Biosphere 3—It's a Small World After All

SYNOPSIS FOR CORE EXPERIMENT

Students will investigate and analyze mathematically the interactions that take place among several variables of a closed ecosystem.

APPROPRIATE BIOLOGY LEVEL

Introductory, intermediate, and advanced

TEACHER PARTNERS

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Directions for Teachers

Note to Teachers: Information below is given for the Core Experiment. Additional information needed for each variation of the Core Experiment may be found beginning on page 65. For a specific variation, check the At-A-Glance Map.

GETTING READY

See sidebars for additional information regarding preparation of the lab.

OBJECTIVES FOR CORE EXPERIMENT

At the end of this lab, students will be able to:

- Develop a simple mathematical model that investigates the complicated processes and systems of an artificial ecosystem.
- Describe the role each biotic and abiotic variable plays within the ecosystem.
- Observe, record, and interpret how different components of the ecosystem change as they interact with each other and the environment.
- Discuss how models are used to investigate complicated processes and systems.
- Discuss the difficulties of controlling all variables in a complicated system.

MATERIALS NEEDED

You will need the following for each group of two students in a class of 24:

- 4 sheets of graph paper
- 1 calculator
- 1 number cube or die
- 1 or more class "closed bottle" systems (*optional*)

SAFETY PROCEDURES

None to consider.

DIRECTIONS FOR SETTING UP THE LAB

One day before

- Collect materials for the Core Experiment.

LENGTH OF LAB

A suggested time allotment follows:

Day 1 (45 minutes)

- Discuss the use of models and how scientists use mathematical models to study living systems.
- Discuss how to develop a simple mathematical equation to study Biosphere 3.

Day 2 (45 minutes)

- Implement the mathematical equation.
- Collect, analyze, and discuss these data.

Day 3 (45 minutes)

- Design a model based on the Core Experiment of another variable.

PREPARATION TIME REQUIRED

15 minutes

- Gather materials.

3 hours

- Gather materials and organisms and set up the class "closed bottle" for observation (*optional*).

TEACHER'S NOTES

One month before (optional)

- Set up a classroom aquatic "closed bottle" or biosphere in a large container, such as a 5-gallon drinking water bottle. Include aquatic organisms such as snails and *Elodea* or other submerged aquatic vegetation (SAV).
- Have students collect mud and water from areas around their home community and seal in a bottle. Place these bottles in a classroom window or under a Gro-Lite®.

TEACHER BACKGROUND

Content Information

The concept of a biosphere is not a new one. In 1875, the Austrian geologist Eduard Suess introduced the term to describe "the 'envelope' around the planet [Earth] that was inhabited by life" (FAQ, 1998). Today, the term biosphere can be described as the many ecosystems of the Earth that interact with each other. An ecosystem is a community of organisms and all of its elements and their functions that exist in nature as an entity. From space, the Earth appears as a self-contained sphere of life and is often referred to as Biosphere 1.

The advent of the space age brought a new perspective of the biosphere—how to make an artificial "biosphere" for extended periods of time. With the focus on space travel, the Soviets began experiments on closed biological systems. In 1961, Soviet scientists sealed physician Evgenii Shepelev with a tank containing algae for his oxygen source inside a 160-cubic-foot cylinder. After 24 hours, he had to leave the system. Although the system had been successful at cycling oxygen and carbon dioxide, it was far too simple to accommodate all of the waste gases produced by himself and the algae (Closed systems, 1998).

In 1968 at the University of Hawaii, microbiologist Clair Folsome studied totally contained systems of microorganisms, rather than humans and higher plants. Folsome sealed samples of ocean water in flasks so nothing could enter or leave them and set them in indirect light on a lab windowsill. To his amazement, the community of microorganisms continued to live. In fact, some still survive today. Folsome continued to study these micro-ecosystems, expanded his collection with samples from other locations, and developed ways to evaluate the systems while maintaining their isolation. He discovered that if the microbial communities were diverse enough they could live indefinitely and establish their own ecosystems (Gentry, 1992). He had rediscovered an observation by the Russian geochemist, Vladimir Vernadsky, that "as life evolves, it actually changes the environment in which it evolves" (Sieloff, 1995).

By 1972, the research started by Shepelev had advanced considerably to the creation of the Soviet Bios-3. This enclosed system was much larger and housed several people and a hydroponic garden, but was still not totally self-contained. Wastes had to be exported and a protein source imported. The challenge remained to create a system that could be self-contained.

On September 26, 1991, this challenge was addressed with completion and sealing of Biosphere 2. It was constructed as a closed system to study how the Earth works. It contains five biomes that simulate those on Earth—ocean, rainforest, marsh, savanna, and desert—with over 4,000 species of organisms. Artificial communities include an agricultural area, micro city, and technosphere for human habitation (Sieloff, 1995).

In Biosphere 1 (Earth), the amount of temperature, rain, and light in any one area determine what kind and how much plant life will grow. Plants change the atmosphere by producing oxygen and using carbon dioxide found in our atmosphere. Organisms feed upon each other and interact with their non-living environment. Organisms depend upon energy from the sun locked in organic compounds that are stored in plants. Nutrients, water, oxygen, carbon, and nitrogen are constantly being recycled in nature. Change occurs when organisms modify their environment, both short term (night and day) as well as long term (succession). Throughout all these interactions, energy travels in a one-way path while all matter is cyclic. Despite population fluctuation, our biosphere maintains stability throughout time.

Organisms interact in mathematically measurable ways. Mathematical models predict the effects of changes in variables. Probability is an example of a common use of mathematical modeling in genetics. In this activity, students will model mathematically the effects of one and multiple variables upon the resources of a closed ecosystem—Biosphere 3. Isolating one variable from this complex system to study is a daunting challenge, as the mathematical modeling of this lab will reveal.

Pedagogical Information

The following is a chart of some concepts related to this lab and some student misconceptions of these concepts.

Correct Concept	Misconception
• Both plant and animal cells respire.	• Only animals undergo cellular respiration.
• Ecosystems are very complicated systems that are difficult to analyze.	• Variables in a complicated system can be controlled.
• Plants and animals share many of the same physiological processes.	• Plants and animals have little in common.

INSTRUCTIONAL PROCEDURES FOR THE CORE EXPERIMENT

If this is the first time your students have designed an experiment, the following paper and pencil exercise will provide design practice.

