Biosphere

Project-Based Learning Module

High School Life Science

PASCO®

PASCO Engineering Design Process

PASCO's STEM Modules guide students through the multi-step engineering design process outlined below. Students work individually and in groups to design, build, test, and evaluate their engineering prototype.

1 Initial Design Ideas

Students work individually to develop design ideas based on the design requirements and constraints of the engineering challenge.

2 Research

Students work in groups to carry out the science and math activities of the module. In carrying out these standards-based activities, students investigate fundamental concepts that apply to the engineering challenge and acquire skill using the standard tools and techniques they will need to complete the challenge successfully.

3 Revise Design

Students work individually to revise, improve, or confirm their initial designs based on the science and math concepts explored in the research stage.

4 Develop Group Design

Students work in groups to produce a collaborative design based on the best elements of the various individual designs, observing the original design requirements and constraints.

5 Build a Prototype

Students work in groups to build a prototype of their group design.

6 Test and Evaluate

Using a standard test bed, students test their prototype and evaluate its success.

7 Design Review

Students analyze and evaluate the test results and propose changes to increase the effectiveness of their design.

Challenge: Biosphere

PASCO

Design and build a closed terrestrial or aquatic environment that will sustain a macroinvertebrate or small fish indefinitely.

Activity: Cellular Respiration in Animals

Quantify the rate of cellular respiration for a macroinvertebrate or fish and determine the oxygen consumption rate.

PASCO CO_2 Gas Sensor

Graphical Analysis, Algebra

Determine the oxygen consumption rate and other resource requirements of the animal inhabitants of the biosphere.

Activity: Ecological Accounting

Determine how carbon cycling, photosynthesis, and respiration relate on a micro-scale by calculating the number of moles of available nutrients in a finite space.

Determine the correct scale for your proposed biosphere.

Activity: Plant Photosynthesis and Respiration

Measure the carbon dioxide levels in a closed environment to determine rates of photosynthesis and respiration for different plant species.

PASCO CO_2 Gas Sensor

Graphical Analysis, Algebra

Determine the amount of primary producers necessary to sustain your biosphere.

Construct a biosphere that satisfies the design requirements and constraints using the information learned in the activities.

Activity: Standardizing Data

Analyze sample data to determine metabolic rates and calculate the micromoles of gas consumed or produced.

Graphical Analysis, Algebra, Dimensional Analysis, SI Units

Convert dimensionless quantities into usable data for comparison and analysis.

Activity: Decomposition

Investigate the rate of decomposition in different soil and substrate samples.

PASCO CO_2 Gas Sensor

Graphical Analysis, Algebra

Determine the best substrate composition to support your biosphere without overwhelming the system with carbon dioxide.

STEM

SCIENCE TECHNOLOGY ENGINEERING MATHEMATICS

Published by
PASCO scientific
10101 Foothills Blvd.
Roseville, CA 95747-7100
800-772-8700
916-786-3800
916-786-8905 (fax)
www.pasco.com

ISBN 978-1-886998-69-8
First Edition
Part Number: 012-12744
Catalog Number: PS-2980

Contributors

PASCO Development Team

- Freda Husic, *Director of Education Solutions*, *Program Manager*
- Michael Blasberg, *Curriculum and Training Developer*, *Lead Author*

Editors and Graphic Designers

- Janet Miller, *Editor*
- Tommy Bishop, *Digital Design and Production Specialist*
- Dan Kimberling, *Media Specialist*

Contents

NOTE: *Headings in bold type indicate student handouts.*

What Is STEM?

STEM education is a trans-disciplinary curriculum connecting **S**cience, **T**echnology, **E**ngineering, and **M**athematics, the combination of which promotes students' understanding of each of these fields and develops their abilities to become self-reliant researchers, innovators, and inventors. When faced with an idea or a problem, students learn how to develop solutions, how to analyze and evaluate different solutions, and how to collaborate with others to construct and test a product.

What this looks like in the classroom, however, is not always clear. In some cases, "S" is presented but not "M"—the math that explains the science. In other cases, STEM curriculum and materials focus on the "S" and the "M," leaving out the "T" and "E" —the technology element that generates solutions and gives rise to a deeper understanding of the science and math components, and the engineering element that centers on solving problems. The four parts of STEM have historically been taught separately and most of the time independently from each other; with STEM, science, technology, engineering, and math all play an important part in teaching these subjects as a whole.

PASCO's Project-Based Learning Modules

Module Principles

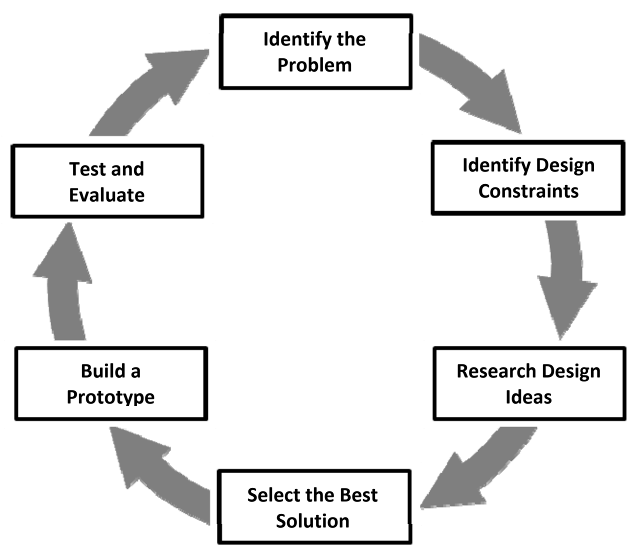
PASCO's Project-Based Learning Modules focus on all four components of S-T-E-M and are guided by various elements, including national standards; activity-, inquiry- and problem-based learning; the expectation of a tangible product or process as an outcome; and formative and summative assessments. They incorporate both independent and collaborative work, and rely on the engineering design process to bring all the pieces together.

A PASCO Project-Based Learning Module is centered on an open-ended Challenge in which students are given the task of designing, constructing, and implementing the solution to an engineering problem. The Challenge is based on fundamental science concepts in one or more genres of science: physics, chemistry, biology, and environmental science, and simulates a real-world problem that a modern engineer may encounter, with similar design constraints. Inside each Challenge are activities that focus on some or all of the key science and mathematics concepts of the Challenge and are part of the students' engineering design research.

These activities provide an opportunity for students to explore and research scientific concepts using PASCO's 21st Century Probeware and data collection systems. Students can then support their engineering designs with quantitative results from the activities. Through the activities, they obtain the science understanding, math skills, and familiarity with the techniques and tools of the field—background necessary to design and build the model or prototype.

Prototype development for a Challenge follows an engineering design process: students independently create initial solutions, they revise these solutions based on the results of the structured group activities, they analyze and evaluate the approaches of the students in their group, they finalize a group design, and they build a model or prototype for testing. Using the results of the test, they review their design and propose improvements.

Although the PASCO Engineering Design Process is shown (on the back of the title page) as a linear process that ends at the Design Review stage, engineering design is an iterative process, as shown in the circular diagram to the right. If time permits, students can use their analysis of the test results to begin again, creating an improved initial design, doing additional research, and building, testing, and analyzing the revised prototype.



Module Organization

A STEM Module contains the student handouts and related information to assist the teacher in presenting, guiding, and assessing the students' work. Material is organized in a chronological manner, with the teacher information immediately following the handouts. For example, the pre-assessment handout is followed by the pre-assessment answer key and includes information that suggests ways to use the results and how to overcome incorrect preconceptions.

Each section of the student Challenge—Initial Design Ideas, Research, Revise Design, Develop Group Design, Build a Prototype, Test and Evaluate, and Design Review—conveys both the students' and the teacher's role for that stage of the engineering design process. The science and math activities (both student handouts and teacher notes) are included in the Research section. The Concluding the Module section provides wrap-up questions to use for discussion and lists possible misconceptions in order to look for changed understanding. The module concludes with a post-assessment handout for the students and answer key for the teacher.

The Challenge and Activity handouts are designed to be copied and used for multiple classes. Students should record all work in their notebook. If desired, you can change the handouts to be used to record the data by modifying the Microsoft® Word documents provided.

Paper versus SPARKlab™ Activities

In addition to the conventional paper format found in the Research section of this module, each activity in the Biosphere Module is available on the accompanying storage device in an electronic SPARKlab format (".spk"). The content found in both the paper format and the SPARKlab format is nearly identical, with some small changes to the step sequence and wording. This provides you, the teacher, an opportunity to choose the format that will be best received by your students.

The SPARKlab activities are presented as fully configured, stand-alone activities used with either a SPARK Science Learning System™ or a computer running SPARKvue™ software. All instructions, procedural steps, data displays, and questions are pre-configured and included in the electronic file. There are two sets of electronic SPARKlabs provided on the accompanying storage device. The two sets of labs have identical content but different resolution.

™	spark ™ Science Learning System	sparkvue ™
SPARKlab folder	Biosphere SPARK Science Learning System	Biosphere SPARKvue
Sample file name	HS STEM Decomposition.spk	HS STEM Decomposition SV.spk
Images	The images are optimized for the size of the SPARK screen.	The images have a higher resolution to take advantage of the size of a computer screen.
Copying files	Refer to your SPARK Science Learning System User's Guide, in the "Saving and Sharing" section under "Managing Files and Folders".	The files can be saved anywhere in your normal filing system. The labs are "read-only" to protect students writing over them.

For information on the different methods for submitting student work when using the SPARK Science Learning System or SPARKvue software, refer to the "Saving and Sharing" section of the appropriate User's Guide.

Projecting SPARKlab™ Activities Using the SPARKvue Emulator

The SPARAKvue emulator can be used to model the SPARK Science Learning System interface. To model opening a SPARKlab you need to save the SPARKlabs in the locations described below.

Windows XP :	C:\Documents and Settings\All Users\ Documents\My SPARK Data\Experiments
Windows Vista/7:	C:\Users\Public\Documents\SPARK Data\Experiments
Mac OS X:	HD>Users>Shared>SPARK>Experiments

The Data Collection System

All activities are carried out on a PASCO data collection system. "Data collection system" refers to the data collection, display, and analysis device used to carry out the various PASCO STEM activities. These include PASCO's DataStudio®, the Xplorer GLX™, SPARKvue™, and SPARK Science Learning System™.

Detailed explanations for using the data collection system to carry out these procedures are found in the Tech Tip file corresponding to your data collection system. You can find these files on the storage device that accompanies this printed module, on the stand-alone storage device, and available for download with the module content.

Data Collection System	**Tech Tip File**
SPARK Science Learning System™	SPARK Tech Tips.pdf
SPARKvue™	SPARKvue Tech Tips.pdf
Xplorer GLX™	Xplorer GLX Tech Tips.pdf
DataStudio®	DataStudio Tech Tips.pdf

Using Project-Based Learning Modules with PASCO's 21st Century Science Guides

Science is a process of inquiry; an ongoing search to explain what goes on around us. PASCO's 21st Century Science Guides focus on students learning science through inquiry-based activities—presenting concepts in a way that develops critical thinking, procedural expertise, proficiency in design and construction, and analytical skills.

Using the Project-Based Learning Modules in conjunction with the 21st Century Science Guides further increases student skills and understanding. Students working on the Project-Based Learning Module Challenge are exercising the highest levels of critical and creative thinking: synthesis and evaluation—students design their prototypes by integrating the skills and knowledge gained in the activities, by comparing and discriminating between their own designs and those of others, and by appraising the strengths and weaknesses of their creation.

Teachers can use the Project-Based Learning Modules together with the 21st Century Science Guides in several ways. They can

- use only the Project-Based Learning Module to teach the unit
- extend a science unit with the activities in the Project-Based Learning Module after students complete related activities from the 21st Century Science Guide
- include additional activities from the 21st Century Science Guide to enhance the module
- use the Project-Based Learning Module as a capstone to review and integrate the topics already covered from the 21st Century Science Guide

In all of these approaches, challenging students with a Project-Based Learning Module enables them to apply their inquiry skills as they combine the science concepts and math skills to engineer something entirely new..

Content and Skills

Within this module, students develop their understanding of carbon cycling and basic ecology concepts. Students explore photosynthesis, cellular respiration, and decomposition by measuring the carbon dioxide concentration in a closed environment and creating a mathematical model. They then synthesize their data to design a balanced ecosystem that can sustain a macroinvertebrate or fish.

Concepts

Carbon cycling

Photosynthesis: storing light energy

Cellular respiration: releasing chemical energy

Cellular respiration: occurs in plants as well as animals

Decomposition

Energy flow through ecosystems

Environmental factors affect living systems

Identify some limitations of modeling

Skills

Graphical analysis and interpretation

Dimensional analysis and unit conversion

Creating mathematical models

Use a carbon dioxide sensor to measure the rate of CO_2 change

Although the Pre-Assessment is a day-one activity, it may be useful to deliver it in advance of the module to determine if additional instruction is required prior to starting the module. For example, finding that students are having difficulty determining the slope of a line would prohibit them from successfully completing some activities; a refresher prior to starting the module would be beneficial.

Success in the Biosphere Module can be assessed using the Challenge Rubric handout, the Challenge questions, questions integrated into each activity, and the Pre- and Post-Assessment handouts found in the Before the Challenge and After the Challenge sections. The Pre-Assessment handout focuses on concepts covered in the activities within the Biosphere Module and also addresses some of the misconceptions associated with them. Math concepts are also covered in the Pre- and Post-Assessment handouts.

Prerequisites

- Know how to determine the slope of a line
- Know how to balance a chemical equation
- Understand ratios and percentages
- Understand moles
- Know how to do basic dimensional analysis

Pacing Guide

Each lab-based activity is designed to fit one 45-minute block of time (one "Day"), unless otherwise noted. The table below indicates a recommended pacing for all lessons and activities within the module, in chronological order. Lessons and activities with the same number in the Day column can be carried out on the same day. Lessons or activities requiring an entire 45-minute block of time are the only ones listed on that day.

Day	Lessons/Activities	Instr. Led	Indiv. Work	Group Work	Lab Work
1	Pre-Assessment—based on the results, assemble student groups[1]		✓		
1	Introducing Students to the Challenge	✓			
2	Biosphere Challenge: Initial Design Ideas		✓		
2	Activity: Standardizing Data		✓		
3	Activity: Cellular Respiration in Animals			✓	✓
4-5	Activity: Plant Photosynthesis and Respiration[2]			✓	✓
6	Activity: Decomposition			✓	✓
7	Activity: Ecological Accounting[1]		✓		
7	Challenge: Revise Design		✓		
7	Challenge: Develop Group Design			✓	
8	Challenge: Build a Model			✓	✓
9	Challenge: Test and Evaluate[3]	✓			✓
9	Challenge: Design Review		✓		
9	Concluding the Module	✓			
9	Post-Assessment		✓		

[1]The activity could be completed as homework.

[2]The activity requires half of a period each day.

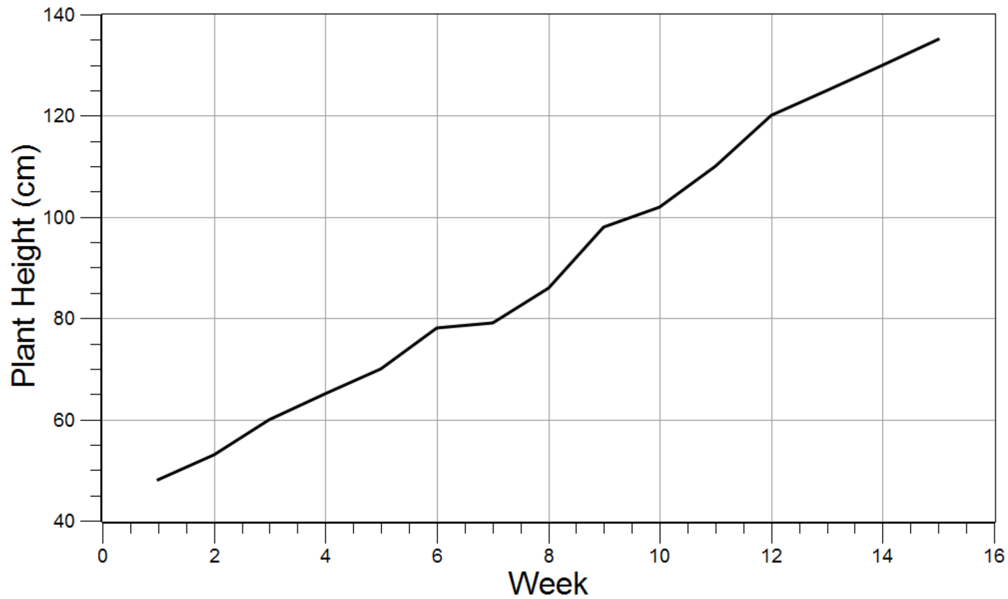
[3]The Test and Evaluate portion of the Challenge takes place over one week.

Safety

Follow standard laboratory safety practices.

