 1 using 5 g $NaHSO_3$ instead of $NaHCO_3$.

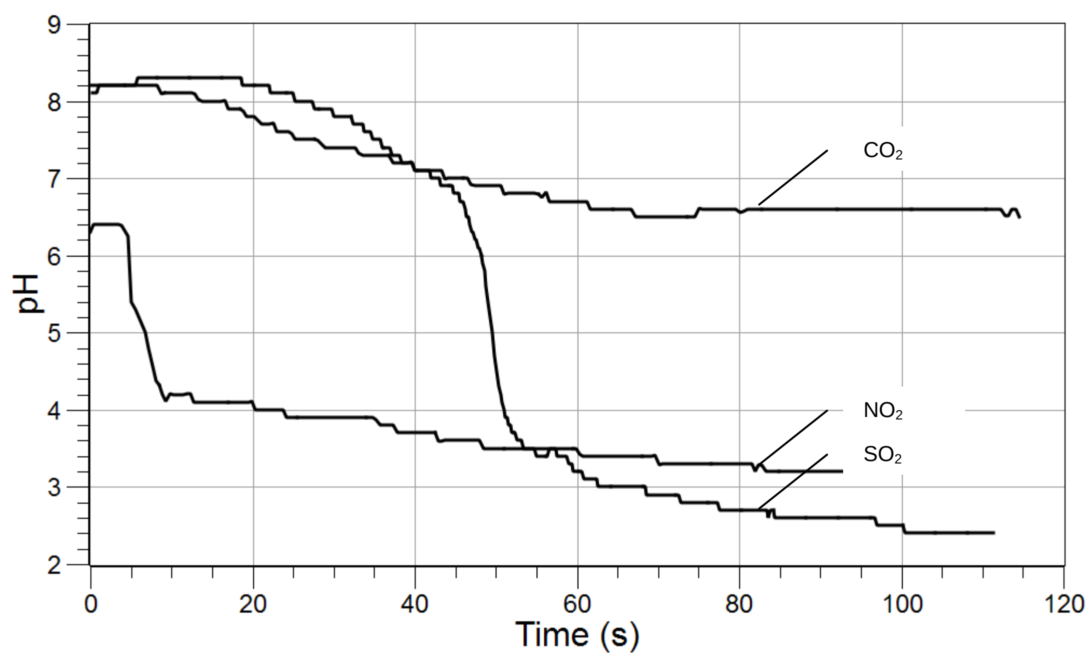
Part 3 – Making nitrogen dioxide (NO_2) gas and measuring its effect on the pH of water

20. Repeat the steps in Part 1 using 5 g $NaNO_2$ instead of $NaHCO_3$.

21. Save your experiment �(11.1), and clean up according to your instructor's instructions.

Sample data

The following graph shows pH versus time as CO_2, SO_2, and NO_2 are bubbled into distilled water.



Data Analysis

1. From the graph display for each run, determine the maximum and minimum pH values, and record them in Table 1. �(9.4)

2. Complete Table 1.

Table 1: pH change due to gases dissolved in water

Gas	Final pH	Initial pH	Change in pH (pH_{final} - $pH_{initial}$)
Carbon dioxide	6.5	8.2	–1.7
Sulfur dioxide	2.9	8.3	–5.4
Nitrogen dioxide	3.2	6.4	–3.2

Analysis Questions

1. Was your prediction correct regarding what would happen to the pH when you dissolved the gases in it? Why or why not?

Answers will depend on what students predicted. Answers should briefly discuss why they were correct or not correct.

2. The following chemical reactions are involved in this lab. Write each formula using chemical notation.

a. One molecule of carbon dioxide gas dissolves in water to form one bicarbonate ion and one hydrogen ion.

$CO_2 + H_2O \rightarrow HCO_3^- + H^+$

b. Two nitrogen dioxide gas molecules dissolve in water to form one nitrate ion, one nitrite ion, and two hydrogen ions.

$2NO_2 + H_2O \rightarrow 2H^+ + NO_3^- + NO_2^-$

c. One sulfur dioxide gas molecule dissolves in water to form one bisulfite ion and one hydrogen ion.

$SO_2 + H_2O \rightarrow HSO_3^- + H^+$

3. Which gas created the smallest change in pH of the water?

The carbon dioxide gas produced the smallest decrease in pH.

4. Compare your results with those from other groups. What factors might have caused some of the variability in the change of the observed pH?

Some factors that might contribute to experimental variability include: 1) variations in the mass of reactants used; 2) variations in the amount of water used; 3) variations in the efficiency of collecting the gases; 4) variations in pH sensors, which may not have been calibrated for this experiment.

5. For the three reactions of gas dissolving in water, what caused the reduction of the pH of the water in which these gases are dissolved?

The pH is lowered because hydrogen ions are formed. When the concentration of hydrogen ions increases, the pH decreases.

Synthesis Questions

Use available resources to help you answer the following questions.

1. What industrial or other man-made (anthropogenic) gases emitted into the atmosphere are considered the primary gases that cause acid rain? What are some sources of these gases?

The primary gases involved in producing acid rain are sulfur dioxide and the nitrogen oxides. The primary sources of these gases are the burning of fossil fuels, smelting of metals, and paper pulp production.

2. Scientists have found that sulfuric acid is the primary acid that causes acid rain. What are some of the chemical reactions that produce sulfuric acid in the atmosphere? Why does radiation from the sun speed up this reaction?