Introduction—The Biosphere 3 Model

The closed bottle or biosphere is a traditional biology classroom activity that offers a wealth of opportunities for student observations throughout the year and discussion of the interrelationship of biotic and abiotic factors. Possible ways to introduce this activity include:

- Have students discuss what factors are necessary for the organisms in the class biosphere system to survive. Discuss Biosphere 2 and how what looks like a very simple system is actually quite complex.
- Introduce the concept of models and why they are used. Models that students may be familiar with are the stick and ball models used for chemical molecules. These are physical models. Have them list other physical models and how they are used. Models may be mathematical also. Such models can be used to predict global warming, forecast the weather, or analyze the spot patterns on leopards or stripe patterns on zebras. Mathematical models can be very useful in science, but the assumptions on which they are based must be considered carefully. For example in the orange roughy model, scientists predicted that the optimum age to harvest orange roughy for food was 40 years of age after they had reproduced. Unfortunately, the life span of the orange roughy was miscalculated. Orange roughy do not reproduce until age 80. Ask students why mathematical models need to be designed carefully.

TEACHING TIPS

- Modeling may be done on any of several levels depending upon student interest. Possible modeling approaches include:
  - graphing simple algebraic equations that assume constant rates of change.
  - generating a calculus-based equation to model variable rates of change among variables in the model.
  - using graphing calculators for calculations.
  - using a computer modeling program such as *Stella*®.
  - using spread sheet software to perform repetitive calculations.
  - writing a computer program.
- Using simulation software such as *SimIsle*™, *SimCity*™, or *Bio-BLAST*™ .

TEACHER'S NOTES

- For this activity, have students imagine Biosphere 3 is an imaginary container that can be sealed after the introduction of bean plants and grasshoppers. The relationship and effects of these species' introduction into the imaginary container are analyzed mathematically. Each biosphere experiment begins by determining how many bean plants and/or how many grasshoppers will be introduced and by specifying the starting conditions within the biosphere. Provide students with the following assumptions of Biosphere 3 (Note to the teacher: In order to keep the mathematical model simple, the relationship between temperature, pressure, and volume within the biosphere is not considered.):

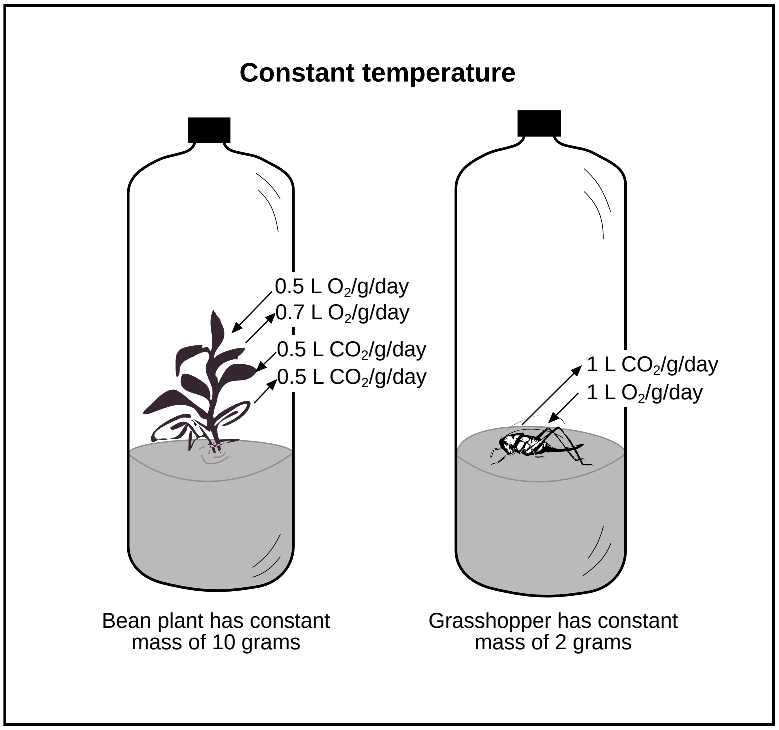


Figure 1. Biosphere 3.

1. Atmosphere contains 1 L O_2 and 1 L CO_2 at the beginning of the experiment.
2. Biosphere 3 can be inhabited by grasshoppers and/or bean plants only.
3. Each grasshopper that inhabits Biosphere 3:
   - has a mass of 2 g throughout the experiment.
   - uses 1 L O_2/gram body mass/day.
   - produces 1 L CO_2/gram body mass/day.
4. Each bean plant that inhabits Biosphere 3:
   - has a constant mass of 10 g.
   - uses 0.5 L O_2/gram plant mass/day.
   - produces 0.7 L O_2/gram plant mass/day.
   - uses 0.5 L CO_2/gram plant mass/day.
   - produces 0.5 L CO_2/gram plant mass/day.
5. All rates, such as the rate of oxygen consumption by grasshoppers, remain constant while in Biosphere 3.
6. Temperature remains constant and the sun shines 24 hours per day.
7. Grasshoppers do not need to eat or drink while they are in Biosphere 3.
8. Plants do not need water while in Biosphere 3.
9. Ignore the fact that the volume of the container does not change to accomodate an increase or decrease in the gas volume. This is done in order to keep the model simple.

Note: Part of the activity can include examining the above assumptions. For example, given that the students understand the basics of physiology:

- Is it reasonable to assume that plants will consume the same amount of CO_2 daily as they produce?
- Is it reasonable to assume that the rate of CO_2 production (on a per gram body weight basis) for a grasshopper is greater than that of a bean plant?

Explain that the classroom biosphere, due to its complex nature, lends itself very well to study by mathematical models.

For the Core Experiment, consider the following dialogue approach to develop student understanding of the process of equation development.

Question

Assume that there is 1 L O_2 in Biosphere 3 at the start of the experiment. How much O_2 is left after 1 hour?

Answer

The amount of O_2 remaining in Biosphere 3 after 1 hour is equal to the starting amount less the amount that is used in 1 hour. This is a "word equation." We could write it in mathematical form to look like this:

$$O_2 \text{ remaining} = \text{Starting amount} - \text{Amount used}$$
$$= 1 \text{ L } O_2 - X \text{ L } O_2$$

Question

In our equation, the amount of O_2 used is an unknown (X). What determines how much O_2 will be used in Biosphere 3 and how fast it will be used?

Answer

The amount of O_2 used and the rate at which it is used is determined by the kinds of living things sealed inside Biosphere 3.

Assume that 1 grasshopper is the only organism inside Biosphere 3. In our experiment, a grasshopper has a mass of 2 grams and uses 1 L O_2 per gram of body mass per day. We can use this information to determine "X" in our equation above.

Question

How much O_2 will a 2-gram grasshopper use per day?

Answer

Since 1 grasshopper uses 1 L O_2 per gram of body mass per day, and our grasshopper has a mass of 2 grams, it will use 2 L O_2 per day.

Question

Can you write this answer as an equation in mathematical form?

Answer

$$O_2 \text{ used per day} = \frac{1 \text{ L } O_2}{\text{gram}} \bullet \frac{2 \text{ grams}}{\text{grasshopper}} \bullet 1 \text{ grasshopper}$$
$$= 2 \text{ L } O_2$$

Question

So, 1 grasshopper will use 2 L O_2 per day. How much will it use in 1 hour?