Pre-Assessment

1. Using the graph, calculate the rate of plant growth in centimeters per week (cm/wk).



2. Using the data below, calculate the percentage of the atmosphere that consists of oxygen.

Table 1: Average composition of the atmosphere at sea level

Gas	Concentration: Parts per Million by Volume (ppm_v)
Nitrogen (N_2)	780,800
Oxygen (O_2)	209,500
Carbon dioxide (CO_2)	360
Other gases	9,340

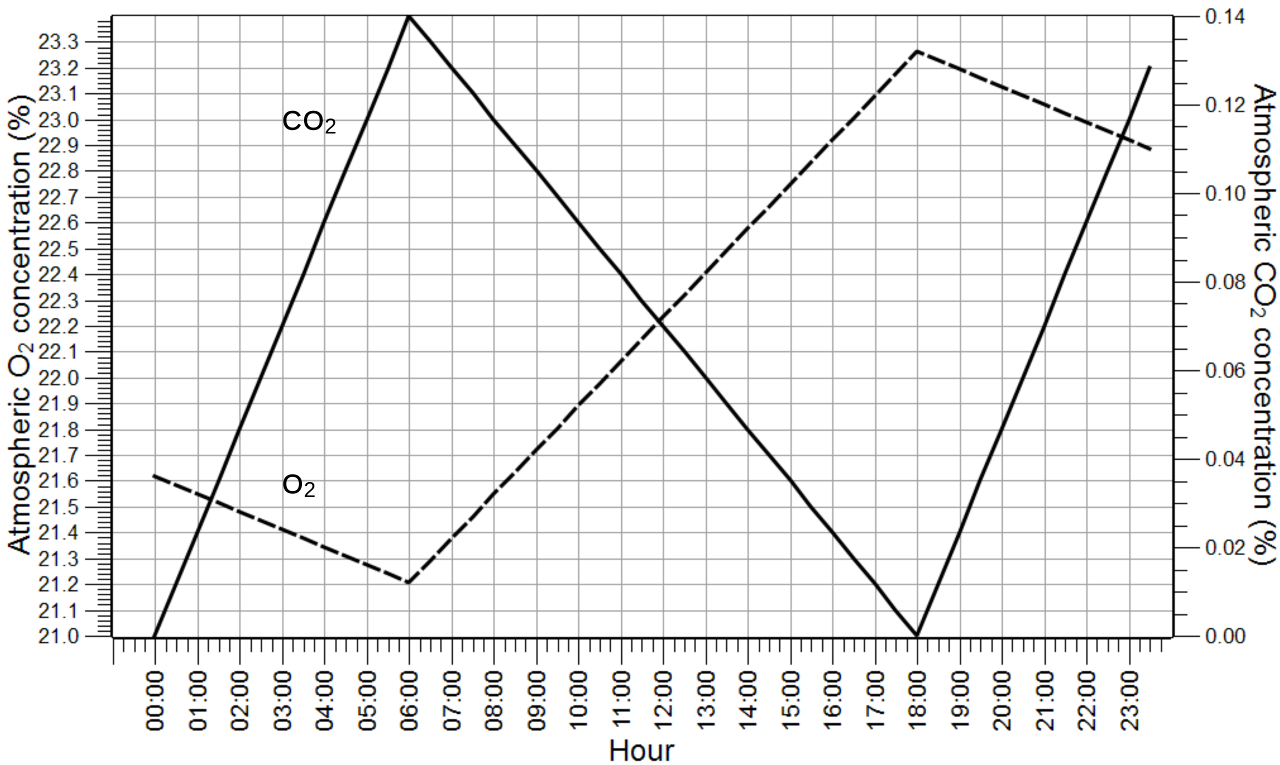
3. Complete the following table of unit conversions.

Table 2: Unit conversions

Measurement	Equivalent Units
1 Kilometers	m
1 Meter	cm
1 Liter	mL
750 mL	L
750 mL	µL
45 kg	µg
35,250 µmol	moles
590,000 *ppm*	µL per L

4. In addition to ATP, what are the chemical products of aerobic cellular respiration?
   A. $C_6H_{12}O_6$, H_2O
   B. CO_2, H_2O
   C. NAD^+ and lactic acid
   D. O_2, CO_2

5. The data below was collected over 24 hours in an airtight aquarium containing several fish and aquatic plants. The light was on from 06:00 to 18:00. How do you explain the decrease in oxygen between 00:00 and 06:00 and between 18:00 and 24:00?



6. Which of the following is true of photosynthesis?
   A. Photosynthesis is the process of releasing energy stored in organic compounds to produce ATP.
   B. Photosynthesis is the process of using light energy to produce organic compounds from carbon dioxide and water.
   C. Photosynthesis consumes oxygen and produces water and carbon dioxide.
   D. Photosynthesis occurs in the mitochondria of the cell.

7. Which of the following are sources of carbon dioxide gas in the carbon cycle?
   A. Cellular respiration of plants and animals.
   B. Combustion of fossil fuels.
   C. Decomposition of organic matter.
   D. All of the above.

8. Maria has started working an after school job to earn money to start a nursery and build a greenhouse. She earns $7.50/hr and works 15 hours a week for 36 weeks and 25 hours a week for 18 weeks over the course of the year. She puts 10% of her total income into savings, and pays 15% in taxes. What is her gross income for the year and the net income she can invest in her greenhouse?

   Gross income = total income

   Net income = gross income minus costs (taxes and savings)

Pre-Assessment Answer Key

The Pre-Assessment is designed to determine a student's understanding of the concepts in this STEM module prior to their work in the module. Each question refers to a topic covered in the Research section of the module to help assess initial knowledge or preconceptions about the topic. There are several strategies for grouping students based on the results of the pre-assessment. One of the most common is to include students with a strong background in each group to act as a group lead or mentor. Further, prior to beginning the module, you may wish to provide extra instruction or resources to students who require additional support.

Question	Correct Answer	Assessment Information
1	~6 cm/wk	Answers may vary slightly depending on which points the students select. Choose two points on the graph and use the following equation to determine the rate of plant growth: $\frac{y_2 - y_1}{x_2 - x_1} = \frac{rise}{run}$. For example, $\frac{110 \text{ cm} - 60 \text{ cm}}{(11 - 3) \text{ wk}} = \frac{50 \text{ cm}}{8 \text{ wk}} = 6 \text{ cm/wk}$ A correct answer shows a good understanding of graphical analysis and an excellent understanding of calculating the slope of a line, which will be important for all of the research activities.
2	20.95%	To convert the concentration of oxygen in the atmosphere to a percentage of oxygen in the atmosphere; $209{,}500 \text{ ppm} = 209{,}500 / 1{,}000{,}000$ $(209{,}500 / 1{,}000{,}000) \times 100 = 20.95\%$ This calculation is related to an understanding of dimensionless quantities and calculating percentages. Students who answered correctly related parts per million (ppm) to percentage, both of which can be expressed as a ratio. Students who answered incorrectly may not be familiar with the concept of *parts per million*. This concept is addressed in the Standardizing Data activity.
3	1,000 m 100 cm 1,000 mL 0.75 L 750,000 µL 45,000,000 µg 0.035250 moles 590,000 µL per L	This question is related to basic SI unit prefixes and conversions. Students who answered correctly have an excellent understanding of SI units, while students who answered incorrectly or were off by a factor of 10 should review SI prefixes and conversion. Unit conversions are important during all of the research activities. This concept is addressed in the Standardizing Data activity.
4	B	The chemical equation for cellular respiration, $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) + 36ATP$ (energy), shows the products are CO_2 and water. This equation is used in both the Cellular Respiration in Animals and Plant Photosynthesis and Respiration activities.
5	Before 06:00 and after 18:00, the plant was conducting cellular respiration.	This question is related to photosynthesis and respiration. Students who answered correctly understand that plant cells also contain mitochondria and conduct cellular respiration, which can be measured in the dark when the plant is not conducting photosynthesis. If students answered incorrectly, they may be influenced by the misconception that plants only conduct photosynthesis. This concept is addressed in the Photosynthesis and Respiration in Plants activity.
6	B	This question relates to photosynthesis. Students who answered correctly have a good understanding of what photosynthesis is, $6CO_2(g) + 6H_2O(l) + \text{Sunlight} \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$ The other choices represent common misconceptions students have about photosynthesis. This concept is addressed in the Photosynthesis and Respiration in Plants activity.

7	D	This question is related to the carbon cycle. Students who answered correctly identified the major sources of atmospheric carbon. Students who answered B are neglecting natural sources of carbon dioxide and students who answered A or C are neglecting anthropomorphic sources. It is not uncommon for students to separate natural and man-made processes. Decomposition and respiration from plants and animals will be addressed in Cellular Respiration in Animals and Photosynthesis and Respiration in Plants activities.
8	Gross income is $7,435 Net income is $5,576.25	To calculate Maria's gross income multiply her hourly wage by the number of hours she works for the year. $\left(\frac{\$7.50}{\text{hr}} \times \frac{15\text{ hr}}{\text{wk}} \times \frac{36\text{ wk}}{1}\right) + \left(\frac{\$7.50}{\text{hr}} \times \frac{25\text{ hr}}{\text{wk}} \times \frac{18\text{ wk}}{1}\right)$ $= \$4{,}050 + \$3{,}375 = \$7{,}425$ To calculate Maria's net income, subtract her savings (10%) and taxes (15%). $\$7{,}425 - (\$7{,}425 \times 0.25) = \$7{,}425.00 - \$1{,}856.25 = \$5{,}568.75$ This process is related to calculating the net changes in a closed system, which will be important in the Ecological Accounting activity and the biosphere design process. Students who answered correctly understand that to calculate a net change, the costs are subtracted from gross production. Students who answered incorrectly may add the costs into the production totals or forget to subtract them. Although this is covered in the Ecological Accounting activity, some students may benefit from review. Financial examples are often easier for students to relate to until they understand the basic concepts. Once the mathematical procedure is mastered, students can apply their skills to biological scenarios.

Introducing Students to the Challenge

Provide students with the Biosphere Challenge handout which identifies the Challenge and follows (chronologically) the stages of the engineering design process outline in the Modular Approach section. Each stage is identified by title in the Challenge handout and includes instructions or questions, or both, requiring students to respond in their notebooks. When beginning the Challenge, make certain that students are aware of this and that they each have their own project notebook for entering responses, data, and design ideas. You may wish to include the project notebook in your existing management system or have students acquire a dedicated notebook for this project.

The first section of the Challenge handout outlines the real world application of a similar engineering challenge, *Biosphere 2*, that should be discussed as a class. You may find useful resources on the Biosphere 2 website to assist in framing an introduction to your curriculum. When introducing the Challenge, be certain to discuss the design constraints in detail (outlined in the Challenge handout) with your students. Make certain they understand that failure to conform to the constraints will affect their overall score on the Challenge.

Students will work individually and in groups throughout the Biosphere Challenge. After introducing the Challenge, it is a good idea to assign students to groups for the group stages of the Challenge (Research, Develop Group Design, Build a Prototype, Test and Evaluate, and Design Review). Although you, as the teacher, will know what grouping method best suits your class, the Pre-Assessment results may provide additional insight. For example, if the Pre-Assessment reveals that your students have a variety of prior concept knowledge, they may benefit from being in groups that distribute this knowledge. We suggest that these groups be the same groups for the research throughout all the stages of the Challenge where students work in groups.

Challenge Rubric

To give students a better understanding of the Challenge expectations, you may choose to pass out the Challenge Rubric with the Challenge handout to indicate the suggested grading criteria. If you feel that the suggested grading criteria are not suitable for your class, the rubric is available in an editable electronic format (MS STEM Biosphere Challenge Rubric.doc file) that allows you to change it as you find necessary.

Materials

The Biosphere module has no constraints on the materials that can be used by students when constructing their model. You may find it necessary to place constraints on the types of materials used. The Challenge handout is also available in an editable electronic format (MS STEM Biosphere Challenge.doc), making it easy to include material constraints in the Design Requirements and Constraints section.

Due to the wide variety of equipment found in classrooms, sensors were not included in the development and assessment of the students' biospheres. If you have sufficient resources for students to include sensors in their biosphere for the duration of the testing, edit the Challenge handout and add to the design requirements:

- Create a $1^1/_8$" hole for inserting the carbon dioxide gas sensor. Make sure the biosphere is airtight once the sensor is inserted.

NOTE: *You and your students must determine the proper tool for making the hole for the sensor in their biospheres.*

Challenge: Biosphere

***NOTE**: Record all work, including data, diagrams, and answers, into your notebook.*

Identify the Problem

In 1991, eight people were sealed inside an airtight greenhouse roughly the size of three soccer fields. The facility, located in the sunny Arizona desert, was known as Biosphere 2. The inside was modeled after the first biosphere, earth, and designed to create a sustainable environment for the inhabitants. Five ecosystems, including an ocean with a coral reef, a tropical rainforest, and a savannah grassland, were constructed and stocked with over 3,000 species of plants and animals. After two years, the experiment ended prematurely when ants overwhelmed several ecosystems, oxygen levels fell, and carbon dioxide levels skyrocketed.

Although the $200 million experiment ended years ahead of schedule, scientists gained valuable insights and authored hundreds of research papers on ecosystem dynamics, waste management, plant physiology, and human environment interactions. Complex research on the emergent properties of ecosystems continues to be important as people try to understand earth's ecosystems, hoping to use that knowledge someday to colonize other planets.

Your challenge is to construct a biosphere that can indefinitely sustain an ecosystem consisting of physical and biological components of your choosing.

Challenge

Design and construct a biosphere modeled after an ecosystem that can sustain macroinvertebrates or fish indefinitely, given a reliable energy source.

Design Requirements and Constraints

- The biosphere must contain one or more macroinvertebrates or fish with a mature size of less than 4 cm. (A macroinvertebrate is any invertebrate that can be seen without magnification.)
- The total volume of the biosphere cannot exceed 8 liters.
- The biosphere must be an airtight, sealed environment.
- Sunlight or artificial lighting must be used for energy input.
- Any available plant, macroinvertebrate or fish, and substrate materials may be used.

1 ☐

Initial Design Ideas

If you were to design this biosphere right now, how would you construct it and what materials would you use? Include the following in your answer:

- Sketch two possible designs in your notebook, including dimensions and labels, and explain your proposals.
- What ecosystem would you model inside the biosphere and what species would you include?
- List three reasons for choosing each design, and list your materials and any safety considerations.

2 Research

☐

Carry out the activities listed below. These will help you revise or validate your initial design ideas in order to complete the challenge successfully. After completing an activity, answer the questions following its description. All questions must be answered before you proceed to the Revise Design portion of the Challenge.

NOTE: When you see the symbol "�" with a number following a step in an activity, refer to the Tech Tip with that number for detailed instructions as needed. Tech Tips will be provided by your teacher.

Standardizing Data

☐ Converting units is not always an easy operation, and it can be confusing. Part of your research will include converting units from scientific data to useable engineering data. This activity introduces *dimensional analysis*, a useful tool to simplify unit conversion.

1. Why it is necessary to convert carbon dioxide or oxygen gas data from a concentration (such as ppm) to a fixed quantity (such as µmol)?
2. Describe why the rate of carbon dioxide production or consumption (in micromoles per hour) is as important as the absolute amount in the biosphere.
3. List the assumptions made in the conversion of *parts per million* to *micromoles* at a given volume.

Cellular Respiration in Animals

☐ This activity investigates the cellular respiration rate of different animal species by measuring carbon dioxide consumption or production of a representative animal. By observing the effect animals have on nutrient cycling in the carbon cycle, determine which individuals could be suitable inhabitants for your biosphere.

1. Compare the chemical equations for photosynthesis and cell respiration; in order to sustain the animals you studied, how much oxygen needs to be produced relative to the carbon dioxide that is consumed? Explain your reasoning and show your calculations.
2. Do you think the data sample you collected is representative of that organism's metabolic rate over a single 24-hour period? Over a 7-day period? Can you think of factors that might influence the metabolic rate of the animal(s) in your biosphere? Explain how you might compensate for these factors in your final design.
3. In addition to a balanced atmosphere, identify other requirements of the animal(s) you're considering using in your biosphere. Identify design elements of your biosphere that support the animals' other needs.

Plant Photosynthesis and Respiration

☐ This activity quantifies the rates of photosynthesis and cellular respiration of a plant over a 24-hour period. You will monitor carbon dioxide gas concentrations to determine the metabolic rate and then calculate the surface area of the plant to determine the size and quantity of primary producers to include in your final design.

1. Do you think the data sample you collected is representative of the plant's metabolic rate over a single 24-hour period? Over a 7-day period? Can you think of factors that might influence the metabolic rate of the plant(s) in your biosphere? Explain how you might compensate for these factors in your final design.
2. Sketch a diagram showing the nutrient cycling that occurs between respiration and photosynthesis in plants and animals. Include oxygen, carbon, and water in your sketch and explain how your data support your diagram.

Decomposition

☐ This activity explores the effect of decomposition on the nutrient cycling in your biosphere. Understanding the effect of decomposers will help you determine what substrates, in what amounts, you will need in your biosphere. Substrate selection will be critical to your plant and animal inhabitants, in addition to affecting the physical characteristics of the environment.

1. How would you vary the mixture of substrate materials in order to mitigate the increase in carbon dioxide due to the substrate and meet the needs of the plants and animals in your biosphere?
2. Can you think of factors that might influence the rate of decomposition in your biosphere? Explain how you might compensate for these factors in your final design.
3. Sketch a flowchart showing the energy flow in an ecosystem. Explain how your data from the activities supports your flowchart.

Ecological Accounting

☐ This activity quantitatively investigates the nutrient cycling inside a biosphere. You will calculate the sustainability of a proposed biosphere model and then manipulate some of the design variables to optimize carbon cycling.

1. Choose two assumptions you identified in the activity that are made in your calculations that could influence your design of a biosphere and explain what impact those assumptions have.
2. For the assumptions you identified, what modifications to either the research procedure or final design could be made to compensate for any errors?

3 Revise Design

☐ After completing the five activities in this Challenge, you should have the conceptual tools necessary to construct a biosphere that will sustain your macroinvertebrate(s) or fish.