$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g)$ (this reaction requires an oxidizer, such as ozone)

$SO_3(g) + H_2O(l) \rightarrow H^+(aq) + HSO_4^-(aq)$

The sun's radiant energy, particularly ultraviolet energy, produces oxidizing molecules from ozone, water molecules, and oxygen gas. These oxidizing molecules speed the reaction.

3. Coal from states in the western United States, like Montana and Wyoming, has a lower percentage of sulfur impurities (lower sulfur content) than coal found in the eastern United States. How would burning low-sulfur coal change acid rain?

Burning low-sulfur coal would decrease the amount of acid rain by reducing the amounts of sulfur oxides (the reactants required to produce sulfuric acid) emitted into the atmosphere.

4. Discuss the relationship between acid rain and the sulfur and nitrogen cycles.

Sulfur and nitrogen trapped in solid materials enter the atmosphere through oxidative chemical reactions. These reactions combine the sulfur or nitrogen with oxygen atoms, creating gas oxide molecules. Examples of these oxidation reactions include: 1) combustion of sulfur-rich and nitrogen-rich fossil fuels; 2) oxidative decay of sulfur- and nitrogen-containing plant and animal matter by microorganisms; and 3) oxidation of sulfur- or nitrogen-containing organic matter during certain industrial processes, such as converting wood to paper pulp.

While in the atmosphere, the sulfur and nitrogen oxide gas molecules are converted to sulfuric acid and nitric acid. These acid molecules are then deposited back on the surface of the earth via dry or wet deposition. Wet deposition is in the form of rain, fog, sleet, or snow. The sulfate, nitrate, and nitrite ions of the acids then serve as nutrients for protein and DNA synthesis by living organisms. Thus, the sulfur and nitrogen are again bound in solid matter, completing the cycle.

5. What are some ways to treat the effects of acid rain?

1) Buffer lakes by adding lime. 2) Add vegetation to the watershed so that water does not run off as rapidly into the body of water. That way, the water seeps into the soil, dissolving buffers contained in the soil. 3) Add large amounts of water that have neutral or basic pH.

6. What are some ways to prevent the formation of acid rain?

Ways to prevent the formation of acid rain include: 1) Burning a lower sulfur-containing fuel will result in less SO_x emissions; 2) Install scrubbers (or other technology) on smoke stacks to reduce SO_x emissions; 3) Install catalytic converters in cars to convert nitric oxide gases to nitrogen gas; 4) Conserve energy. Using less energy will require burning less fossil fuels, which contain sulfur and nitrogen; 5) Develop more fuel-efficient cars, thus reducing NO_x emissions; 6) Develop energy-producing methodologies that do not emit sulfur and nitrogen oxides.

7. Although carbonic acid produces only a small decrease in the pH of water, why is it of concern in the environment?

In the oceans, CO_2 is taken from the atmosphere and is converted to carbonic acid. There is concern that as CO_2 levels increase in the atmosphere, more CO_2 will become dissolved in the oceans. This forms more carbonic acid, which might decrease the pH of ocean water and adversely affect many forms of life there.

Multiple Choice Questions

1. Which of the following is true about acid rain?

- **A.** Acid rain is linked to NO_x and SO_x molecules in the atmosphere.
- **B.** Acid rain can result in the death of many species of water-dwelling organisms when it causes the pH of lakes to decrease to a level outside their tolerance.
- **C.** Acid rain affects soil chemistry and the ability of plant roots to take in nutrients.
- **D.** Acid rain increases the mobility of toxic metals in ecosystems.
- **E. All of the above are true.**
- **F.** Only A, B, and C are true.

2. Which of the following play important roles in the formation of acid rain?

- **A.** Solar radiation
- **B.** Buffers in soils and water
- **C.** Water in the atmosphere
- **D.** Nitrogen gas (N_2) in the atmosphere
- **E.** All of the above
- **F. Only A and C**

3. In general, rain exerts harmful effects on ecosystems when it falls below a pH of

- **A.** 3.6
- **B.** 4.6
- **C.** **5.6**
- **D.** 6.6
- **E.** 7.6

4. Acid rain has been linked to

- **A.** Contamination of fish with highly toxic methylmercury
- **B.** Damage to fish through reactions that create high aluminum concentrations in the water.
- **C.** Reduced nutrient uptake by tree roots
- **D.** Weakening trees, so they become more susceptible to other types of damage
- **E.** **All of the above**

Extended Inquiry Suggestions

What is the pH of your local rainwater? Challenge students to design a method for collecting rainwater and then measure the pH of the sample using a pH sensor.

What is the pH of a local water system? Ask students to collect samples from a local pond, stream, lake, or river. Then determine the pH of the samples using a pH sensor.

Visit a local cemetery and observe the wearing away of the headstones or other grave markers. Military cemeteries use limestone markers that are more easily affected by acid rain than the granite markers in some private cemeteries. Use the dates on the marker stones and the condition of the stones to determine which ones acid rain may have damaged. Remember that these materials would naturally deteriorate when exposed to the weather and rain (even unpolluted rain). Acid rain would accelerate this damage.

Ask students to write, produce, and direct a “weather special” segment for TV on how weather patterns affect the travel of acid rain over large distances. Contact the weather bureau or a local television station's weather department to ask about the wind patterns in your area. This information and data for your area may also be available on the Internet.

Encourage students to contact a local natural resource specialist at your local zoo or park. Ask that person about the impact, if any, of both acid rain and dry acid deposition in the local lakes.