Answer

$$O_2 \text{ used per hour} = \frac{2 \text{ L } O_2}{\text{day}} \bullet \frac{1 \text{ day}}{24 \text{ hours}} \bullet 1 \text{ hour}$$
$$= 0.083 \text{ L}$$

Question

Let's go back to the original question above. If Biosphere 3 starts out containing 1 L O_2 and 1 grasshopper, how much O_2 will it contain after 1 hour?

TEACHER'S NOTES

TEACHER'S NOTES

Answer

O_2 remaining $= 1\ L\ O_2 - 0.083\ L\ O_2$
$= 0.917\ L\ O_2$

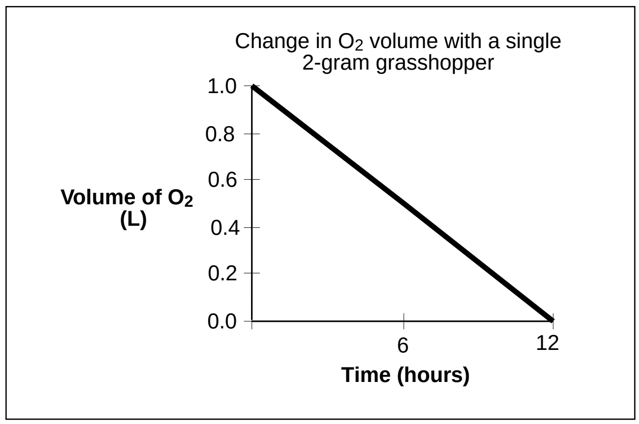
Question

Based on this result, would you predict that 1 grasshopper can survive for 24 hours if sealed inside Biosphere 3? Why or why not?

Answer

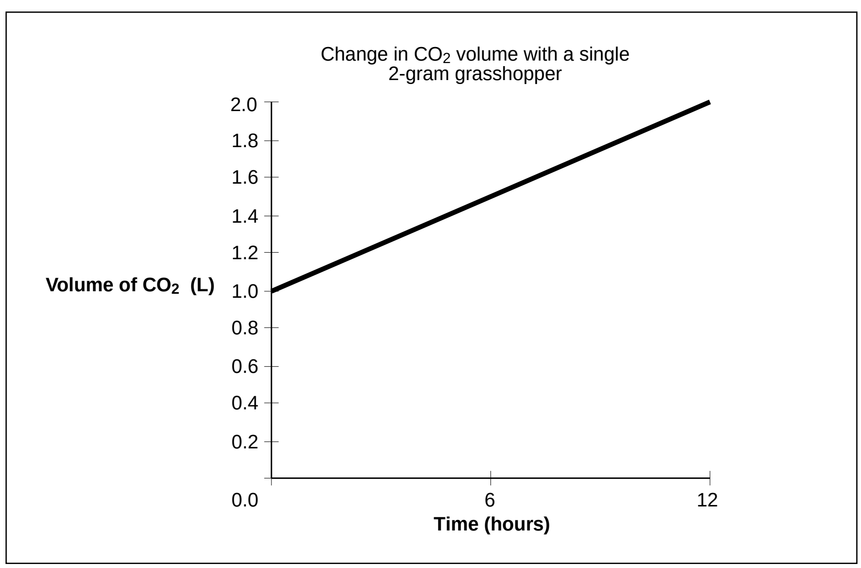
Given the rate at which a 2-gram grasshopper uses O_2, there is only enough O_2 in Biosphere 3 to support the grasshopper for 12 hours. Thus, our model predicts that the grasshopper would not be able to live inside Biosphere 3 for 24 hours.

Following this introduction, ask the students to draw a graph that will show what happens to the amount of O_2 inside Biosphere 3 during the course of the above experiment. Sample results are shown in Graph A.



Graph A. Amount of oxygen in Biosphere 3 containing 1 grasshopper.

Draw a second graph to show what happens to the level of CO_2 in Biosphere 3 during the experiment if 1 L CO_2 were present at the start of the experiment and grasshoppers produce 1 L CO_2 per gram of body mass per day. Sample results are shown in Graph B for Biosphere 3 with a single 2-gram grasshopper.



Graph B. Amount of carbon dioxide in Biosphere 3 containing 1 grasshopper.

HYPOTHESIS GENERATION

Ask students how they would develop a mathematical model of a biosphere that contained grasshoppers, but no plants. The following questions may be used to generate a mathematical equation to describe how the volume of oxygen present changes over time in relation to the number of grasshoppers present in Biosphere 3.

1. What is the initial volume of oxygen in Biosphere 3?
2. What is the relationship between grasshopper body mass and oxygen used?
3. What is the mass of the grasshopper?
4. How much oxygen is used in 1 day by 1 grasshopper?
5. Is there enough oxygen for 1 grasshopper to survive for 1 hour in Biosphere 3? How would you write a mathematical equation to determine this?
6. What is the reasoning behind your prediction?

Sample Hypothesis

If 1 grasshopper is sealed inside Biosphere 3 with 1 L O_2, it will survive for 1 day.

On the following pages are a sample hypothesis, procedure, and data analysis set with interpretation that students might develop for the Core Experiment. It is followed by related test questions and answers for teacher evaluation. This example has been included as a potential outcome of the activity and should not be given to the students. Students should develop their own hypotheses and procedures. Make sure they understand that there is not just one correct hypothesis, procedure, or data set. The Variations of the Core Experiment will give each group of students the opportunity to expand on the Core Hypothesis.

Question

Can the volume of oxygen in Biosphere 3 be determined if the rate of oxygen consumption by grasshoppers is known?

Hypothesis for Equation Model

If grasshoppers consume 1 L O_2/g/day, then the volume of oxygen in Biosphere 3 at any time "*t*" can be determined mathematically.

Procedure

1. Write an equation that describes how oxygen concentration is related to time and to the number of grasshoppers.
2. Roll the die to determine how many grasshoppers your group will seal inside Biosphere 3.
3. Use the equation to determine the change in oxygen volume at 1-hour intervals for the number of grasshoppers sealed in your Biosphere 3.
4. Record your results in a data chart.
5. Write a second equation to show what happens to carbon dioxide concentration.
6. Calculate mathematically what happens to the CO_2 volume within Biosphere 3 within 12 hours, based on the number of grasshoppers sealed in your container. Record your results in a chart.
7. Graph your mathematical conclusions for a 12-hour period.