1. Do your initial design ideas still work? Explain how those initial thoughts have or haven't changed and why.
2. Sketch your revised design in your notebook and explain your proposal, indicating the important components of the design. Include a mathematical model with your design and explain how you will construct the final model to ensure a stable environment.
3. Include a description of the materials you will use in your proposed design and any safety concerns you anticipate.

4 Develop Group Design

☐ Discuss as a group the different designs of each group member and agree on a collaborative design that will be most effective. After deciding on an approach, draw the group's final design, including the following points, and have your teacher approve your group's proposal. Every group member should have a copy of the proposal.

1. Record in your notebook the important design points and explain why you chose to construct it the way you did.
2. Include a description of the materials you will use in your proposal and any safety concerns.

5 Build a Model

Using your collaborative design, build your model.

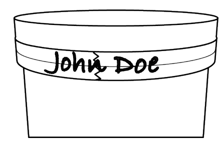
☐

1. After constructing your group's model, list in your notebook your specific responsibilities during the construction process.
2. The model may not exactly match the group's design due to some unforeseen construction challenges. Were any design points changed during the construction process? If you did make changes, list those changes in your notebook and explain why your group made them.
3. Before sealing the biosphere and beginning the evaluation, develop an observation schedule and determine what factors to observe. Your group's design will be assessed on the quality of your observations, in addition to the success of your design. Your observations should incorporate qualitative and quantitative data that indicate the health of your ecosystem.

6 Test and Evaluate

☐

Seal your biosphere by placing tape over the lid and the enclosure and sign the overlap as shown. Follow your teacher's instructions to place the biosphere in the testing area. Your model will remain sealed for a period of one week, during which time your group will carry out your observation plan. After one week, conduct a final inspection of your biosphere to assess the vitality of the biosphere's inhabitants.



7 Design Review

☐

1. How successful was your design? What observations and data support your assessment?
2. How could you have constructed your biosphere differently to be more effective? List at least two improvements and explain why they would help.
3. Look at another group's design. What was different about their design and how do you think those differences affected their performance relative to yours?

Congratulations! You have finished the Biosphere Challenge. Complete the information in your notebook and turn it in to your teacher.

Challenge Rubric

	Excellent	Good	Fair
Initial Design Ideas	Included two or more detailed sketches with appropriate labels and dimensions Included a detailed explanation for each design with alternatives	Included two detailed sketches Included a detailed explanation for each design	Included one or two rough sketches Included an explanation with one or two reasons for each design
	9 8 7	6 5 4	3 2 1
Research	Completed all activities Answers to Activity and Challenge questions show understanding of all concepts Included outside source notes Conducted additional material or concept testing	Completed all activities Answers to Activity and Challenge questions show understanding of some concepts Included outside source notes	Completed all of the activities Answers to Activity and Challenge questions show concepts are not well understood
	9 8 7	6 5 4	3 2 1
Revise Design	Included notes on how the activities changed or affirmed their initial design with evidence and detailed explanations for the changes made Provided a revised design with a sketch and detailed notes and calculations on the changes made	Included notes on how the activities changed or affirmed the initial design Provided a revised design with a sketch and detailed notes on the changes made	Provided a revised design
	9 8 7	6 5 4	3 2 1
Develop Group Design	Produced a group design with notations indicating individual contributions and group decisions Provided detailed explanations, with evidence, for the choices	Produced a group design with notations indicating individual contributions and group decisions	Produced a group design
	9 8 7	6 5 4	3 2 1
Build a Model	Produced a well-constructed model with detailed notes about the construction, including changes made Created an observation schedule and determined the factors to observe	Produced a model with notes regarding any changes made during the construction process	Produced a model
	9 8 7	6 5 4	3 2 1
Test and Evaluate	Plants and animals are alive and appear as healthy and active as they were at the start of the experiment after 7 days. Detailed daily observations of inhabitants are recorded and sensor data, if used, is complete.	Plants and animals are alive but not as active as they were at the start of the experiment after 7 days. Daily observations completed.	Plants and animals are alive but visibly stressed after 7 days. Daily observations completed.
	9 8 7	6 5 4	3 2 1
Design Review	Provided a detailed description of what worked and what did not work with the design, and made inter-group comparisons Suggested design improvements with explanations.	Provided a detailed description of what worked and what did not work with the design Suggested at least one design improvement	Indicated what worked and what did not work with the design
	9 8 7	6 5 4	3 2 1
	Total Score (out of 63 points)		

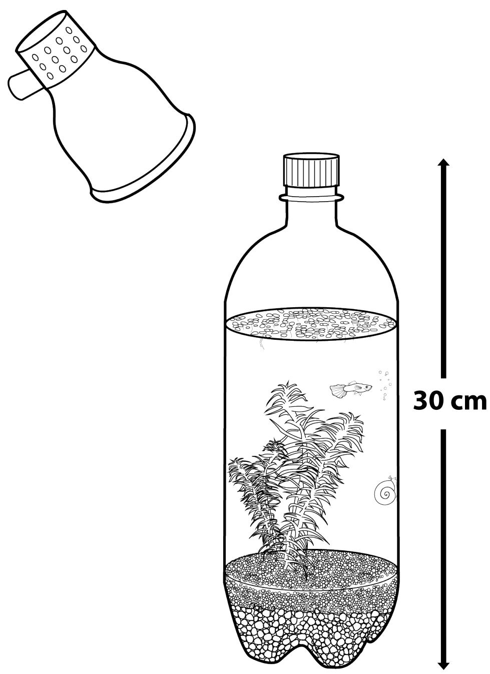
1 Initial Design Ideas

Give students a finite amount of time (~10min) to write their thoughts and sketch their initial designs. Remind them to consider and define dimensions; it may be helpful to have containers of different sizes, up to 8 liters, available as a visual reference. Encourage your students to annotate their sketches with their thoughts about the design. Your students should understand they are not being assessed on artistic merit, but on their ability to effectively communicate their initial thoughts and explain their reasoning. There is no right answer, and it is likely that they will change their design as they work through the process.

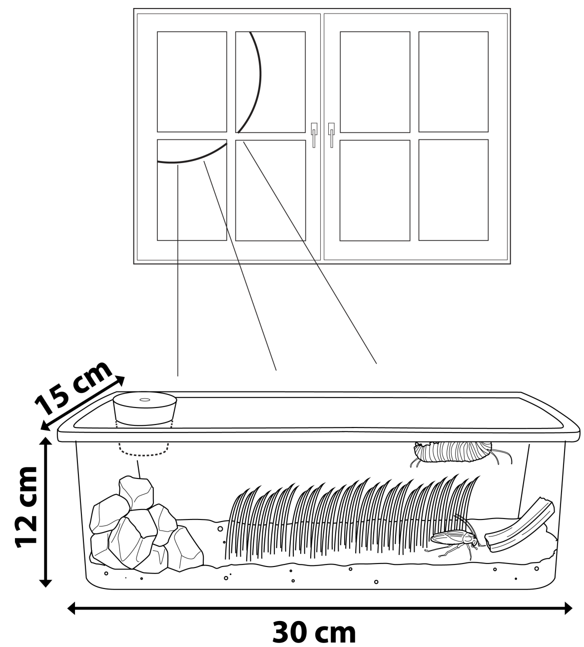
Sample Student Designs

These are sample designs as they might appear in a student notebook:

Sample design 1



Sample design 2



SAMPLE RESPONSES TO INITIAL DESIGN IDEA QUESTIONS

Design	Sample Response
1	The biosphere is modeled after a tropical, freshwater stream and will support a small male guppy (*Poecilia reticulata*) inside a clear plastic bottle. Reasons for choosing this design: ▪ The duckweed and aquatic plants will provide oxygen for the fish and food for the *Daphnia*, which will also serve as fish food. ▪ The sand and gravel will support and provide nutrients to the plants, which will get energy from a grow light on twelve-hour cycles. ▪ The materials are readily available and an aquatic ecosystem will be less susceptible to temperature fluctuations. Materials: Water, 2 L bottle, duckweed, *Elodea* or similar aquatic plant, small male guppy, play sand, limestone gravel, small snail, *Daphnia* culture
2	The biosphere is modeled after an urban environment and will support a cockroach and caterpillar. Reasons for choosing this design: ▪ The cockroach was selected because of its hardiness and dietary flexibility. ▪ The grass will provide habitat and food for the cockroach as well as the caterpillar. The rocks will provide a hiding place and a carrot stick has been added for food as well. ▪ The materials are readily available and the container's dimensions will provide a large area for plants needed to produce oxygen. Materials: 6 L Tupperware® container, potting soil, cockroach, carrot stick, rocks, caterpillar, Kentucky Bluegrass

Addressing Preconceptions

Students' exposure to biospheres or model ecosystems may vary widely; any number of preconceptions could influence student thinking. Common misconceptions that may be evident in their initial design include:

- Plants do not conduct cellular respiration
- Producers' sole function is as a food source (neglecting gas exchange)
- Gaseous compounds do not play a significant role in nutrient cycling
- There is a 1:1 energy transfer moving up the trophic structure
- Energy is consumed or cycled

At this point, it is best to question students on their design and have them explain their reasoning. Bringing misconceptions to the forefront of the class discussion may be sufficient to correct them. To address some of the most flagrant, you should challenge students' thinking using their data collected during the research activities. Prior to starting the activities, ask students to make a prediction and support their reasoning for the specific case being tested. When the data does not support their hypothesis, students will be compelled to develop a new explanation.

Possible Student Designs

Students may sketch a bottle or similar container with a plant, animal, and substrate material present. It is likely they will have some idea of what is required to create a successful biosphere but without adequate consideration for the relationships between the organisms and the environment; it is critical to have the reasoning written out so they can compare their experimental results to their original ideas.

2 Research

Engineering research and development is usually an iterative process: the engineering research determines how something can be made to function for a given purpose, and development is the process of building and testing prototypes or working models based on this research. While engineering research includes exploring other people’s research, reading articles in journals, and investigating what has been done before, this section directs students to carry out scientific research activities which explore the science concepts and math skills related to the engineering challenge. In carrying out these activities, students will also become familiar with some of the standard tools and techniques of this field of study.

In the Standardizing Data activity, students learn how to convert from ppm, a dimensionless quantity, to micromoles. From the Cellular Respiration in Animals, Plant Photosynthesis and Respiration, and Decomposition activities, students quantify the carbon cycling taking place and relate it back to their knowledge of photosynthesis and cellular respiration to inform a balanced design. In the final activity, Ecological Accounting, students will synthesize sample data that relates the quantities and proportions of the various inhabitants, substrates, and volume of the biosphere. Students should look to design a biosphere that will be balanced and can sustain itself indefinitely with consistent energy input.

At a minimum, your students should complete each of the activities and answer the associated Challenge questions. This should provide them with enough information and experience to complete the Challenge. Encourage advanced students to extend their research into transpiration, the greenhouse effect, primary productivity, and mold prevention.

If you are going to have students bring their own materials, it is important to give them time to research and test the materials they wish to use. If you have given your students a fixed list of materials, they may wish to experiment with the materials. To encourage group interaction and debate, it is best to allow time for materials testing once students are in their design groups.

In addition to monitoring student progress through the activities, it is important to ensure that they are relating their work back to the Challenge. At the very least, be sure they are answering the Challenge questions, but they will gain even more if they include notes relating the activity to their design as they add to their growing body of knowledge. Encourage students to record their thoughts and observations in writing, particularly if there will be a substantial amount of time between activities.

All Research questions must be answered before students proceed to the Revise Design portion of the Challenge.

NOTE: *Students use a variety of technical procedures in the activities. Detailed explanations for using the data collection system* to carry out these procedures are found in the Tech Tip file corresponding to your data collection system. Please make copies of these instructions available for your students. (Tech Tips are identified in the activities by the* "�" *symbol followed by the Tech Tip number.)*

You can find these files on the storage device that accompanies this printed module, on the stand-alone storage device, and available for download with the module content.

Data Collection System	**Tech Tip File**
SPARK Science Learning System	SPARK Tech Tips.pdf
SPARKvue	SPARKvue Tech Tips.pdf
Xplorer GLX	Xplorer GLX Tech Tips.pdf
DataStudio	DataStudio Tech Tips.pdf

**Data collection system refers to the data collection, display, and analysis device used to carry out the various activities and includes PASCO's DataStudio, the Xplorer GLX, SPARKvue, and SPARK Science Learning System.*

SPARKlab Activities

In addition to the conventional paper format found in this section of the Biosphere module, each activity is available in an electronic SPARKlab format. All electronic SPARKlab files can be found on the accompanying storage device with a .spk file extension and the title of each activity within the filename, for example, "HS STEM Decomposition.spk". For instructions on how to move the electronic SPARKlab files from the storage device to your SPARK Science Learning System, please refer to your SPARK Science Learning System User's Guide, "Managing Files and Folders" section.

For information on the different methods for submitting student work when using the SPARK Science Learning System, refer to the "Saving and Sharing" section of the SPARK Science Learning System User's Guide.

Activity: Standardizing Data

Objective

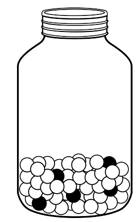
Use dimensional analysis and unit conversion to standardize data from different experiments for comparison.

Materials and Equipment

- Calculator (optional)
- Pencil

Procedure – Problems

***NOTE**: Record all work, including tables, data, diagrams, and answers, into your notebook.*



☐ 1. For each problem below, calculate the percentage of the marbles in the jar that are black.

a. 10 black marbles, 90 white marbles

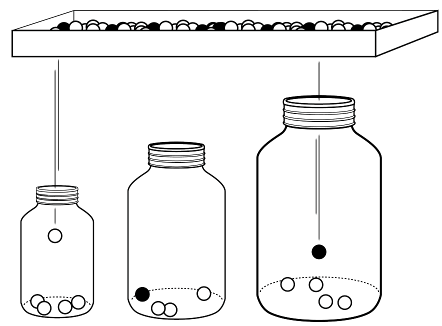
b. 10 black marbles, 990 white marbles

c. 10 black marbles, 9990 white marbles

d. 10 black marbles, 9,999,990 white marbles

☐ 2. Is the number of black marbles the same as the percentage of black marbles? Explain your reasoning.

☐ 3. A tray is assembled above 3 jars that will drop 1 marble per minute into a jar below, as shown. Copy the data table into your notebook, then calculate the concentration in *parts per hundred* (pph) for each jar. The first increment has been completed for you as an example. Finally, create a graph of your data in your notebook.



***NOTE**: Calculate pph by using a ratio of the number of marbles per jar volume (total number of marbles the jar can hold).*

Table 2: Marble drop data

Time (min)	100-Marble Jar (pph)	200-Marble Jar (pph)	500-Marble Jar (pph)
0	0	0	0
5	5	2.5	1
10			
15			
20			
25			

RECORD YOUR DATA AND ANSWERS IN YOUR NOTEBOOK.

a. Based on your graph and the above data, what is the rate of increase for each jar in pph/min?

b. After 25 minutes, how many marbles are in each jar?

c. How do you explain the difference between your calculated rates and the constant rate of 1 marble per minute?

☐ 4. There are some limitations to working with dimensionless quantities such as *parts per hundred* or *parts per million*. As you just demonstrated, the measurement is affected by volume, even though the absolute quantity does not change. Since gases like carbon dioxide (CO_2) are measured in parts per million, this is an issue you'll need to work with in the remaining activities. Fortunately, if the volume is known, then with some simple calculations the absolute quantity can be determined.

Solve the following problems working backwards from the *parts per million* measurements to find the total number of black marbles in different size jars filled with marbles.

a. 125 ppm black marbles, total jar volume is 8,000 marbles.

b. 315 ppm black marbles, total jar volume is 6,500,000 marbles.

c. 395,500 ppm black marbles, total jar volume is 300,000 marbles.

☐ 5. The same technique can be applied to convert *parts per million* to *moles* or *micromoles* (μmol). This is useful in the remaining activities because you will be able to compare how much CO_2 is being produced and consumed regardless of the air volume of the sample container.

NOTE*: A mole is* 6.02×10^{23} *molecules of a compound and a micromole is one millionth of a mole* (6.02×10^{17})*, which is still an enormous number.*

To convert *parts per million*, to *micromoles* at a given volume, you need the molar volume: 24.46 L, which is the volume of one mole of any gas at 25 °C and 101.3 kPa. Assume that all gases are the same size, just like all the marbles in the jar were the same size, even though this is not the case. Compensating for molecular size, temperature, and pressure changes would involve many more calculations than you have time to do!

Use the formula below to solve the following:

A plant is placed in an empty, sealed 5.00 L container with an initial oxygen concentration of 210,000 ppm. After 3 hours in direct sunlight, the oxygen levels have risen to 240,000 ppm.

a. How many micromoles of oxygen were produced by the plant? You may find the following equations useful in your calculation (copy them to your notebook).

$$\frac{\text{parts}}{\text{million parts}} = \frac{\text{microliter}}{\text{liter}} \text{ (Since there are 1,000,000 μL per liter.)}$$

$$\frac{(\text{concentration value})\ \mu\text{L}}{\text{L}} \times \left(\frac{1\ \mu\text{mol}}{24.46\ \mu\text{L}}\right) \times \left(\frac{(\text{air volume of sample jar})\ \text{L}}{1}\right) = \_\_\_\_\_\_\_\_\_\_\ \mu\text{mol}$$

b. What is the average rate, in micromoles per hour, of oxygen production?

☐ 6. With some algebra, the calculation can be reversed. Rearrange the equations you used above to solve the following problem.