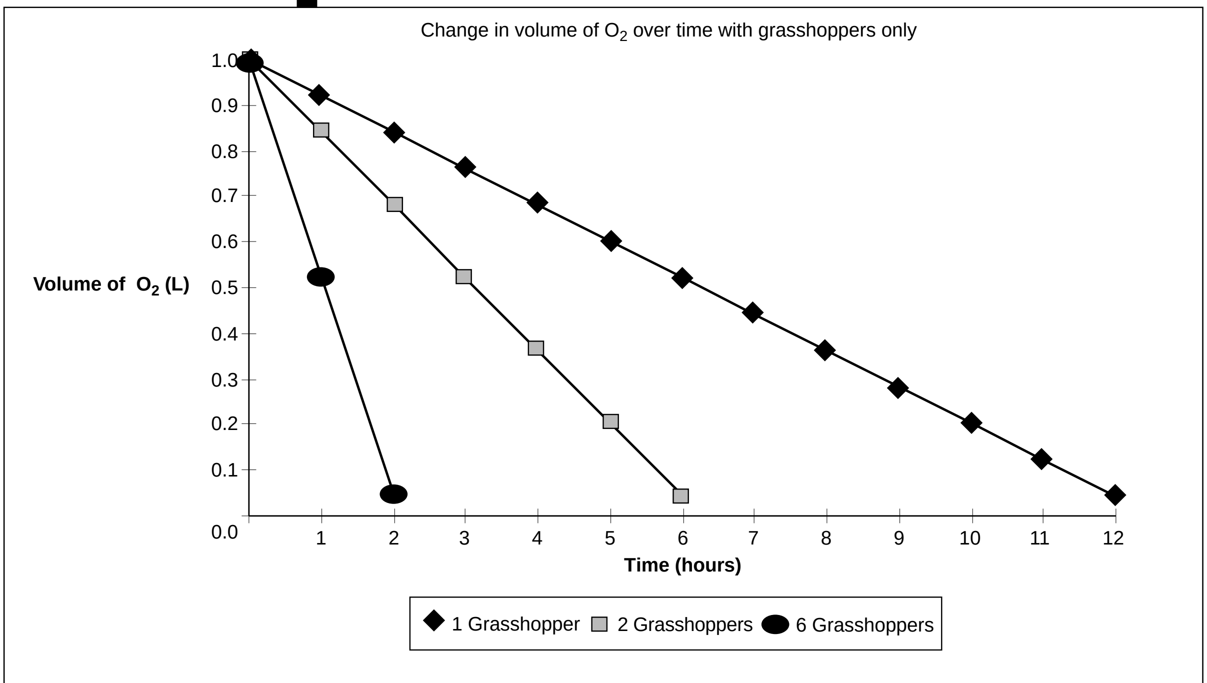
TEACHER'S NOTES

TEACHER'S NOTES

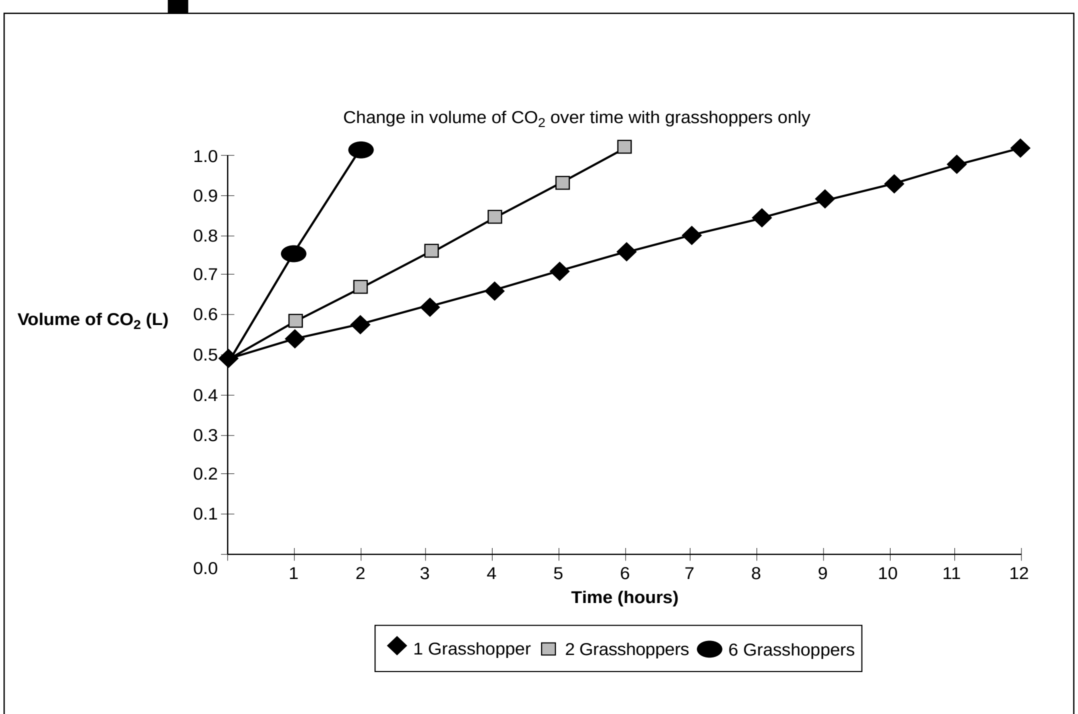
SAMPLE DATA ANALYSIS AND INTERPRETATION

Sample Data

Students should graph change in volume of O_2 and CO_2 inside Biosphere 3 over 12 hours. Each group will model a different number of grasshoppers to produce an array of graphs to show class predictions. See Graphs C and D.



Graph C. Change in Biosphere O_2 volume over time with grasshoppers only.



Graph D. Change in Biosphere CO_2 volume over time with grasshoppers only.

TEST QUESTIONS

1. Based on starting assumptions, what changes occurred over the 12-hour period in Biosphere 3?
2. What was the effect on the grasshoppers?
3. What variables have been excluded from the model that might really be important?
4. Why does the volume of carbon dioxide rise and the volume of oxygen fall in Biosphere 3?
5. What happens to the rate of oxygen used as the number of grasshoppers is increased?

STUDENT DESIGN OF THE NEXT EXPERIMENT

Class discussion about the results of the Core Experiment should lead to student questions for developing additional mathematical models for Biosphere 3. Possible questions include:

- What happens if both grasshoppers and plants are in Biosphere 3 at the same time?
- How will respiration rates be affected in Biosphere 3 if the temperature increases?
- What effect will changing periods of light have on photosynthesis?
- Will plants consume the same volume of CO_2 daily as they produce?
- Will the rate of CO_2 production on a per gram body weight basis for a grasshopper be greater than that of a bean plant?

SUGGESTED MODIFICATIONS FOR STUDENTS WHO ARE EXCEPTIONAL

These are possible ways to modify this specific activity for students who have special needs, if they have not already developed their own adaptations. General suggestions for modification of activities for students with disabilities are found in the AAAS *Barrier-Free in Brief* publications. Refer to p.15 of the introduction of this book for information on ordering FREE copies of these publications. Some of these booklets have addresses of agencies that can provide information about obtaining assistive technology, such as Assistive Listening Devices (ALDs); light probes; and talking thermometers, calculators, and clocks.

Blind or Visually Impaired

This experiment is too detailed to have some exceptional students rely on laboratory partners to explain the setup and communicate observations. The teacher should request the experiment be brailled well in advance of the time it will be used in the classroom. The material in the Teacher Background Content Information should be included.

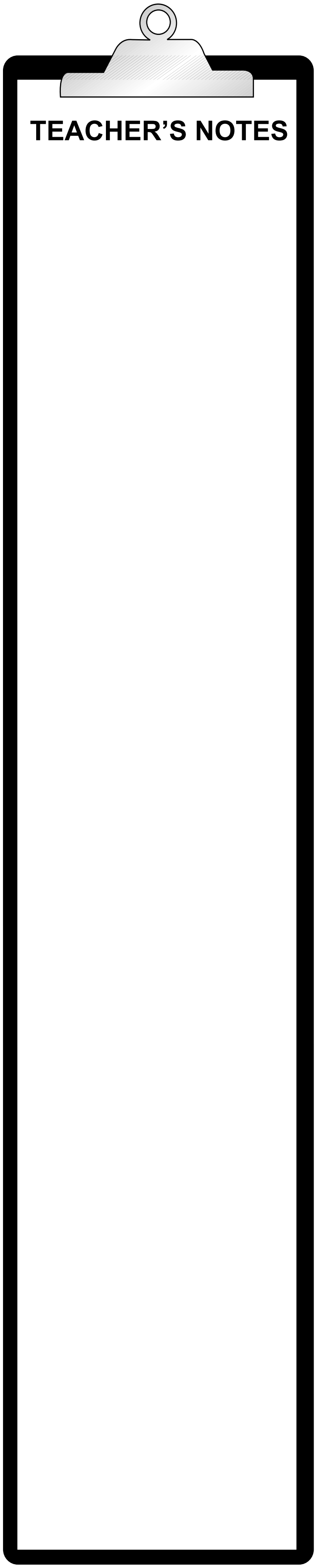
- Have the student use a computer with graphing capabilities. If one is not available, braille graph paper can be used. If braille graph paper is unavailable, students can make it on their braille writing machine.
- Have students devise their own braille symbols for the long words in the equations.
- Provide die that are large enough to have dots which can be discerned by touch for toss of die.
- Provide print enlargers with a large viewing screen for students who are visually impaired but do not read braille. They could make or purchase large size graph paper or use braille graph paper.
- Construct graphs for the entire class that can be viewed by sight or by touch using a 4-foot square of Pegboard™. Golf tees may be notched with a different shape for each data point. The data points may be connected with string, yarn, ribbon, or cord of various colors and textures.

Answers to Test Questions

1. When 1 grasshopper was sealed inside Biosphere 3, CO_2 volume increased, doubling in 12 hours. O_2 was depleted at the end of 12 hours.
2. At the end of 12 hours, the grasshopper has no O_2 for respiration and it can be predicted that it will die.
3. The needs of the grasshoppers for food and water were ignored. Lack of water, especially, might be important in determining whether the grasshoppers will survive.
4. The volume of carbon dioxide rises and the volume of oxygen falls in Biosphere 3 as a result of cellular respiration by the grasshoppers.
5. As the number of grasshoppers is increased, the rates of carbon dioxide production and oxygen use both increase.

Answers to Questions and Analysis on Student Page

1. A possible conclusion is that models can predict changes in systems.
2. Answers will vary with student models.
3. A computer program that will predict the weather or model global warming will have to consider a multitude of variables and interactions.
4. Changes in temperature would affect respiration rates.
5. Answers will vary with the software used for comparison. Overall, students should come to the conclusion that larger quantities of data and more complex systems may be studied more easily with computer models.



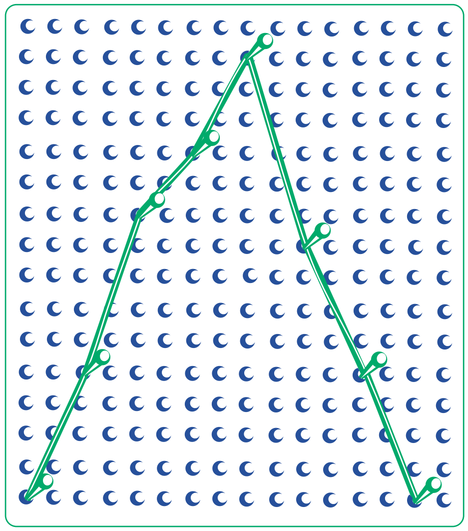


Figure 2. Pegboard™ graph for class use.

Deaf or Hard-of-Hearing

- This experiment presents no new problems. There will be considerable discussion necessary so communication skills are necessary. When there is a large amount of material to be covered in lecture or in question and answer, a signer may be helpful for deaf students if they so desire.

Gifted

- Perform statistical analyses of results.

Mobility Impaired

- Students with manual impairments will need assistance from their instructor and laboratory partners in performing this experiment. Their laboratory group might use the Pegboard™ graph.
- Provide access to tape recorders for students to record the teacher's directions, student discussion, and laboratory partner's comments.

REFERENCES AND SUGGESTED READINGS

Berry, J. (1997, November). A new life for Biosphere 2. *Spectra*, 7.

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Closed systems. (1998). Biospherics. *www.biospherics.org/closedsys.html*.

Frequently asked questions (FAQ). (1998). Columbia University's Biosphere 2 Center. Columbia University's Earth Institute: *http://www.bio2.edu/working/home_faq.htm*.

Gentry, L. (1992). Creating artificial worlds. *Biosphere 2 Newsletter*, *2*(3), 16-18.

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POSSIBLE SOURCES OF MENTORS

- Local college or university statistics or computer modeling professor
- Local research or industry that uses mathematical models

VARIATIONS OF THE CORE EXPERIMENT

After completing the Core Experiment, students should use the results to develop a variation of the experiment. The following directions are intended only as a guide for the teacher. They suggest possible hypotheses students may develop and data that may result.

Note to Teachers: Only information that is unique to each Variation of the Core Experiment is found in this section. Unless otherwise noted, teacher information not listed for each variation is the same as that found in the Core Experiment. Materials listed in this section are needed in addition to the materials listed for the Core Experiment.

VARIATION 1
A Plant Kingdom—All Bean Plants, No Grasshoppers

SYNOPSIS

Students will develop a mathematical model of the relationship between plants and oxygen supply in a closed system.

HYPOTHESIS GENERATION

Question

What is the relationship between oxygen supply in a closed system and the survival of plants?

Sample Hypothesis for Equation Model

If plants consume 0.5 L O_2/g/day and produce 0.7 L O_2/g/day, then the volume of O_2 in Biosphere 3 at any time "*t*" can be determined mathematically.