Increased carbon dioxide concentrations can double an organism's breathing rate at levels as low as 2 to 3% and is typically toxic at levels above 5%. In laboratory testing, a mouse produced 550 micromoles of CO_2 per hour. With a starting concentration of 400 ppm in an 8.0 L container, how many hours could the mouse survive before carbon dioxide levels become toxic? Assume the mouse has a constant respiration rate and there are no other sources of carbon dioxide.

Questions

NOTE*: Record all work, including calculations and answers, into your notebook.*

1. Complete the questions on the Challenge: Biosphere handout.

Teacher Notes: Standardizing Data

Learning Objectives

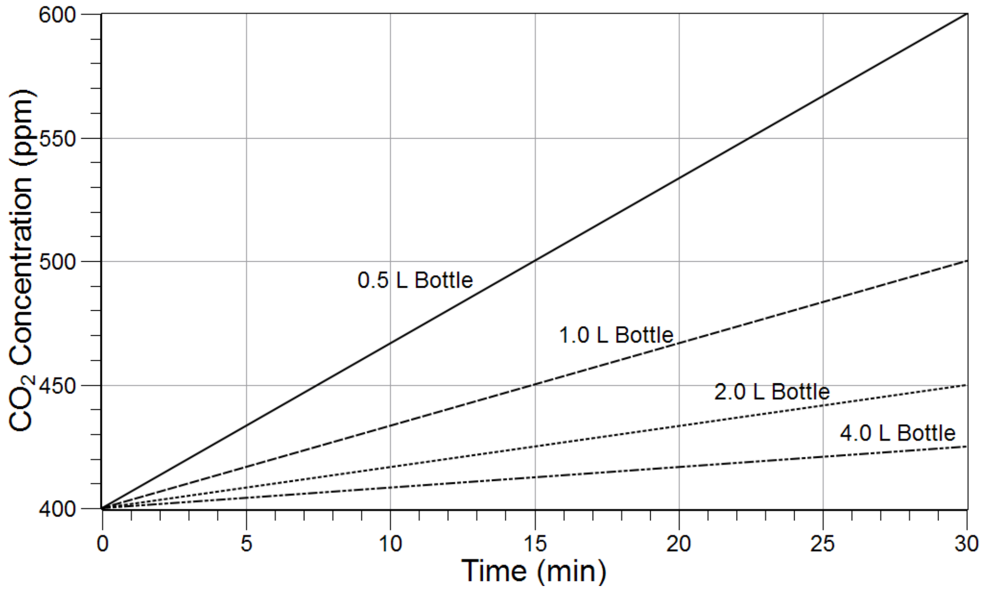
In this activity, students

- Practice converting units using dimensional analysis.
- Standardize data in order to compare results from tests carried out in containers of different volumes.

Activity Introduction

This activity lays the foundation for the analysis skills used in the other activities and it is imperative that students feel comfortable with the conversion techniques before moving forward. To introduce this activity and demonstrate the importance of converting the raw data students collect to an absolute quantity, use the following probe.

A beetle is placed inside a 0.5 L sealed container for 30 minutes with a carbon dioxide sensor measuring *parts per million* (ppm). The same insect is then placed inside a larger container and the experiment is repeated. This is repeated two more times with even larger containers. How can you explain the differences in CO_2 concentration in the data recorded in the graph below?



As students search for the answer (see below), some may question the experimental method used. Encourage their questions and assure them that no variables were changed other than the size of the sampling container. For the purposes of this example, the beetle's rate of carbon dioxide production is assumed to have been constant.

Students may solve the question, but in the likely event they do not, direct the discussion towards the measurements made in *parts per million*. Students may recognize at this point the limitations of dimensionless measurements and are probably trying to work around them. To familiarize students with the concept of dimensionless measurement, introduce a fraction such as $\frac{parts}{million\ parts}$. Ask students to provide examples of when this might be a useful measurement.

If they struggle to come up with suggestions, lead them by asking when it is useful to measure concentration instead of an absolute amount of something. Air and water quality testing both offer good examples since pollutants are usually only harmful above certain concentrations.

After the students have provided some examples, see if they can add a dimension to the measurement, such as $\frac{grams}{million\ grams}$ or $\frac{liters}{million\ liters}$. Point out that the same unit is always in the numerator and denominator, which then cancels, leaving a dimensionless term. See if the students can apply their knowledge of the International System of Units (SI) measurements and prefixes to express *parts per million* in more useful ratios, such as $\frac{\mu L}{L}$ or $\frac{\mu g}{g}$.

At this point, begin the activity; students will learn how to convert from dimensionless measurements to absolute quantities. If you feel that completing the example is necessary to guide students, you can walk them through the solution shown here.

SOLUTION:

The differences in the CO_2 concentration are due to the different size containers. Since an increase in concentration is inversely proportional to the volume of the bottle, when the volume increases, the concentration (amount per volume) of the CO_2 produced decreases, and the opposite is true when a smaller bottle is used. (Remember that the beetle's rate of respiration is assumed constant, regardless of the container size.) When the volume was halved, the net increase in concentration doubled, when the volume quadrupled, the net increase was one fourth as much.

Students can standardize the results by converting the change in concentration and container size to that of a 1.0 L bottle. To do this, multiply the change in concentration by the increase (or decrease) in container size relative to the 1 L bottle.

0.5 L Bottle: (600 ppm – 400 ppm) × 1/2 = 100 ppm

1.0 L Bottle: (500 ppm – 400 ppm) × 1 = 100 ppm

2.0 L Bottle: (450 ppm – 400 ppm) × 2 = 100 ppm

4.0 L Bottle: (425 ppm – 400 ppm) × 4 = 100 ppm

After students learn to standardize the data so experiments carried out in different size containers can be directly compared, they will learn to convert the concentration to a quantity, enabling them to determine, for example, the beetle's carbon dioxide production, which remains unchanged regardless of the container volume.

Teacher Tips

Depending on students' background knowledge, review the concept of moles and Avogadro's number before completing this activity. As a refresher, ask students to calculate the mass of a micromole of common elements and compounds. Although not addressed in the activity, these calculations present an opportunity to discuss significant figures and scientific notation.

Calculations use standard temperature and pressure (STP) of 25 °C and 101.3 kPa, referred to in the student handout. In the other activities, student calculations will not compensate for changes in these variables.

Answer Key

SAMPLE RESPONSES TO THE QUESTIONS IN THE STANDARDIZING DATA ACTIVITY HANDOUT

Procedure	Sample Response
1a	To calculate the percentage of black marbles in the jar, add the black and white marbles together to find the total number of marbles, then divide the number of black marbles by the total and multiply by 100. 10 black marbles + 90 white marbles = 100 total marbles $\frac{\text{10 black marbles}}{\text{100 total marbles}} \times 100 = 10\%$ black marbles
1b	10 black marbles + 990 white marbles = 1,000 total marbles $\frac{\text{10 black marbles}}{\text{1000 total marbles}} \times 100 = 1\%$ black marbles
1c	10 black marbles + 9990 white marbles = 10,000 total marbles $\frac{\text{10 black marbles}}{\text{10,000 total marbles}} \times 100 = 0.1\%$ black marbles
1d	10 black marbles + 999,990 white marbles = 1,000,000 total marbles $\frac{\text{10 black marbles}}{\text{1,000,000 white marbles}} \times 100 = 0.001\%$ black marbles
2	No, the number of black marbles is not the same as the percentage of black marbles. Although the number of black marbles remained constant, the total number of marbles increased so the amount of black marbles relative to white marbles declined dramatically.

3

Table 1: Marble drop data

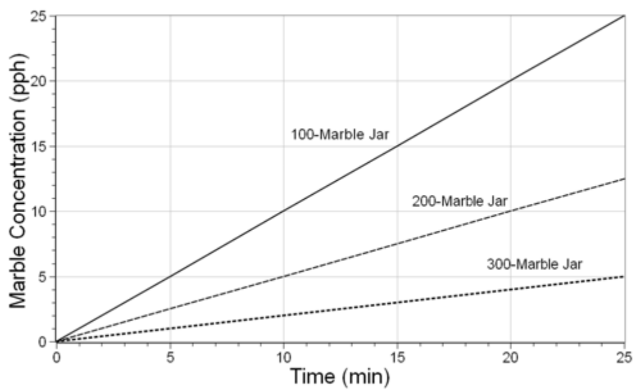
Time (min)	100-Marble Jar (pph)	200-Marble Jar (pph)	500-Marble Jar (pph)
0	0	0	0
5	5	2.5	1
10	10	5	2
15	15	7.5	3
20	20	10	4
25	25	12.5	5

CALCULATIONS FOR THE LAST ROW:

100-Marble Jar: 25 marbles/100 marble jar volume = 25 pph

200-Marble Jar: 25 marbles/200 marble jar volume = 12.5 pph

500-Marble Jar: 25 marbles/500 marble jar volume = 5 pph



3a

To determine the rate of increase for each jar in pph/min, calculate the slope: choose two points from any of the lines and perform the following calculation:

$$\frac{y_2 - y_1}{x_2 - x_1} = \frac{rise}{run}$$

For the 100 marble jar, $\frac{25 - 5}{25 - 5} = \frac{20}{20} = \frac{1}{1}$, which is 1 pph per minute

For the 200 marble jar, $\frac{12.5 - 2.5}{25 - 5} = \frac{10}{20} = \frac{1}{2}$, which is 0.5 pph per minute

For the 500 marble jar, $\frac{5 - 1}{25 - 5} = \frac{4}{20} = \frac{1}{5}$, which is 0.2 pph per minute

3b

After 25 minutes, 25 marbles are in each jar.

3c

The calculated rates (in 3a) and the constant rate that marbles are dropped into the jar are different because the calculated rate refers to the change in the number of marbles relative to the total volume of the jar over time, while the constant rate is the same for each jar, regardless of the jar's volume.

4a

Use an equation to find the number of black marbles in 8,000 marbles when the ratio of black marbles to white marbles is 125 ppm.

$$\frac{125}{1{,}000{,}000} = \frac{x}{8{,}000};\ 1{,}000{,}000x = (125)(8{,}000)$$

$$x = \frac{(125)(8{,}000)}{1{,}000{,}000};\ x = 1 \text{ marble}$$

4b

Use an equation to find the number of black marbles in 6,500,000 marbles when the ratio of black marbles to white marbles is 315 ppm.

$$\frac{315}{1{,}000{,}000} = \frac{x}{6{,}500{,}000};\ 1{,}000{,}000x = (315)(6{,}500{,}000)$$

$$x = \frac{(315)(6{,}500{,}000)}{1{,}000{,}000};\ x = 2047.5 \text{ marbles}$$

4c	Use an equation to find the number of black marbles in 300,000 marbles when the ratio of black marbles to white marbles is 395,500 ppm. $\frac{395{,}500}{1{,}000{,}000} = \frac{x}{300{,}000}$; $1{,}000{,}000x = (395{,}500)(300{,}000)$ $x = \frac{(395{,}500)(300{,}000)}{1{,}000{,}000}$; $x = 118{,}650$ marbles
5a	To find the number of micromoles of oxygen produced by the plant sealed in a 5 L container, first find the change in the oxygen concentration: $240{,}000\text{ ppm} - 210{,}000 = 30{,}000\text{ ppm increase}$. Then calculate the number of micromoles produced (remember, 30,000 ppm is equivalent to 30,000 µL/L). ***NOTE**: Because the least accurate measurement in the calculation has only 1 significant figure (5 L), the answer contains only 1 significant figure.* $\left(\frac{30{,}000\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{5\ L}{1}\right) = 6{,}000\ \mu mol$
5b	The average rate of oxygen production, in micromoles per hour, is 2×10^3 µmol per hour (6×10^3 µmol divided by 3 hours).
6	The starting concentration of carbon dioxide in the 8.0 L container is 400 ppm, or 0.04% of the atmosphere. To determine the number of hours the mouse can survive before the carbon dioxide level become toxic, first calculate the ppm, or µL/L, of carbon dioxide being produced per hour using dimensional analysis. (The mouse produces 550 micromoles of carbon dioxide per hour in an 8.0 L container.) $\left(\frac{550\ \mu mol}{1}\right) \times \left(\frac{24.46\ \mu L}{1\ \mu mol}\right) \times \left(\frac{1}{8.0\ L}\right) = \frac{1700\ \mu L}{L} = 1{,}700$ ppm produced per hour To get to a toxic concentration of 5% CO_2, the mouse must add 49,600 ppm: the final concentration (5% CO_2 is equivalent to 50,000 ppm) minus the initial concentration of 400 ppm (50,000 ppm – 400 ppm = 49,600 ppm). At a rate of 1700 ppm/hr, this will take 29 hours: $\frac{49{,}600\text{ ppm}}{1{,}700\text{ ppm/hr}} = 29\text{ hr}$

Connecting the Activity to the Challenge

As students finish the Activity questions, direct them back to the Challenge handout to complete the research connection questions. At this point it may be useful to facilitate a class discussion on how the problems in the Activity relate to the Challenge. Ask students to share their ideas and then guide the discussion to address the two key ideas: 1) a unit conversion is necessary to eliminate a quantity's relationship to volume and 2) a sustainable biosphere will have a balanced relationship between photosynthesis and respiration. This is an opportune time to revisit the chemical equations for photosynthesis and respiration and reinforce the connection between them.

SAMPLE RESPONSES TO STANDARDIZING DATA RESEARCH QUESTIONS

Question	Sample Response
1	It is necessary to convert carbon dioxide or oxygen gas data from a concentration (such as ppm) to a fixed quantity (such as µmol) because "ppm" is a ratio that is relative to volume. Converting ppm to micromoles allows for comparisons of data independent of volume.
2	The rate of carbon dioxide production or consumption (in micromoles per hour) is as important as the absolute amount in the biosphere because in order for the biosphere to be sustainable, the rate of carbon dioxide production cannot exceed the rate of carbon dioxide consumption over a 24-hour period. If it does, the carbon dioxide concentration will continue to increase over time, upsetting the nutrient cycling balance and plants or animals die.
3	If the data collected in the other activities is not collected at standard temperature and pressure, 25 °C and 101.3 kPa, then the result of the conversion between *parts per million* and *micromoles* at a given volume will be slightly off. In addition, the ideal gas law assumes that all gases are the same size and mass, which is not the case. All of these variables will reduce the accuracy of the calculations and are not compensated for.

Activity: Cellular Respiration in Animals

Objective

Compare the rate of cellular respiration in several different animal species to determine if they would be suitable candidates for your biosphere.

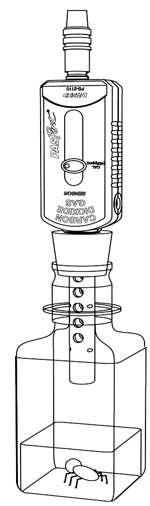
Materials and Equipment

- Data collection system
- Carbon dioxide sensor
- Sensor extension cable
- Macroinvertebrate, 3 to 5
- Sampling bottle or beaker*

* If the specimen is too big for the sample bottle, a larger beaker may be used. Use available materials (for example, plastic wrap) to be sure the sensor has a tight seal with the mouth of the beaker.

Safety

- Use care when handling living organisms.
- Wash your hands with soap and water after handling organic specimens.



Procedure – Measuring Cellular Respiration

NOTE*: Record all work, including tables, data, diagrams, and answers, into your notebook.*

☐ 1. Start a new experiment on the data collection system, �(1.2) connect the carbon dioxide gas sensor to the data collection system using the extension cable, �(2.1) display CO_2 concentration on the *y*-axis of the graph with time on the *x*-axis, �(7.1.1) and set the units to measure *parts per million* (ppm). �(5.3)

☐ 2. Calibrate the carbon dioxide gas sensor. �(3.1)

☐ 3. Obtain one macroinvertebrate from your teacher and place the animal into the sampling container. Carefully insert the sensor until it is firmly seated. Be careful not to harm the animal.

☐ 4. Copy table 1 into your notebook.

☐ 5. Record the volume of air in the sampling bottle.

NOTE*: The sample bottles are graduated to 250 mL but have additional volume above the 250 mL mark of about 50 mL. Ignore the volume of air displaced by the sensor because it is impractical to measure without damaging the sensor.*

☐ 6. Start data recording and continue collecting data for 10 minutes. �(6.2)

☐ 7. Once data collection has finished, return the animal to your teacher.

☐ 8. Apply a linear fit to your data to determine the carbon dioxide production or consumption rate. �(9.5) Record the slope in *ppm per hour* in Table 1 (copied into your notebook). �(9.5)

☐ 9. Follow the above procedure to determine the carbon dioxide production or consumption rate for at least 2 other macroinvertebrates.

Procedure – Data Analysis

☐ 10. Convert *ppm carbon dioxide per hour* to *micromoles carbon dioxide per hour* to standardize your data (as directed in the Dimensional Analysis activity) and record your results in Table 1.

Table 1: Rate of cellular respiration for different macroinvertebrates

Macroinvertebrate	**Volume of Air (L)**	**CO_2 Consumption or Production Rate (ppm/hr)**	**CO_2 Consumption or Production Rate (μmol/hr)**
RECORD YOUR DATA AND ANSWERS IN YOUR NOTEBOOK.			

☐ 11. Compare your standardized data to the standardized data of other groups in your class. How do your results compare to theirs?

☐ 12. What inferences can you draw about the effect of species, size, and other characteristics on the rate of carbon dioxide production?

Questions

***NOTE**: Record all work, including calculations and answers, into your notebook.*

1. Identify the dietary needs and environmental preferences for two of the animals you tested. What food will be required to support these animals?
2. Examine the chemical equation for respiration. What prediction can you make about the rate of oxygen consumption compared to the rate of carbon dioxide production for one of the samples you measured?