Sample Experimental Procedure

1. Write an equation that describes how oxygen volume is related to time and to numbers of plants. A possible equation is:

Oxygen volume in Biosphere 3 = Starting volume - Oxygen used + Oxygen produced where

$$O_2 \text{ used} = \frac{0.5\text{ L}}{\text{gram/day}} \bullet \frac{\#\text{ grams}}{\text{plant}} \bullet \#\text{ plants} \bullet \#\text{ hours} \bullet \frac{1\text{ day}}{24\text{ hours}}$$

and

$$O_2 \text{ produced} = \frac{0.7\text{ L}}{\text{gram/day}} \bullet \frac{\#\text{ grams}}{\text{plant}} \bullet \#\text{ plants} \bullet \#\text{ hours} \bullet \frac{1\text{ day}}{24\text{ hours}}$$

Since more O_2 is produced than is used by each plant, combining the O_2 used and the O_2 produced gives

$$O_2 \text{ volume} = 1\text{ L} + \frac{0.2\text{ L}}{\text{gram/day}} \bullet \frac{\#\text{ grams}}{\text{plant}} \bullet \#\text{ plants} \bullet \#\text{ hours} \bullet \frac{1\text{ day}}{24\text{ hours}}$$

which represents an increasing volume of O_2 over time.

TEACHER'S NOTES

VARIATION 1

TEACHER'S NOTES

If all plants are 10 grams, this model reduces to

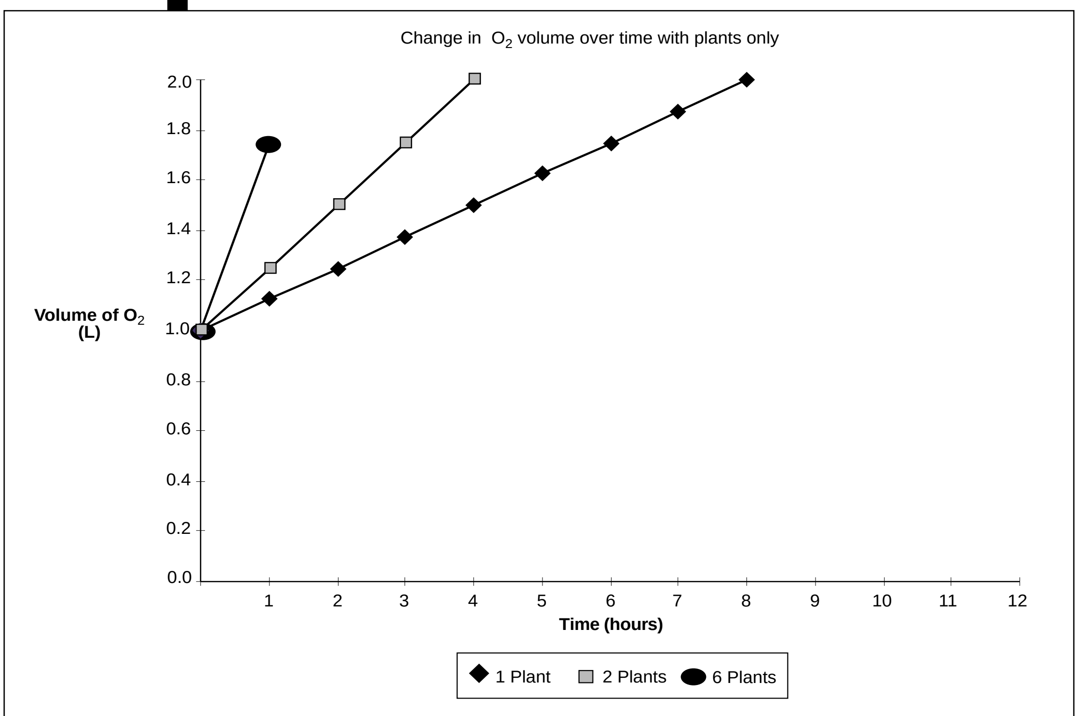
$$O_2 \text{ volume} = 1\text{ L} + 0.2\text{ L} \bullet 10 \bullet \#\text{ plants} \bullet \frac{\#\text{ hours}}{24\text{ hours}}$$

2. Roll the die to determine how many bean plants your group will seal inside Biosphere 3.
3. Use the equation to determine the change in O_2 volume at 1 hour intervals for the number of plants sealed in Biosphere 3.
4. Record your results in a chart.
5. Write a second equation to show what happens to the carbon dioxide volume.
6. Calculate mathematically what occurs to the volumes in your container during a 12-hour period based on the number of plants in your Biosphere 3.
7. Graph your mathematical conclusions for a 12-hour time period.

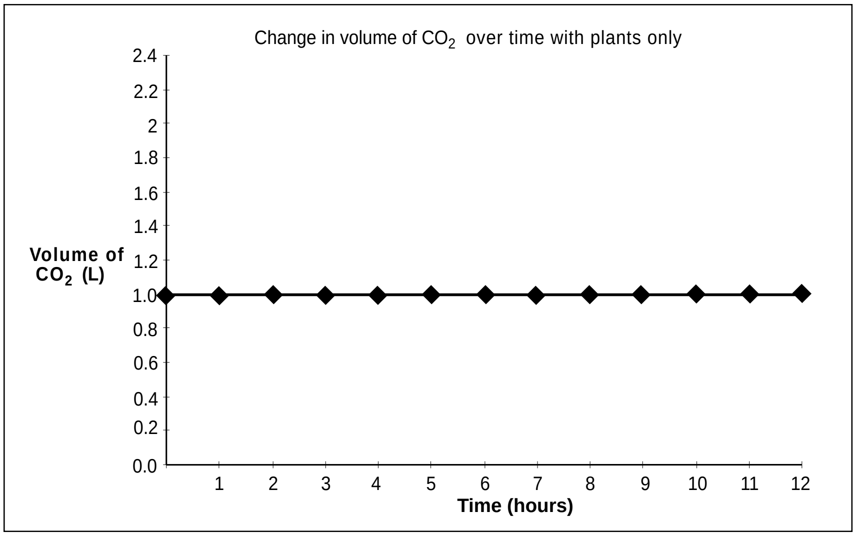
DATA ANALYSIS AND INTERPRETATION

Sample Data

Students should graph change in the volumes of O_2 and CO_2 inside Biosphere 3 over 12 hours. Each group will model a different number of bean plants to produce a range of class predictions. See Graphs E and F.



Graph E. Change in O_2 volume over time with plants only.



Graph F. Change in CO_2 volume over time with plants only.

TEST QUESTIONS

1. Based on starting assumptions, what changes occur inside Biosphere 3 over 12 hours?
2. What was the effect on the bean plants?
3. Is carbon a limiting factor?
4. Why is it necessary to make so many assumptions? Why is it necessary to make Biosphere 3 as simple as it is?

VARIATION 2
An Animal and Plant Kingdom

SYNOPSIS

Both grasshoppers and bean plants are sealed in Biosphere 3 with the assumption that the grasshoppers do not consume the bean plants.

HYPOTHESIS GENERATION

Question

What will be the oxygen consumption when both beans and grasshoppers are sealed in Biosphere 3?

Sample Hypothesis Equation Model

If grasshoppers and bean plants are sealed inside Biosphere 3, then the equations for their oxygen consumption can be combined for a mathematical model of their combined effect. A suggested model is as follows:

O_2 Volume = Starting volume + Net oxygen from grasshoppers + Net oxygen from plants

$$+\,1\text{ L} + \left(\frac{-1\text{ L}}{\text{gram/day}} \bullet \frac{\#\text{ grams}}{\text{grasshopper}} \bullet \#\text{ grasshoppers} \bullet \#\text{ hours} \bullet \frac{1\text{ day}}{24\text{ hours}}\right)$$

$$+\left(\frac{0.2\text{ L}}{\text{gram/day}} \bullet \frac{\#\text{ grams}}{\text{plant}} \bullet \#\text{ plants} \bullet \#\text{ hours} \bullet \frac{1\text{ day}}{24\text{ hours}}\right)$$

Answers to Test Questions

1. CO_2 volume is constant, but O_2 volume increases by a factor of 0.125 L/hr.
2. Bean plants will continue to grow.
3. This should not be a factor in this model as CO_2 volume remains the same.
4. Discussion of this question should lead students to realize that even the simple Biosphere 3 model becomes complicated very quickly as variables are added.

TEACHING TIP

This model is a combination of the two models developed previously. Ask students how the two previous equations for oxygen change with grasshoppers and plants could be used to describe the change in oxygen volumes inside Biosphere 3 at any time "*t*" if both grasshoppers and bean plants are sealed inside.

TEACHER'S NOTES

and for grasshoppers of 2 grams each and bean plants of 10 grams each this model becomes

$$O_2\text{ Volume} = 1\text{ L} - \left(1\text{ L} \bullet 2 \bullet \#\text{ grasshoppers} \bullet \frac{\#\text{ hours}}{24\text{ hours}}\right) + \left(0.2\text{ L} \bullet 10 \bullet \#\text{ plants} \bullet \frac{\#\text{ hours}}{24\text{ hours}}\right)$$

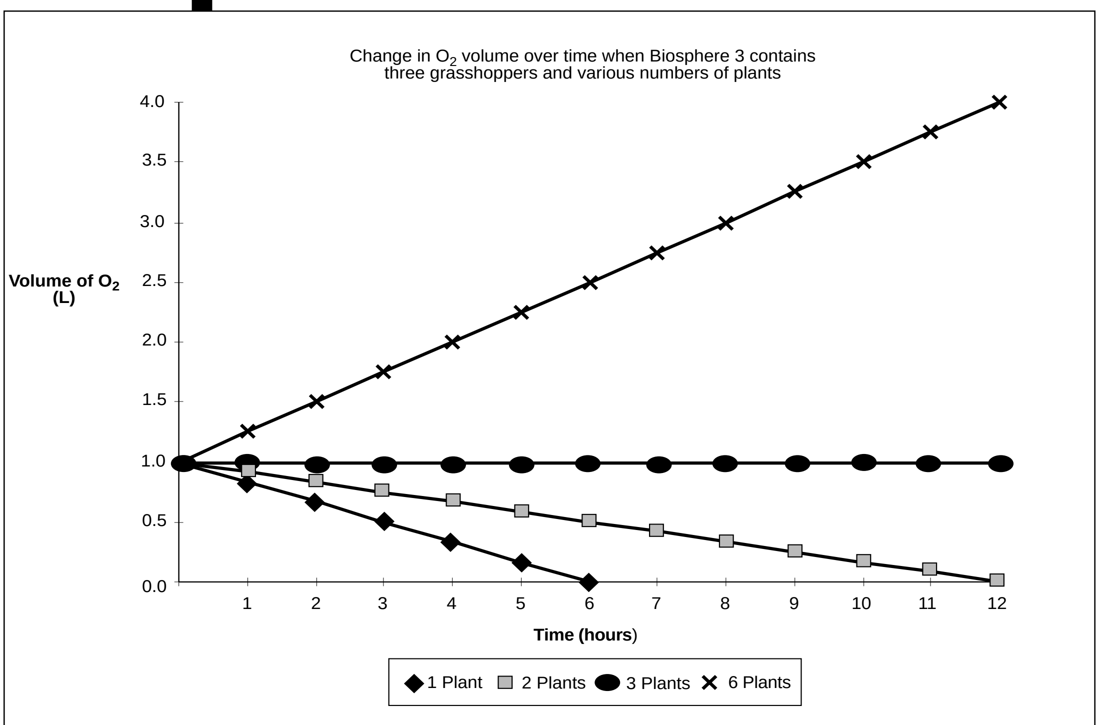
Sample Experimental Procedure

1. Write a single equation to describe the effect of both grasshoppers and bean plants on oxygen volumes inside Biosphere 3.
2. Roll the die to determine how many grasshoppers your group will seal inside Biosphere 3.
3. Roll the die again to determine how many bean plants your group will seal inside Biosphere 3.
4. Calculate mathematically what occurs with the O_2 and CO_2 volumes for a 12-hour period.
5. Graph your calculations.

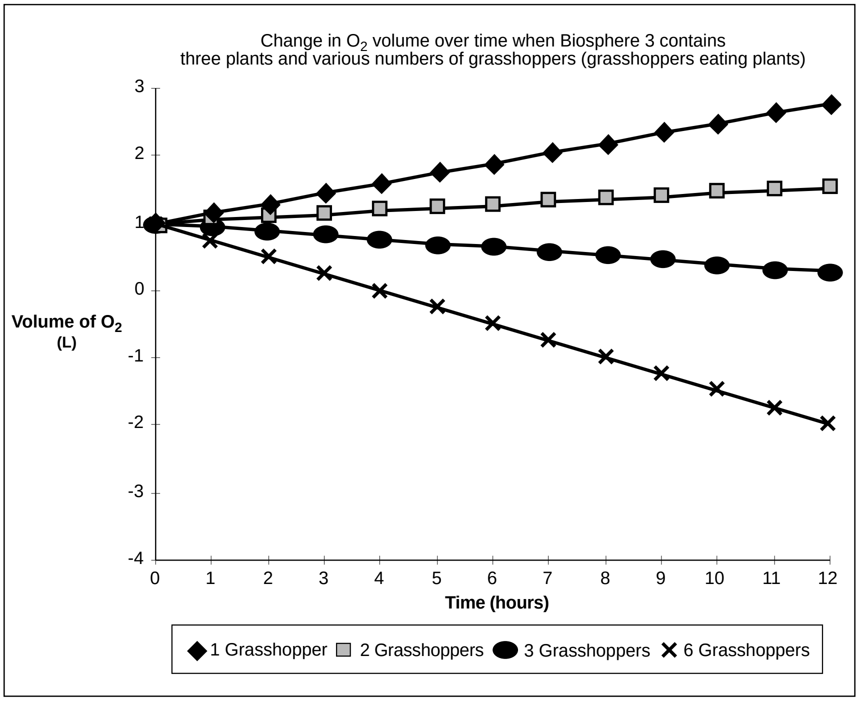
SAMPLE DATA ANALYSIS AND INTERPRETATION

Sample Data

Students might graph change in volume of O_2 inside Biosphere 3 over a 12-hour period as shown below.