   $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l) + \text{energy}$

3. In a closed environment, what process in the carbon cycle is responsible for removing carbon dioxide from the atmosphere?
   A. Combustion
   B. Decomposition
   C. Photosynthesis
   D. Evaporation
4. Complete the questions in the Challenge: Biosphere handout for this activity.

Teacher Notes: Cellular Respiration in Animals

Learning Objectives

In this activity, students

- Compare the rates of cellular respiration in different animal species.
- Understand that cellular respiration is a source of carbon dioxide.

Safety

Use care when handling living organisms. Make sure students wash their hands with soap and water after handling organic specimens. This activity should not result in excess stress on the organisms, abort the experiment immediately if the organisms show any respiratory stress or otherwise appear unhealthy.

Activity Preparation

You can allow students to bring in organisms for this activity or you may wish to have a selection available. Choose organisms that are safe for handling, such as crickets, mealworms, gold fish, earthworms, or non-stinging insects. Remind students that during the research phase of the engineering process they should still conform to the design requirements and use organisms that are within the size constraints.

If you are providing fish for testing, you may want to place them in the sample bottles prior to the activity, to minimize their handling.

Activity Introduction

Write the equation for cellular respiration on the board and remind students it is the process of converting stored chemical energy into a useable form for the cell, usually adenosine triphosphate (ATP). This reaction can be summarized as $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$ + energy. The process can be measured using the carbon dioxide gas, oxygen gas, or dissolved oxygen sensors. Light a match or candle and ask students to explain how combustion is similar to cellular respiration and how it is different. Discuss their responses as a class.

Teacher Tips

The carbon dioxide gas sensor operates by measuring the absorption of infrared (IR) radiation emitted by an LED inside the barrel of the sensor. Any IR light sources can influence the sensor readings, so be sure to place the sampling apparatus away from incandescent lights or other heat sources, especially when calibrating the sensor.

***NOTE**: The sample bottles are graduated to 250 mL but have additional volume above the 250 mL mark of about 50 mL. The volume of air displaced by the sensor is ignored because it is impractical to measure without damaging the sensor.*

Students should leave the organisms in the sample bottles and pass around the bottles as opposed to forcing the organisms in and out of the bottles. Since the activity is asking for the rate of carbon dioxide production and not the carbon dioxide concentration in the bottles, their results should not be affected if each run does not begin with atmospheric concentration levels.

Students can measure the respiration of aquatic organisms by placing water in the sample bottle below the sensor and recording the changes in atmospheric carbon dioxide. Great care should be taken to ensure that the sample bottle cannot tip over and the sensor is never immersed in water. It is the responsibility of the teacher and student to protect the equipment from being damaged.

***NOTE**: If a fish or other creature in water is tested, the effect of the temperature and saturation levels of CO_2 and O_2 in the water should be negligible.*

Sample Data

Table 1: Rate of cellular respiration for different macroinvertebrates

Macroinvertebrate or Fish	Volume of Air (L)	CO_2 Consumption or Production Rate (ppm/hr)	CO_2 Consumption or Production Rate (µmol/hr)
Snail	0.300	1520	18.6
Freshwater guppy	0.100	517	2.11
Cockroach	0.300	730	8.95

CALCULATIONS

Snail: $\left(\frac{1{,}520\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{0.300\ L}{1}\right) = 18.6\ \mu mol\ of\ CO_2$ produced per hour

Freshwater Guppy: $\left(\frac{517\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{0.100\ L}{1}\right) = 2.11\ \mu mol\ of\ CO_2$ produced per hour

Cockroach: $\left(\frac{730\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{0.300\ L}{1}\right) = 8.95\ \mu mol\ of\ CO_2$ produced per hour

Answer Key

Below are sample responses to the questions in the Cellular Respiration in Animals activity handout. Responses numbered under the "Procedure" heading in the first column are responses to questions in the "Procedure" sections in the handout, while those responses under "Questions" are to the questions in the "Questions" section of the activity handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

SAMPLE RESPONSES TO THE QUESTIONS IN THE CELLULAR RESPIRATION IN ANIMALS ACTIVITY HANDOUT

Procedure	Sample Response
10, S9	Answers will vary, but in this example, other groups that used the same species had similar results. There was some difference within species based on size but it was fairly small. One group was near a heating unit and observed significantly higher rates of respiration than the rest of the class.
11, S10	Answers will vary. Larger or more active specimens are likely to have a higher rate of respiration. Temperature also makes a difference; animals in cooler temperatures will have a lower rate of respiration than those in a warmer environment. Differences based on size and activity level were observed.
Questions	**Sample Response**
1, S1	1. The guppy we tested is an omnivore and prefers to eat algae and small crustaceans. *Daphnia* and brine shrimp would both make suitable food sources that could be included in the biosphere. As primary consumers, the daphnia and shrimp could eat algae and plant material. *Daphnia* and brine shrimp reproduce quickly enough to sustain a population. Guppies can tolerate a range of salinity levels and water temperatures, and need to have some cover available in their habitat. 2. The cockroach we tested is a very adaptable species, able to survive on a wide variety of food items and in a range of environments. It can eat almost any organic material and is primarily a scavenger.
2, S2	The rate of carbon dioxide product in µmoles per hour measured is due to the production of carbon dioxide from cellular respiration. The equivalent amount of oxygen in µmoles per hour is consumed to balance the chemical equation for cellular respiration: $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$ + energy. In our sample, the cockroach produced 8 µmoles of carbon dioxide per hour. Based on the formula, we would expect 8 µmoles of oxygen were consumed.
3, S3	The correct answer is "C. Photosynthesis." Photosynthesis is the process of synthesizing organic molecules from carbon dioxide using light energy. Combustion (answer "A") is the process of burning materials in the presence of oxygen and typically liberates carbon from organic molecules while releasing energy and forming carbon dioxide. Decomposition (answer "B") is the breakdown of organic molecules by bacteria and other decomposers such as fungi, and also releases carbon dioxide gas. Evaporation (answer "D") is not related to the carbon cycle at all.

Connecting the Activity to the Challenge

As students finish the Activity questions, direct them back to the Challenge handout to complete the research connection questions. To help students connect their data to the Challenge, ask them how they propose to provide oxygen and remove carbon dioxide from the atmosphere so their animal can survive. Remind students they need to provide for their animals' other needs, including food, water, and shelter.

SAMPLE RESPONSES TO CELLULAR RESPIRATION IN ANIMALS RESEARCH QUESTIONS

Question	Sample Response
1	Answers will vary. Cell respiration: $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$ + energy Photosynthesis: $6CO_2(g) + 6H_2O(l)$ + light energy $\rightarrow C_6H_{12}O_6(s) + 6O_2(g)$ These equations show that for every 6 moles of carbon dioxide produced during respiration, 6 moles of oxygen gas are consumed. The glucose and water also contain oxygen atoms but these do not affect the 1:1 relationship between oxygen gas and carbon dioxide gas in the equations.
2	Answers will vary but in some cases the metabolic rate may not be representative of the organism's metabolic rate over a 24-hour period, since the sampled data may be the result of depressed respiration during sleep or accelerated respiration due to heightened activity or growth. To compensate for these influences, students might suggest implementing a more rigorous scientific investigation over a longer period of time or repeating the trial to come up with a statistical range of values. Additionally, temperature and other environmental factors inside the biosphere could impact the rate of respiration. To control temperature, students should place their biosphere away from heat or cold sources other than light.
3	In addition to a balanced atmosphere, animals also need food, water, and shelter. Students should consider what food their animals will need. If they choose to incorporate a secondary consumer, they need to explain how they plan to maintain a stable population of primary consumers. Further, students need to ensure the environmental conditions such as humidity and temperature are kept at reasonable levels for their organism. The mechanisms for providing food and maintaining environmental conditions will vary greatly. For instance, in their design students may choose not to use a totally transparent container in order to reduce the greenhouse effect. In addition, they may include a small cup or bowl to provide a water supply to animals that is separate from water in the substrate.

Activity: Plant Photosynthesis and Cellular Respiration

Objective

Explore the rates of photosynthesis and respiration in a plant and determine the mathematical relationship between leaf surface area and carbon dioxide production or consumption.

Materials and Equipment

- Data collection system
- Carbon dioxide gas sensor
- Sensor extension cable
- EcoChamber™ or large sampling bottle
- Balance, accurate to 0.01 g or greater
- Light source (lamp with timer or window)
- Small plant
- Paper towel
- Scissors
- Ruler
- Plastic wrap, ~(20 cm × 20 cm)
- Water

Safety

- Use caution when collecting and handling plants.
- Wash your hands with soap and water after handling organic specimens.

Procedure – Measuring photosynthesis and respiration

***NOTE**: Record all work, including tables, data, diagrams, and answers, into your notebook.*

☐ 1. Remove the plant from the soil and wash the roots to remove as much soil as possible. Place the plant into the sampling chamber on top of a damp paper towel to keep the roots moist.

☐ 2. Start a new experiment on the data collection system, �(1.2) use the extension cable to connect the carbon dioxide gas sensor to the data collection system, �(2.1) display CO_2 concentration on the *y*-axis of the graph with time on the *x*-axis, �(7.1.1) and set the units to measure *parts per million* in a graph display (ppm). �(5.3)

☐ 3. Calibrate the carbon dioxide gas sensor. �(3.1)

☐ 4. Insert the carbon dioxide sensor into a hole in the sampling chamber and tightly seal the chamber using plastic wrap around the seal.

☐ 5. Place the chamber near a window or light source that mimics daylight cycles.

☐ 6. Copy table 1 into your notebook.

☐ 7. Record the volume of air in the sampling bottle.

- Before starting data collection, change the sample rate on your data collection system to one sample every 15 minutes. �(5.1)

☐ 8. Collect data for 24 hours. �(6.2) Record the start time, as well as the time of sunset and sunrise, in your notebook.

☐ 9. When data collection is completed, remove the plant from the chamber.

☐ 10. Cut all the leaves off the plant and place them in a pile. Cut a 1-cm^2 section from a leaf and record its mass.

☐ 11. Place all the leaves, including the square section and any scraps, on the balance and record the mass.

☐ 12. Calculate the total surface area of your plant using the total mass of the leaves and the known mass of the 1-cm^2 section. Record the total surface area in cm^2.

Procedure – Data Analysis

☐ 13. Review the graph of CO_2 data for the past 24 hours. Select the portion of your data where the plant was in the light and then apply a linear fit to your data to determine the carbon dioxide production or consumption rate. �(9.5) Record the slope in *ppm per hour* in Table 1 (copied into your journal).

☐ 14. Select the portion of your data where the plant was in the dark and apply a second linear fit to determine the carbon dioxide production or consumption rate. �(9.5) Record the slope in *ppm per hour* in Table 1.

Table 1: Plant photosynthesis and respiration in light and dark conditions

Environ. Conditions	**Volume of Air (L)**	**CO_2 Production Rate**		
		Whole Plant (ppm/hr)	**Whole Plant (Standardized) (μmol/hr)**	**1-cm² Leaf Surface Area (Standardized) [(μmol/hr)/cm²]**
Light				
Dark				

RECORD YOUR DATA AND ANSWERS IN YOUR NOTEBOOK.

☐ 15. Convert *ppm carbon dioxide per hour* to *micromoles carbon dioxide per hour* to standardize your data (as directed in the Dimensional Analysis activity).

☐ 16. Divide the CO_2 consumption or production rate (μmol/hr) by the total leaf surface area of the plant to find the rate of production or consumption per cm^2 of leaf surface area. Record the results in Table 1.

☐ 17. Compare your standardized data to the standardized data of other groups in your class. How do your results compare to theirs?

☐ 18. What inferences can you draw about the effect of species, light intensity, leaf structure, and other plant characteristics on the rate of carbon dioxide production or consumption?

Questions

NOTE*: Record all work, including calculations and answers, into your notebook.*

1. Why was it necessary to remove the soil from the roots of the plant before beginning your experiment?
2. Why was it necessary to calculate the leaf surface area?
3. Are there areas on the graph where the rate of carbon dioxide production or consumption deviated from the rate described by the linear fit? Explain what might account for inconsistencies in the metabolic rates.
4. Using your data, how many additional micromoles of carbon dioxide could be produced in this environment by cellular respiration without causing a net increase over a 24-hour period?
5. Complete the questions in the Challenge: Biosphere handout for this activity.

Teacher Notes: Plant Photosynthesis and Cellular Respiration

Learning Objectives

In this activity, students

- Calculate the rate of carbon dioxide production or consumption in micromoles per hour per square centimeter of a plant leaf.
- Relate calculated data to the metabolic activities taking place in the plant cells.

Activity Preparation

House plants work well for this activity; spider plants (*Chlorophytum sp.*) are particularly hardy and may be replanted following the experiment. The light source for the experiment should model the area where the biospheres will be placed during the Test and Evaluate period.

Activity Introduction

Before the activity, facilitate a brief class discussion on photosynthesis. One question you may want to ask is "If plants rely on the sun for energy, how do they survive at night?" Students' responses may illustrate a prevalent misconception that plants only conduct photosynthesis and are totally dormant at night. If students are struggling to come up with an explanation, you can remind them that plant cells also have mitochondria. At this point in the discussion, have students make some predictions about the relative rates of photosynthesis and respiration for a single plant; they should predict that plants produce more oxygen and organic compounds than they consume in the course of a 24-hour day.

Teacher Tips

The roots of the plant must be thoroughly cleaned to eliminate cell respiration by bacteria as a variable. When using PASCO's EcoChamber™, it may be necessary to wrap the top of the chamber and seam with plastic wrap to ensure an airtight seal. Large Erlenmeyer flasks or plastic bottles with a wide mouth make suitable alternatives if EcoChambers are not available. Also, use an outlet timer to simulate daylight hours if using artificial light as an energy source.

The carbon dioxide gas sensor operates by measuring the absorption of infrared (IR) radiation emitted by an LED inside the barrel of the sensor. Any IR light sources can influence the sensor readings, so place the sampling apparatus away from incandescent lights or other heat sources, especially when calibrating the sensor. When performing a linear fit of the data, students should use only sections that have trending data (omit sections of the graph where carbon dioxide levels are zero).

Sample Data

Table 1: Plant photosynthesis and respiration in light and dark conditions

Environ. Conditions	Air Volume (L)	CO_2 Production Rate		
		Whole Plant (ppm/hr)	Whole Plant (Standardized) (μmol/hr)	1-cm² Leaf Surface Area (Standardized) [(μmol/hr)/cm²]
Light	2.6	–279	–30	–0.10
Dark	2.6	114	12	0.038

NOTE*: Leaf surface area in this sample is 311 cm², calculated by mass. A negative value for CO_2 production rate indicates that carbon dioxide was being consumed.*

CALCULATIONS

Light:

$$\left(\frac{-279\ \mu L/hr}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{2.6\ L}{1}\right) = -30\ \mu mol/hr \text{ of } CO_2 \text{ produced per hour}$$

$$\frac{-30\ \mu mol}{311\ cm^2} = -0.10\ \mu mol/cm^2 \text{ produced per hour}$$

Dark:

$$\left(\frac{114\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{2.6\ L}{1}\right) = 12\ \mu mol \text{ of } CO_2 \text{ produced per hour}$$

$$\frac{12\ \mu mol}{311\ cm^2} = 0.038\ \mu mol/cm^2 \text{ produced per hour}$$

Answer Key

Below are sample responses to the questions in the Plant Photosynthesis and Respiration activity handout. Responses numbered under the "Procedure" heading in the first column are responses to questions in the "Procedure" sections in the handout, while those responses under "Questions" are to the questions in the "Questions" section of the activity handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

SAMPLE RESPONSES TO THE QUESTIONS IN THE PLANT RESPIRATION AND PHOTOSYNTHESIS ACTIVITY HANDOUT

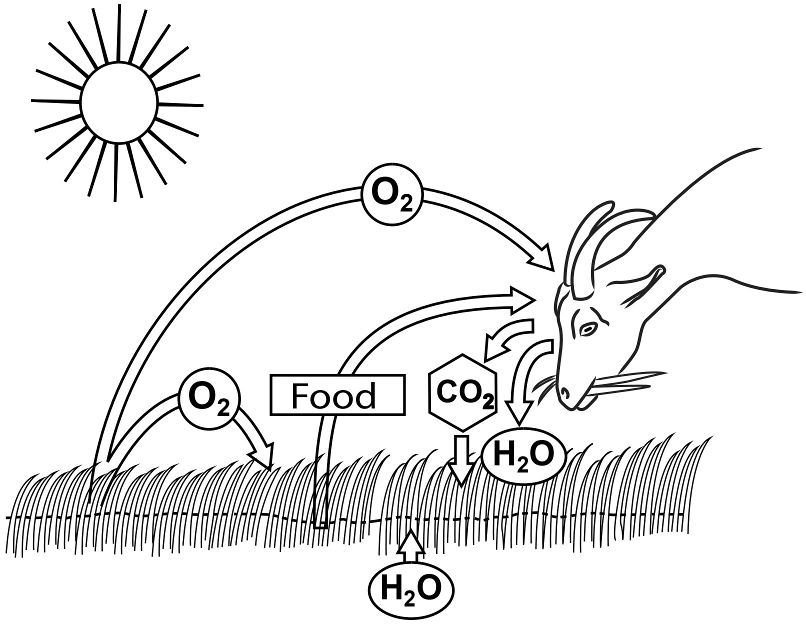
Procedure	Sample Response
16, S18	Groups that used the same plant species should have similar results, there may be significant differences across species.
17, S19	Higher light intensity resulted in increased photosynthesis, as did dark green broad leaf plants when compared to coniferous trees.
Questions	**Sample Response**
1, S1	It was necessary to remove all soil from the roots of the plant to remove microscopic organisms such as bacteria that could contribute to carbon dioxide levels through cellular respiration.
2, S2	It was necessary to calculate the area of the leaf surface to allow the data to be compared in different student groups, otherwise the size of the plant would be a variable. Additionally, assuming the same plant species is used in the design of the biosphere, the CO_2 production and consumption rates can be scaled for different size plants and environments.
3, S3	Yes, there is one area on the graph that deviates from the rate described by the linear fit: in the evening as the sun was setting, CO_2 consumption was lower than the rate described by the linear fit. As the light intensity decreased, it appears the rate of photosynthesis decreased as well, which is expected. (***NOTE****: This experiment and analysis assumes constant light levels during the daytime.*)
4, S4	Over a 24-hour period, 144 µmoles of CO_2 are produced (12 hr × 12 µmol/hr) by the plant while 360 µmoles are consumed (12 hrs × 30 µmol/hr). Therefore, an additional 216 µmoles of CO_2 (360 µmoles – 144 µmoles) could be produced without a net increase.

Connecting the Activity to the Challenge

As students finish the Activity questions, direct them back to the Challenge handout to complete the research connection questions. To help students connect the Activity to the Challenge, discuss the implications of Activity question #3 and Challenge question #2. Ideally, students will begin to assign numerical values to the nutrient cycling taking place in the diagram and integrate this information into their final biosphere design.

SAMPLE RESPONSES TO THE PLANT RESPIRATION AND PHOTOSYNTHESIS RESEARCH QUESTIONS

Question	Sample Response
1	Our data is a reasonable approximation of the plant's metabolic rate over 24 hours. There were some areas on the graph where the model did not fit the data. For instance, after the light went off, the carbon dioxide level remained at zero for almost an hour. It is possible the plant had some residual ATP from the light reactions that were being used by the cell so any respiration taking place was being neutralized by the dark reactions that were also taking place. Obviously, light intensity and duration play a role in regulating photosynthesis. Depending on whether or not our final design uses artificial or natural light, these factors may be beyond our control. Additionally, water availability can affect the rate of photosynthesis. To compensate for this, our final design will include a gravel substrate below the soil which we can add more water to without overwatering the plant. That amount of water should be sufficient for the duration of the testing.

2	Sample diagram  	The goat is eating the grass which it will break down internally, releasing energy stored in the chemical bonds. The byproducts of this reaction are H_2O and CO_2, which are released into the atmosphere and will be used by producers and stored again as chemical energy. The byproduct of this reaction is O_2, which is used by the goat. In the activities carbon dioxide production by plants (in the dark) and animals was observed as well as the uptake of CO_2 by plants conducting photosynthesis.

Activity: Decomposition

Objective

Investigate the decomposition activity in different substrate samples by measuring the carbon dioxide output and temperature change.

Materials and Equipment

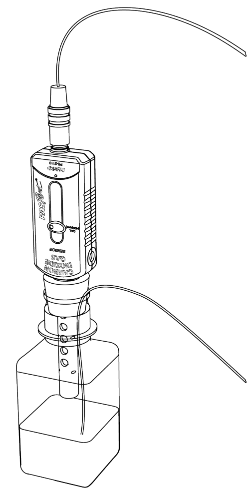
- Data collection system
- Fast response temperature sensor
- Carbon dioxide gas sensor
- Sensor extension cable
- Sample bottle, 250-mL
- Substrate samples (3 to 5) with different composition and amounts of organic debris, 100 mL

Safety

- Wash your hands with soap and water after handling organic specimens.

Procedure – Measuring decomposition

***NOTE**: Record all work, including tables, data, diagrams, and answers, into your notebook.*



- ☐ 1. Start a new experiment on the data collection system, [(1.2)] connect the carbon dioxide gas sensor to the data collection system using the extension cable, [(2.1)] and set the units to measure *parts per million* (ppm). [(5.3)]
- ☐ 2. Calibrate the carbon dioxide gas sensor. [(3.1)]
- ☐ 3. Connect the fast response temperature sensor to your data collection system [(2.2)] and set the units to measure degrees Celsius. [(5.3)]
- ☐ 4. Measure and record the room temperature in your notebook.
- ☐ 5. Copy Table 1 into your notebook and record your qualitative observations of the substrate sample.
- ☐ 6. Estimate the percentage of the sample that is made up of organic material (such as leaves, twigs, and plant matter) and record the percentage in Table 1.
- ☐ 7. Place 100 mL of the substrate into the 250-mL sample bottle; pack it gently to get an accurate volume.
- ☐ 8. Place the fast response temperature sensor into the bottle and make sure the tip of the sensor is covered with the substrate sample.
- ☐ 9. Insert the carbon dioxide gas sensor, display both temperature and CO_2 concentration on the *y*-axis of the graph with time on the *x*-axis, [(7.1.10)] and collect data for 10 minutes. [(6.2)]
- ☐ 10. Find the maximum temperature reached and calculate the difference between the maximum temperature and room temperature. Record your results in Table 1.
- ☐ 11. When data collection is completed, remove the substrate and thoroughly rinse out the sample bottle, or exchange your sample bottle for a different substrate sample tested by another group.
- ☐ 12. Repeat the procedure for your remaining substrate samples.

Procedure – Data Analysis

Table 1: Rate of carbon dioxide production in different types of substrate

#	Substrate Description	Volume of Air (L)	ΔT (°C)	Organic Debris (%)	Rate of CO_2 Production or Consumption per 100 mL of Substrate	
					(ppm/hr)	(μmol/hr)
Ex.	Fine grain topsoil, light brown in color with little visible organic material, very low moisture content.	0.200	1.3	~15%	450	3.67
1						
2	RECORD DATA AND ANSWERS IN YOUR NOTEBOOK.					
3						
4						

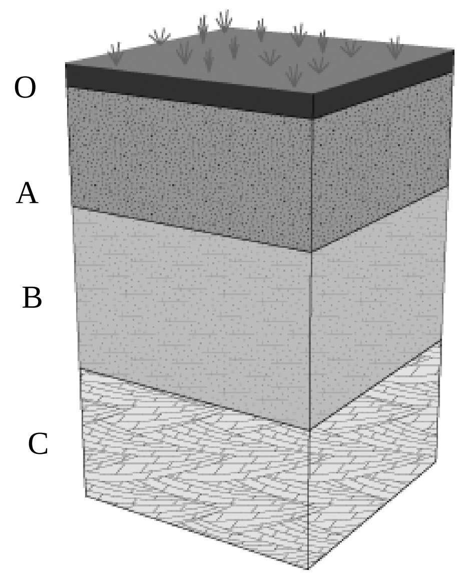
***NOTE**: The volume of air in the sample bottle is 200 mL (300 mL total volume – 100 mL substrate).*

- ☐ 13. Apply a linear fit to your data to determine the carbon dioxide production or consumption rate. Record the slope in *ppm per hour* in Table 1. �(9.5)
- ☐ 14. Convert *ppm carbon dioxide per hour* to *micromoles per hour* to standardize your data (as described in the Dimensional Analysis activity).
- ☐ 15. Compare your standardized data to the standardized data of other groups in your class. How do your results compare to theirs? Propose an explanation for any differences.

Questions

***NOTE**: Record all work, including calculations and answers, into your notebook.*

1. What effect, if any, did the sediment particle size have on the rate of decomposition? What effect did the amount of organic material have on the rate of decomposition?
2. How does the temperature data correlate to the carbon dioxide production rates? What does this indicate?
3. Which horizon in the soil profile shown to the right would you expect to have the highest rate of decomposition? Explain your answer.
4. Complete the questions in the Challenge: Biosphere handout for this activity.



Teacher Notes: Decomposition

Learning Objectives

In this activity, students

- Investigate the decomposition activity in different substrate samples by measuring carbon dioxide output.
- Understand that energy flows through an ecosystem and that heat is a major byproduct of cellular respiration.

Activity Preparation

The activity is most effective with a wide range of substrate samples for the class to use. Ideally, samples are selected from a variety of terrestrial and aquatic ecosystems and have a diverse mix of organic content and moisture levels. Place the samples into several sampling jars.

Activity Introduction

Several days before the activity, bury some bread or banana peels (the same type of food in each place) outside in different environments and soil substrates (sunny area, shady, wet, dry, etc.). Bring the samples back into class on a plate and label the plate with the type of environment it is in. To introduce this activity, tell students what you did and ask them to predict which sample will have decomposed the most and why. Show them the samples and see how their predications compared to the results. Discuss as a class how decomposition might occur inside a biosphere. Ask them to explain what organisms are responsible for decomposition and how they might be able to measure that activity with sensors.

Teacher Tips

Place 100 mL of the substrates into the 250-mL sample bottles and have groups exchange bottles rather than repeatedly cleaning and refilling the same bottle.

***NOTE**: Students are asked to use an air volume of 200 mL in their calculations. The sample bottles are graduated to 250 mL but have additional volume above the 250 mL mark of about 50 mL. The volume of air displaced by the sensor is ignored because it is impractical to measure without damaging the sensor.*

The carbon dioxide gas sensor operates by measuring the absorption of infrared radiation (IR) emitted by an LED inside the barrel of the sensor. Any IR light sources can influence the sensor readings, so be sure to place the sampling apparatus away from incandescent lights or other heat sources, especially when calibrating the sensor.

Sample Data

Table 1: Rate of carbon dioxide production in different types of substrate

#	Substrate Description	Air Volume (L)	ΔT (°C)	Organic Debris (%)	Rate of CO_2 Production or Consumption per 100 mL of Substrate	
					(ppm/hr)	(µmol/hr)
1	Fine grain topsoil, light brown in color with little visible organic material, very low moisture content.	0.200	1.3	~15%	450	3.67
2	Leaf litter layer, black soil with lots of organic debris such as leaves and sticks that are partially decomposed.	0.200	1.8	~60%	1050	8.58
3	Wet sand from 0" to 3" deep in a stream bed. Very little organic debris is visible. No organisms are visible in the sample.	0.200	0.8	~5%	576	4.71

CALCULATIONS

#1: $\left(\frac{450\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{0.200\ L}{1}\right) = 3.68\ \mu mol\ of\ CO_2$ produced per hour

#2: $\left(\frac{1050\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{0.200\ L}{1}\right) = 8.59\ \mu mol\ of\ CO_2$ produced per hour

#3: $\left(\frac{576\ \mu L}{1\ L}\right) \times \left(\frac{1\ \mu mol}{24.46\ \mu L}\right) \times \left(\frac{0.200\ L}{1}\right) = 4.71\ \mu mol\ of\ CO_2$ produced per hour

Answer Key

Below are sample responses to the questions in the Decomposition activity handout. Responses numbered under the "Procedure" heading in the first column are responses to questions in the "Procedure" sections in the handout, while those responses under "Questions" are to the questions in the "Questions" section of the activity handout. SPARKlab questions may be numbered differently and are indicated in the table with an "S" before the number.

SAMPLE RESPONSES TO THE QUESTIONS IN THE DECOMPOSITION ACTIVITY HANDOUT

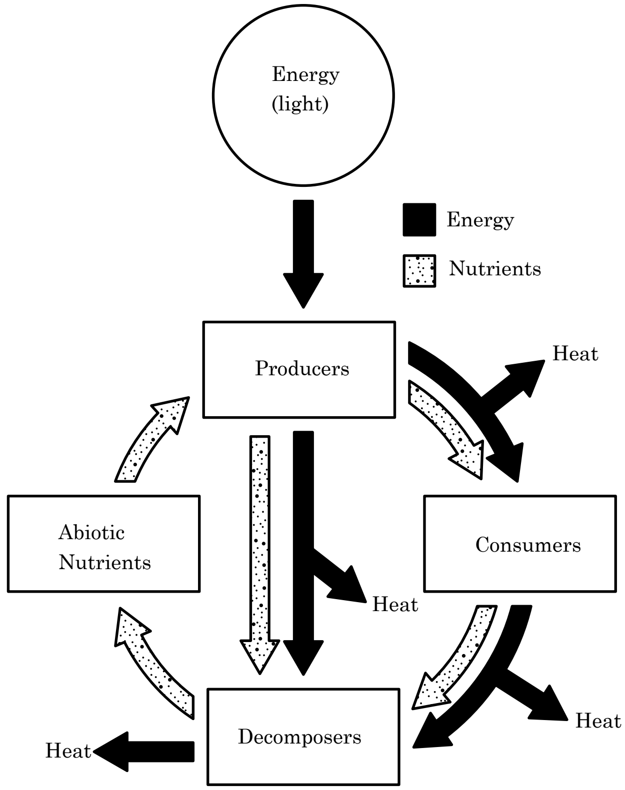
Procedure	Sample Response
15, S16	Results compared across groups were comparable. The greatest differences were observed in the leaf litter layer, which may have resulted from packing the substrate differently. Highly compressed soil has a greater mass in the same volume and would show a higher rate of decomposition. The data for topsoil and sand was very similar in other groups.
Questions	**Sample Response**
1	The sediment size had a mixed effect on the rate of decomposition: in wet samples, smaller sediment correlated with higher rates of decomposition but in dry samples there was no effect. The amount of organic material was directly correlated to the rate of decomposition—samples with a higher percentage of organic material had a higher rate of decomposition.
2	The temperature difference was greatest in the samples that had the highest carbon dioxide production. Since carbon dioxide is a product of cellular respiration and some energy is released as heat during cellular respiration, a higher carbon dioxide production rate indicates a higher rate of respiration, so more heat energy is also produced.
3	The "O" horizon would have the highest rate of decomposition because it contains the highest amount of organic material and is exposed to more oxygen.

Connecting the Activity to the Challenge

As students finish the Activity questions, direct them back to the Challenge handout to complete the research connection questions. To help students connect the Activities to the Challenge ask them to consider, individually, how their initial designs incorporated decomposition into the nutrient cycling. If their initial design did not, ask them to propose a way of incorporating it when they revise the design.

SAMPLE RESPONSES TO THE DECOMPOSITION RESEARCH QUESTIONS

Question	Sample Response
1	In order to reduce the increase in carbon dioxide in the biosphere due to the substrate materials needed to physically support the plants, different layers of substrate will be used. Topsoil, then sand, and finally some gravel should provide sufficient substrate for the roots to anchor while allowing for a small water reservoir in the bottom layer. The topsoil has the highest rates of decomposition, so by including some sand and gravel, and reducing the amount of topsoil, the additional carbon dioxide produced by the substrate should be minimized.
2	In the samples, organic content made the biggest difference in decomposition followed by moisture content. Since decomposition is a fairly slow process, the observed rates should be reasonably consistent in the biosphere, especially since moisture levels and organic content should remain fairly constant. Although it was not tested in this activity, light and temperature may also affect the rate of decomposition in the biosphere, more research would be needed to determine the relationship between the rate and these variables.

3	 Light energy from the sun is converted by producers into chemical energy. The producers are then either eaten by consumers or broken down by decomposers. In either case, the nutrients are transferred to the consumer or decomposer to use for growth, or put back into the ecosystem as waste. Some of the energy that was stored in chemical bonds is used to do work but most of it is released as heat into the environment. Eventually, the nutrients are taken up by producers again which use light energy to build new chemical bonds and the cycle repeats itself.

Activity: Ecological Accounting

Objective

Synthesize sample data from multiple activities to create a mathematical model for a sustainable biosphere and identify some of the limitations of modeling and propose modifications to address them.

Materials and Equipment

- Calculator
- Pencil

Problems – Balancing the Equation

***NOTE**: Record all work, including tables, data, diagrams, and answers, into your notebook.*

☐ 1. The data in Table 1 was obtained experimentally by measuring the carbon dioxide levels inside a sealed environment containing only the sample.

Table 1. Carbon dioxide production rates for biosphere calculations

Sample	Carbon Dioxide Production Rate
1 Shrimp	50.00 (µmol/hr)
Sandy Substrate	5.00 [(µmol/hr)/100.0 mL]
Gravel Substrate	3.00 [(µmol/hr)/100.0 mL]
Elodea in darkness	0.050 [(µmol/hr)/cm^2]
Elodea in direct sunlight	–0.25 [(µmol/hr)/cm^2]

A terrestrial biosphere was built that contained all the samples in Table 1, and used the parameters below.

- Total volume of 4 L
- 12 hours of direct sunlight (6:00 am to 6:00 pm), the remaining 12 hours of darkness
- Plants with a total leaf surface area of 600.0 cm^2
- 200.0 mL of each substrate
- Starting CO_2 concentration of 400.0 ppm

a. Determine the net change of carbon dioxide (in µmoles) over a 24-hour period.

b. Determine the net change in concentration (in ppm) over a 24-hour period.

☐ 2. Using the data in Table 1, graph the net carbon dioxide levels in parts per million over a 24-hour period in two-hour increments. Use the same parameters you used in Problem 1. The graph should run from 12:00 am–12:00 am. At your teachers discretion the included spreadsheet modeling tool may help you with the calculations.

***NOTE:** Carbon dioxide levels cannot fall below 0 ppm (or 0 µmol).*

☐ 3. Compare your results from Problems 1 and 2. Was the CO_2 concentration at the end of 24 hours different? If so, what would explain the difference in your calculations?

☐ 4. In the 24-hour period, did the carbon dioxide levels ever rise above 3% in the biosphere? This is the level at which most organisms experience respiratory stress.

☐ 5. Based on your analysis, what would you predict will happen to the carbon dioxide levels in the biosphere over the period of one week?

☐ 6. What changes, if any, to the biosphere volume, substrate ratios or amounts, and plant surface area could you make to stabilize the carbon dioxide levels so the net change day-to-day is minimal? Support your response with calculations to demonstrate the feasibility of your solution.

Questions

***NOTE**: Record all work, including calculations and answers, into your notebook.*

1. List 3 to 5 assumptions that are made in the calculations you completed.
2. Complete the questions in the Challenge: Biosphere handout for this activity.

Teacher Notes: Ecological Accounting

Learning Objectives

In this activity, students

- Synthesize data from multiple activities to create a mathematical model for a sustainable biosphere.
- Identify some of the limitations of modeling and propose modifications to address them.

Activity Introduction

As a class, discuss how the data collected in the preceding activities could be integrated and how it might inform students' designs. Any questions not completed in class can be assigned as homework.

Teacher Tips

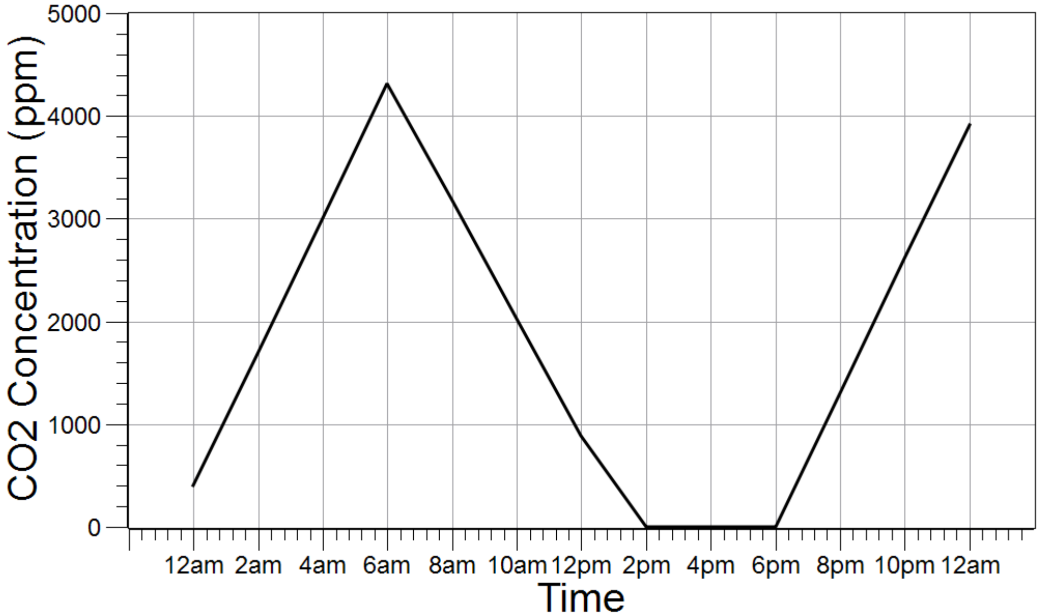
After students have completed the activity, they may wish to run additional modeling exercises. Have students use the Microsoft Excel™ spreadsheet, Biosphere Modeling.xls, included on the storage device or in the download, which allows students to manipulate variables related to producers and consumers and view the results without having to conduct tedious calculations.

Answer Key

Below are sample responses to the questions in the Ecological Accounting activity handout. Responses numbered under the "Procedure" heading in the first column are responses to questions in the "Procedure" sections in the handout, while those responses under "Questions" are to the questions in the "Questions" section of the activity handout.

SAMPLE RESPONSES TO THE QUESTIONS IN THE ECOLOGICAL ACCOUNTING ACTIVITY HANDOUT

Procedure	Sample Response
1a	The net change of carbon dioxide (in µmoles) over a 24-hour period is $\left(\frac{50.00\ \mu\text{mol}}{1\ \text{hr}} \times \frac{24\ \text{hr}}{1\ \text{day}}\right)_{\text{shrimp}} = 1200\ \mu\text{mol}$ $\left(\frac{5.00\ \mu\text{mol}}{(1\ \text{hr})(100.0\ \text{mL})} \times \frac{200.0\ \text{mL}}{1} \times \frac{24\ \text{hr}}{1\ \text{day}}\right)_{\text{sandy substrate}} = 240\ \mu\text{mol}$ $\left(\frac{3.00\ \mu\text{mol}}{(1\ \text{hr})(100.0\ \text{mL})} \times \frac{200.0\ \text{mL}}{1} \times \frac{24\ \text{hr}}{1\ \text{day}}\right)_{\text{gravel substrate}} = 144\ \mu\text{mol}$ $\left(\frac{0.050\ \mu\text{mol}}{(1\ \text{hr})(1\ \text{cm}^2)} \times \frac{600.0\ \text{cm}^2}{1} \times \frac{12\ \text{hr dark}}{\text{day}}\right)_{\textit{Elodea}\ \text{in darkness}} = 360\ \mu\text{mol}$ $\left(\frac{-0.25\ \mu\text{mol}}{(1\ \text{hr})(1\ \text{cm}^2)} \times \frac{600.0\ \text{cm}^2}{1} \times \frac{12\ \text{hrs light}}{\text{day}}\right)_{\textit{Elodea}\ \text{in light}} = -1800\ \mu\text{mol}$ $1200\ \mu\text{mol} + 240\ \mu\text{mol} + 144\ \mu\text{mol} + 360\ \mu\text{mol} + (-1800\ \mu\text{mol}) = 144\ \mu\text{mol}\ CO_2$ over a 24-hour period
1b	The net change of carbon dioxide (in ppm) over a 24-hour period is $\left(\frac{144\ \mu\text{mol}}{1}\right) \times \left(\frac{24.46\ \mu\text{L}}{1\ \mu\text{mol}}\right) \times \left(\frac{1}{3.6\ \text{L}}\right) = \frac{978\ \text{uL}}{\text{L}} = 978\ \text{ppm}$ This question asks for the net change, which can be negative, depending on the plant and animal combinations. If the net change is –400 ppm or less, then the concentration of CO_2 inside the biosphere would be zero, as it cannot be negative (the initial concentration of CO_2 in this question is 400 ppm). ***NOTE**: Do not forget to subtract the volume of the substrate from the total volume of the biosphere.*

2	Carbon Dioxide Concentration over 24 Hours 
3	Yes, the calculation of net change resulted in a CO_2 concentration of 978 ppm after 24 hours, while the graph showed a CO_2 concentration of 3,914 ppm after 24 hours. There are several reasons for the difference. First of all, the calculation in 1b does not include the initial CO_2 concentration of 400 ppm. Even so, there is still approximately a 2,536 ppm difference between the calculations. Another reason for the difference is that the calculation in 1b does not account for the fact that CO_2 levels cannot fall below zero. On the graph, where the CO_2 levels were calculated to be below zero for several hours, the value is shown as zero. Not taking this into account in the calculation results in a lower concentration. The graph provides a clearer picture of the change in CO_2 levels inside the biosphere.
4	No, the stress level for organisms of 30,000 ppm (3%) was not reached in the 24-hour period.
5	In this scenario, the carbon dioxide levels stay stable over a one week period. During the daytime, carbon dioxide levels fall at about 660 ppm per hour (determined by calculating the slope of the line between 6 am and 12 pm). During the nighttime, carbon dioxide levels due to cellular respiration rise at about 570 ppm per hour. At that rate, the biosphere carbon dioxide level drops to zero and rises to about 6840 ppm daily.
6	Decreasing the plants' surface area to 580 cm² would increase the rate of carbon dioxide consumption in the biosphere. Also, decreasing the amount of substrate to 100 mL of sand and 100 mL of gravel would decrease the carbon dioxide production rate. With both those changes, the rate of carbon dioxide consumption during the day equals the rate of carbon dioxide production during the nighttime. Even with a starting concentration of 400 ppm and CO_2 levels falling to zero during the day, a balanced rate should produce a stable environment. In the dark: $\underset{\text{plant}}{\frac{29\ \mu\text{mol}}{\text{hr}}} + \underset{\text{shrimp}}{\frac{50\ \mu\text{mol}}{\text{hr}}} + \underset{\text{sand}}{\frac{5\ \mu\text{mol}}{\text{hr}}} + \underset{\text{gravel}}{\frac{3\ \mu\text{mol}}{\text{hr}}} = 87\ \mu\text{mol/hr}$ In the light: $\underset{\text{plant}}{\frac{-145\ \mu\text{mol}}{\text{hr}}} + \underset{\text{shrimp}}{\frac{50\ \mu\text{mol}}{\text{hr}}} + \underset{\text{sand}}{\frac{5\ \mu\text{mol}}{\text{hr}}} + \underset{\text{gravel}}{\frac{3\ \mu\text{mol}}{\text{hr}}} = -87\ \mu\text{mol/hr}$
Questions	**Sample Response**
1	The assumptions made in these calculations include the following: ▪ Constant rates of respiration in substrate samples ▪ Constant rates of respiration in animal samples ▪ Plant photosynthesis and respiration scale perfectly with surface area ▪ Decomposition scales perfectly with volume ▪ The biosphere receives exactly twelve hours of daylight and darkness with constant brightness (in this example) ▪ That oxygen and carbon dioxide gases behave like an ideal gas ▪ That the environment is constantly at 25°C and 101.3 kPa

Connecting the Activity to the Challenge

As students finish the Activity questions, direct them back to the Challenge handout to complete the research connection questions. To help students connect the Activity to the Challenge, discuss the Challenge connection questions as a class. Create a class list of assumptions and limitations of the mathematical model and have students suggest ways of dealing with them in the research or design phase.

SAMPLE RESPONSES TO THE ECOLOGICAL ACCOUNTING RESEARCH QUESTIONS

Question	Sample Response
1	1. One assumption that affects my biosphere is that animals have a constant rates of respiration. If the animal is more active than it was during the sampling period, it will likely produce more CO_2 than the model suggests. The opposite is also true. Additionally, depending on the species lifecycle, the animal may be in a growth phase, which could increase its respiration levels. 2. A second assumption that affects my biosphere is that plant photosynthesis and respiration scale perfectly with surface area. However, if different parts of the plant conduct respiration and photosynthesis differently, then it would be difficult to balance CO_2 production and consumption. For instance, the spider plants (*Chlorophytum sp*.) have relatively small stem and root systems relative to the leaf surface area. Other plant species may have larger stem and root systems which would increase the amount of respiration while decreasing photosynthetic activity. The relationship between photosynthesis and respiration for each plant tissue will vary by species. The best way to evaluate this variable is with additional testing to quantify the plant's needs before including it in the biosphere.
2	In both cases, the best solution would be to conduct additional research using the samples that are proposed for the biosphere. Alternatively, it is possible to compare the data collected with other groups and find a range of carbon dioxide production and consumption values. Since it is likely that day-to-day respiration and photosynthetic activity will vary slightly, the second approach may provide a realist prediction.

3 Revise Design

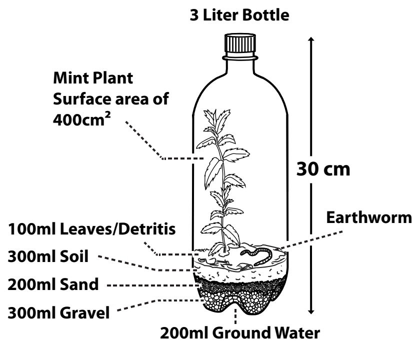
Prior to beginning revisions, revisit the engineering process as a class and discuss how research should support the design phase. Emphasize to students that unlike their initial designs which were based on prior concept knowledge, their revised design should be data driven. As they revise their design ask them to consider how the data and concepts covered in the activities validates or challenges their initial design ideas. They should create a new design that integrates their new knowledge. Additionally, students are asked to incorporate a detailed mathematical model in their revised design to support their approach; they may use data from the activities or conduct additional research.

The data obtained from the Cellular Respiration in Animals, Photosynthesis and Respiration in Plants, and Decomposition activities should directly inform the plants, animals, and substrate selections and quantities in the students' designs. Whether or not they choose to use data from the activities, their revised design should include proposed carbon cycling rates for the biotic components of their model.

Challenge students' decisions as they answer the questions and modify their initial designs. Identify specific design components and ask students to explain their reasoning by using data in their response. If students have generic responses, challenge them by asking "does your data support that?"

SAMPLE RESPONSES TO THE QUESTIONS IN THE REVISE DESIGN SECTION OF THE CHALLENGE

Question	Sample Response
1	While some aspects of the initial design worked well, other components needed modifications and greater detail to produce a sustainable biosphere. The initial design did not account for decomposition, which the activity clearly showed is a significant source of carbon dioxide. Additionally, the initial design assumed producers were a source of oxygen but not also a consumer of oxygen, which the data from the Plant Photosynthesis and Respiration activity show. Further, the revised design includes enhanced details on the carbon dioxide exchange rates between the organisms in the biosphere shown in a mathematical model of the carbon cycling.

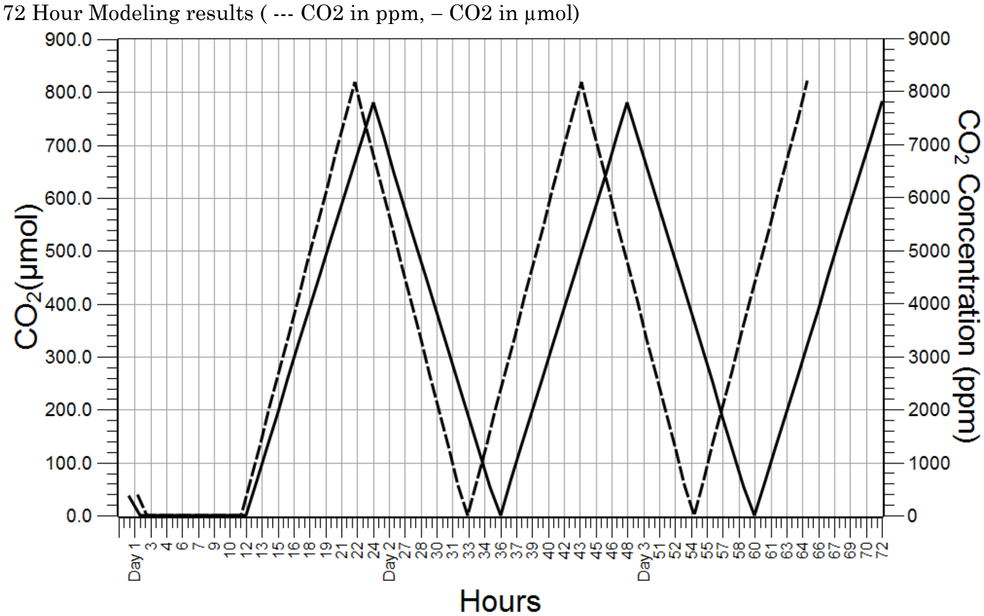
<table>
<tr>
<td>2</td>
<td>


Design Parameters:

- Earthworm, CO_2 production at 45.0 µmol/hr
- Mint plant, CO_2 production in the dark, 0.05 µmol/hr and in the light at –0.35 µmol/hr per cm^2
- Gravel, CO_2 production at 0.0 µmol/hr per 100 mL
- Sand ,CO_2 production at 3.0 µmol/hr per 100 mL
- Soil, CO_2 production at 5.0 µmol/hr per 100mL
- Leaves and detritus, CO_2 production at 8.0 µmol/hr per 100 mL

The earthworm was chosen because of its relatively low respiration, dietary flexibility, and preference for environmental conditions that were easy to maintain and re-create. The mint plant

72 Hour Modeling results (--- CO2 in ppm, – CO2 in µmol)



</td>
</tr>
<tr>
<td>3</td>
<td>
Materials:

- 3 L plastic bottle
- 300 mL coarse gravel
- 200 mL sand
- 300 mL top soil
- 200 mL water
- Mint plant (*Mentha sp.*) with ~250 cm^2 surface area
- Earthworm (*Lumbricus terrestris)*
</td>
</tr>
</table>

4 Develop Group Design

In order to finalize their design, students share their individual designs and collaborate with group members to design the prototype that best satisfies the design requirements and constraints. Students should spend 2 to 3 minutes explaining their individual revised design concept, calculations, and reasoning for their approach. Other group members should take notes and identify strengths and weaknesses of their peers' approaches.

The group may elect to take the best design and modify it, or start from scratch and create a new design that integrates individual approaches. This stage of the project helps students learn to critically evaluate others' work, a crucial skill in research and engineering. Students should maintain their individual notebook throughout the group design process and remainder of the Challenge. Their notebook will serve as a record of their contributions to the group project and their reflections.

The teacher's role in this phase is to check group designs prior to beginning construction. Apply sanity rules to designs (is this design feasible) and check that designs conform to constraints and requirements. Ensure that students have a clear idea of how they will construct their biosphere, in addition to their design and materials list. Engineering research is not necessarily a linear process. There are many different and equally valid ways to solve the same problem, so expect a variety of proposed solutions.

SAMPLE RESPONSES TO THE QUESTIONS IN THE DEVELOP GROUP DESIGN SECTION OF THE CHALLENGE

Question	Sample Response
1	Answers will vary but should include the important design points and why they were chosen.
2	Answers will vary but should include a description of the materials to be used and any safety concerns.

5 Build a Model

As a group, students should construct their biosphere model using the materials specified in their group design. (Depending on your classroom process, students could begin this process on a Friday and have the weekend to gather materials and begin building.) Your role is primarily as an observer. Remind students to document the building process and include an explanation for any deviations from their design. One class day plus time out of class should be sufficient for students to complete construction.

Encourage students to conduct additional tests as needed. The design and build phases may become iterative, depending on the students' approach.

After students have completed the construction of their biosphere and added inhabitants (and before sealing the biosphere), they should answer the Challenge questions for this section.

SAMPLE RESPONSES TO THE QUESTIONS IN THE BUILD A MODEL SECTION OF THE CHALLENGE

Question	Sample Response
1	I helped draft the final design, obtained the main biosphere container, and assisted with obtaining and testing of plants and animals to ensure a sustainable gas exchange.
2	The final design called for 500 cm^2 of leaf surface area. Upon further research and testing we found another species that had a higher rate of photosynthesis. We changed the plant species and only needed a leaf surface area of 425 cm^2, which allowed us to have more airspace and a smaller day-to-day fluctuation in oxygen and carbon dioxide concentrations. Also, when we constructed the biosphere, we determined that the amount of substrate had to be increased to support the plant.
3	Observation frequency: Daily (except weekends) Factors to observe: Light levels (unless using artificial lighting), temperature outside the biosphere, population levels of primary consumers, activity and vitality of secondary consumers, color and vitality of plants, and condensation inside the environment. In addition to written observations, our group will take a color photo using a digital camera each day to document the state of the biosphere.

6 Test and Evaluate

Each biosphere model has been designed and built to sustain its inhabitants indefinitely. However, in the interest of time, it is recommended that students place their biosphere in an area with indirect sunlight for a period of one week after the biosphere is sealed. The entire class should place their biosphere in the same area. After 7 days, students will conduct a final assessment and discontinue the experiment. If additional time is available, the evaluation may be extended at the teacher's discretion.

The test is subjective, given the difficulty of measuring the environment without disturbing it and the equipment demands of quantitative testing. During the evaluation period, students are asked to develop an observation schedule and record qualitative and quantitative information relevant to assessing the success of their design. Students may choose to monitor the number of organisms, their breathing rate, and the temperature and light levels outside the biosphere so they can supplement their observations with data. Their observations, in combination with the health of their biosphere after one week, will be assessed (as noted in the Challenge rubric). Students should record their observations in their notebooks and keep in mind that those observations will be used to answer the questions in the Design Review section in the Challenge handout. At your discretion, students may incorporate sensors into their biosphere as part of the assessment, as long as the biosphere can be made airtight.

NOTE*: If any animals become visibly stressed during the testing process, discontinue that experiment immediately.*

7 Design Review

In this stage, students will use the observations made during the Test and Evaluate stage to review where their model succeeded and where it failed. Students are expected to answer the Design Review questions in the Challenge handout. The teacher's role is to facilitate questioning and discussion, direct students to compare their results with those of other groups in the class, and have students propose explanations for any differences in the outcome of their evaluation.

Based on their reviews, students could reenter the engineering process at several points in the Engineering Design Process if time allows. They may wish to pursue additional avenues of research, or revise their design and construct a new model based solely on the results of their test and evaluations. Extensions for advanced students may include integrating sense and control systems to regulate temperature, water flow, or light intensity.

Samples responses to the questions in the Design Review section of the Challenge

Question	Sample Response
1	The design succeeded in that the inhabitants survived and appeared to be in good health throughout the experiment. Our daily observations showed stable populations of primary consumers, and the producers remained in good health. The secondary consumer remained active and showed good vitality during daily observations. On two days when the sun was particularly bright, there was a lot of condensation inside the biosphere. We were concerned about warming due to the greenhouse effect, but there were no long term effects.
2	If we were to revise the design, we would include some sense and control systems to moderate light exposure and circulate water in the biosphere. This would maintain a sealed environment but stabilize fluctuations in humidity and temperature. Flowing water might also reduce some of the algae growth that occurred. Further, a larger biosphere might prove more stable and buffer the internal environment from variations in light and external temperature changes, reducing the greenhouse effect.
3	In our class, groups with larger biospheres had better results. Smaller biospheres were less insulated from temperature changes and in a few instances the test had to be aborted. All of the groups that created aquatic biospheres were successful, although one did experience a significant algae bloom. It seemed that because algae grows so quickly, aquatic systems survived due to a robust primary producer population and stable environmental conditions.

Concluding the Module

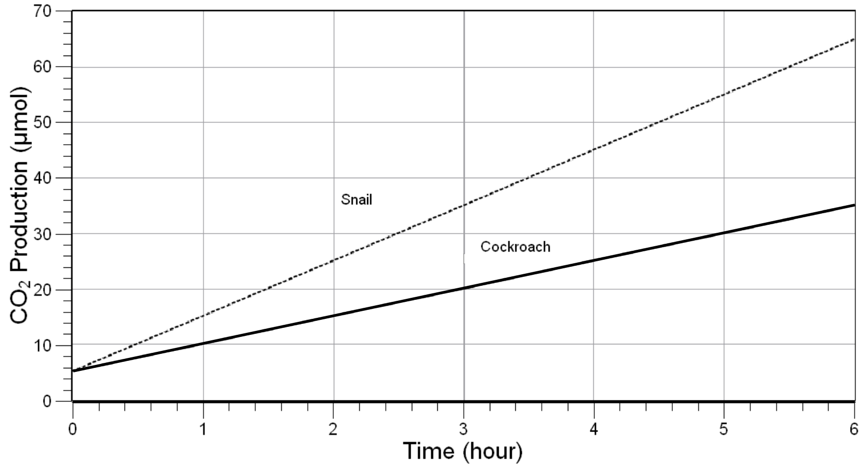
Have each group discuss its results and try to identify what did and did not work. Try to identify how biospheres that failed developed an unbalanced nutrient cycle. In some instances it may not be clear what went wrong; ask students to propose additional research avenues or identify uncontrolled variables that could be controlled in future iterations. After each group has had the opportunity to reflect on its model, have a class discussion to identify commonalities between models that succeeded and those that failed. Discuss some of the misconceptions that students had in their Initial Design Ideas and how the activities and their model have affected those ideas.

Close by reminding students that the engineering process is a continuous cycle. There is a saying in engineering that "The perfect design is at least one iteration away." If resources are available, consider allowing students to conduct additional research and construct a new model to repeat the process.

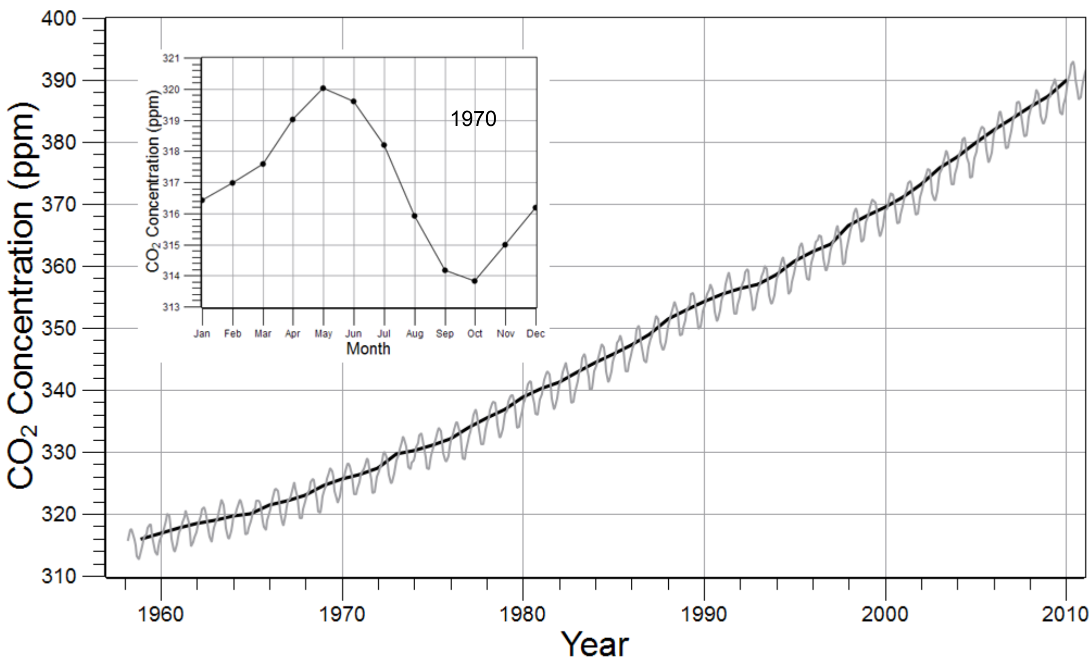
Have students review and complete their notebooks and submit them for assessment.

Post Assessment

1. The CO_2 production of a snail and a cockroach was measured individually. They were then put in the same container. Using the graph, calculate the net rate of CO_2 production in micromoles per hour (mol/hr).

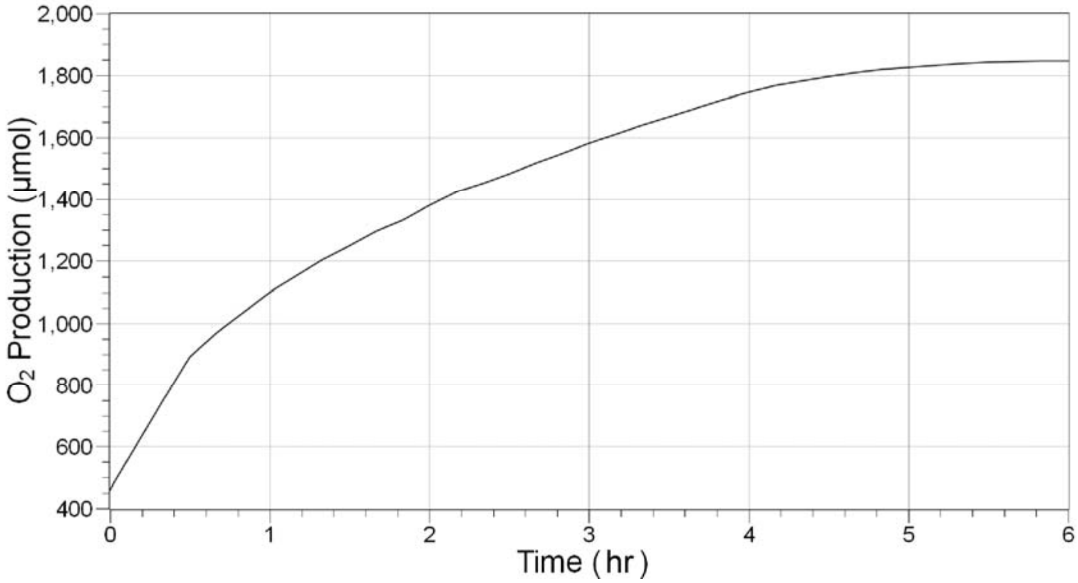


2. If algae in a 2.0 L container produces 750   mol of oxygen and the initial concentration was zero, what would the concentration be in *parts per million* (ppm)?
3. The graph below shows atmospheric carbon dioxide levels over each year for the past 50 years, along with the average shown by the black line. Most of the increase is correlated to increased industrial activity. How do you explain the annual fluctuation shown in the graph (note the expanded section displaying the CO_2 concentration fluctuations during the year)?



4. Cameron is setting up a terrarium for his younger brother's elementary school class. He collects soil and other material from the leaf litter layer of a local forest. He places a small amount of sand underneath several inches of the sticks, leaves, and topsoil. Then he plants several seeds, which should take 2–4 weeks to germinate. He includes insects and earthworms as the major inhabitants and seals the terrarium. After several days, half of the insects have died and he is forced to unseal the environment to ensure their health. Assuming food and water were available, what do you think happened to cause the animals to die?

5. The data below was collected over 6 hours in an airtight container with a bright light shining directly onto several plants inside. How do you explain the trend in the graph? What additional data would you need to collect to test your hypothesis?



6. Photosynthesis is represented by which of the following equations?

   A. $C_6H_{12}O_6(s) + 6O_2(g) \rightarrow 6CO_2(g) + 6H_2O(l)$ + energy

   B. $C_6H_{12}O_6(s) + 6CO_2(g) \rightarrow 6O_2(g) + 6H_2O(l)$ + energy

   C. $6CO_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$

   D. $6O_2(g) + 6H_2O(l) \rightarrow C_6H_{12}O_6(s) + 6CO_2(g)$

7. Which of the following accounts for the large fraction of the energy consumed by an organism that is not used to increase body mass?

   A. Digestive process and work
   B. Heat
   C. Reproduction
   D. All of the above

8. 15.0 L of bleach is spilled into a 10,000,000 L aquarium, what is the concentration in *parts per million?*

Post-Assessment Answer Key

Question	Correct Answer	Assessment Information
1	Net rate of CO_2 production: 15 µmol/hr	Choose any two points on the graph and use the following equation to calculate the slope of the line: $\frac{y_2 - y_1}{x_2 - x_1} = \frac{\text{rise}}{\text{run}}$. For the snail, the rate of CO_2 production is: $\frac{65\ \mu\text{mol} - 15\ \mu\text{mol}}{6\ \text{hr} - 1\ \text{hr}} = \frac{50\ \mu\text{mol}}{5\ \text{hr}} = 10\ \mu\text{mol/hr}$. Then calculate the slope of the line for the cockroach, $\frac{35\ \mu\text{mol} - 10\ \mu\text{mol}}{6\ \text{hr} - 1\ \text{hr}} = \frac{25\ \mu\text{mol}}{5\ \text{hr}} = 5\ \mu\text{mol/hr}$ and add them together for a net rate of 15 µmol/hr. This concept relates to the Cellular Respiration in Animals and Ecological Accounting activities.
2	9,200 ppm	$\left(\frac{750\ \mu\text{mol}}{1}\right) \times \left(\frac{24.46\ \mu\text{L}}{1\ \mu\text{mol}}\right) \times \left(\frac{1}{2.0\ \text{L}}\right) = 9{,}200\ \text{ppm}$ This calculation relates to the Standardizing Data activity.
3	The fluctuations are due to the seasonal changes in the northern hemisphere where most biomass is located.	From April to October in the northern hemisphere trees sequester carbon through photosynthesis as they grow and produce leaves. In the fall, when the leaves drop and decompose, the carbon dioxide levels rise. (The northern hemisphere has much greater forested area than the southern hemisphere.) This concept relates to the Plant Photosynthesis and Cellular Respiration activity.
4	Because the terrarium contained no producers, the respiration requirements of the decomposing organic material and animals could not be met. The oxygen levels plummeted and the carbon dioxide levels increased to toxic levels after a short period of time.	This concept relates to the Decomposition activity.
5	The rate of oxygen production shown on the graph decreases, possibly because the plants consumed most of the reactants (CO_2 and H_2O) for photosynthesis. It is also possible that due to environmental conditions, the stomata closed. If we could measure carbon dioxide levels and rates of transpiration, we could test both hypotheses.	This concept relates to the Plant Photosynthesis and Cellular Respiration activity.
6	C	This concept relates to the Cellular Respiration in Animals and Plant Photosynthesis and Cellular Respiration activity.
7	D	This concept relates to the Decomposition and Ecological Accounting activities.
8	1.5ppm	$\frac{15.0\ \text{L}}{10\ \text{million L}} = 1.5\ \textit{parts per million}$ This calculation relates to the Standardizing Data activity.

Appendix – Master Materials and Equipment

Teachers can conduct some lab activities with sensors other than those listed here. For assistance with substituting compatible sensors for a lab activity, contact PASCO Teacher Support (1-800-772-8700 inside the United States or http://www.pasco.com/support).

***NOTE**: Italicized entries indicate items not available from PASCO. The quantity indicated is per student or group.*

Equipment by Activity

Act	Title	Materials and Equipment	Qty
1	**Standardizing Data (p.23)** Practice unit conversion using dimensional analysis.	*Calculator* *Pencil*	1 1
2	**Cellular Respiration in Animals (p.29)** Use a carbon dioxide sensor to compare the rate of cellular respiration in several different animal species to determine if they are suitable candidates for a biosphere.	Data Collection System PASPORT Carbon Dioxide Sensor with sensor extension cable and 250-mL sampling bottle Beaker and *material for an airtight seal* (optional) *Macroinvertebrates or fishes*	1 1 1 3 to 5
3	**Plant Photosynthesis and Cellular Respiration (p.35)** Use a carbon dioxide sensor to explore the rates of respiration and photosynthesis in a plant and determine the mathematical relationship between leaf surface area and carbon dioxide production or consumption.	Data Collection System PASPORT Carbon Dioxide Sensor with sensor extension cable and 250-mL sampling bottle PASCO EcoChamber ™ or large sampling bottle Balance, accurate to 0.01 g or greater *Light source (lamp with timer or window)* *Small plant* *Paper towel* *Scissors* *Plastic wrap* *Ruler*	1 1 1 1 1 1 1 1 ~(20 cm × 20 cm) 1
4	**Decomposition (p.41)** Use a carbon dioxide sensor and a fast-response temperature sensor to investigate the decomposition activity in different substrate samples.	Data Collection System PASPORT Carbon Dioxide Sensor with sensor extension cable and 250-mL sampling bottle PASPORT Fast Response Temperature Sensor *Substrate samples, 100-mL*	1 1 1 3 to 5
5	**Ecological Accounting (p.47)** Synthesize sample data from multiple activities to create a mathematical model for a sustainable biosphere.	*Calculator* *Pencil*	1 1

Activity by Equipment

Items Available from PASCO	Qty	Activity Where Used
Data Collection System	1	2, 3, 4
PASPORT Carbon Dioxide Sensor*	1	2, 3, 4
PASPORT Fast Response Temperature Sensor	1	4
PASCO EcoChamber	1	3

*The PASPORT Carbon Dioxide Sensor includes a sensor extension cable and 250-mL sampling bottle.