Graph G. Change in O_2 volume over time with 3 grasshoppers and variable numbers of plants.



Graph H. Change in O_2 volume over time with 3 plants and variable numbers of grasshoppers.

TEST QUESTIONS

1. Based on starting assumptions, what change or changes occurred over 12 hours in Biosphere 3?
2. What effect was there on the grasshoppers?
3. What effect was there on the bean plants?
4. When there are 6 grasshoppers, does the model reflect what will really happen over 12 hours?

VARIATION 3
Another Look at the Animal and Plant Kingdom

SYNOPSIS

Both grasshoppers and bean plants are sealed in Biosphere 3, with the assumption that the grasshoppers do eat the bean plants.

ADDITIONAL INSTRUCTIONAL PROCEDURES

This variation requires the following additional assumptions:

- Each grasshopper grows at a rate of +0.1 g/day.
- Bean plants grow at a rate of +0.1 g/day.
- Grasshoppers eat 2 g plant tissue/day/grasshopper.

HYPOTHESIS GENERATION

Question

What will be the oxygen consumption when both beans and grasshoppers are sealed in Biosphere 3 and grasshoppers can eat plants?

Sample Hypothesis Equation Model

If grasshoppers and bean plants are sealed inside Biosphere 3 with the grasshoppers

Answers to Test Questions

1. Only when bean plants equal or outnumber grasshoppers does O_2 remain constant or rise in Biosphere 3.
2. Whenever grasshoppers outnumber plants, oxygen is depleted in Biosphere 3.
3. Since plants require oxygen too, low levels will harm them also.
4. No, since after 4 hours, all the oxygen will be gone. The graph beyond 4 hours is incorrect. All plants and grasshoppers will die when all oxygen is depleted. Oxygen levels cannot be negative in reality even if our mathematical model says they can be.

TEACHING TIPS

- Approach to modeling—The same strategy used earlier to develop a model is applied again. Each term in the model that follows describes one of the effects on oxygen volume, such as the change in oxygen volume inside Biosphere 3 at any time "*t*" where P represents plants and G represents grasshoppers.

TEACHER'S NOTES

eating the plants, then the equations for their oxygen consumption can be combined for a mathematical model of their combined effect. A suggested model where P = # plants and G = # grasshoppers is as follows:

1 L O_2 + [P • 10 g/plant • (0.7 L O_2 - 0.5 L O_2)/g • *t* hours/24 hours] - [G • 2g/grasshopper • 1 L O_2/g • *t* hours/24 hours] - [G • 2 g/grasshopper • (0.7 L O_2 - 0.5 L O_2) /g • *t* hours/24 hours] - [G • 0.1 g • 1 L O_2/g • *t* hours/24 hours] + [P • 0.1 g • (0.7 L O_2 - 0.5 L O_2)/g • *t* hours/24 hours]

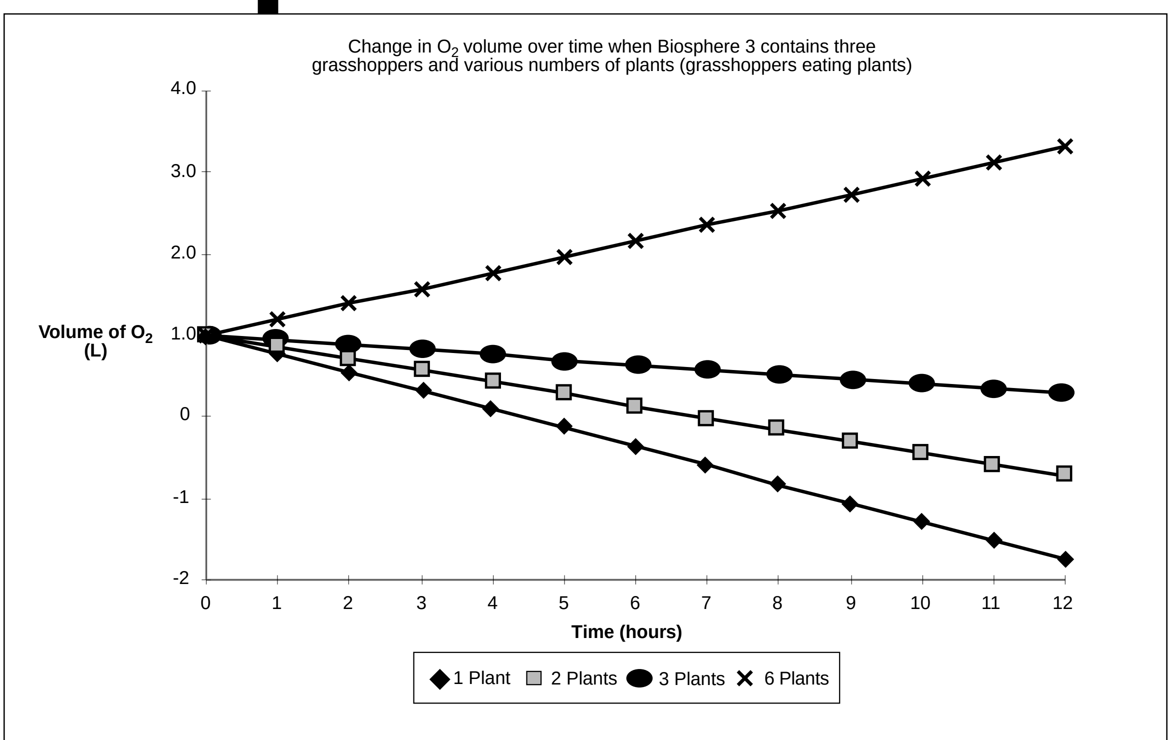
Sample Experimental Procedure

1. Write an equation that describes the effect on oxygen volume of all of the following: a) the presence of plants, b) the presence of grasshoppers, c) animals eating plants, d) animals growing—thus consuming more oxygen, e) plants growing—thus producing more oxygen.
2. Roll the die to determine how many grasshoppers your group will seal inside Biosphere 3.
3. Roll the die again to determine how many bean plants your group will seal inside Biosphere 3.
4. Calculate mathematically what occurs with the O_2 and CO_2 concentrations for a 12-hour period.
5. Graph your calculations.

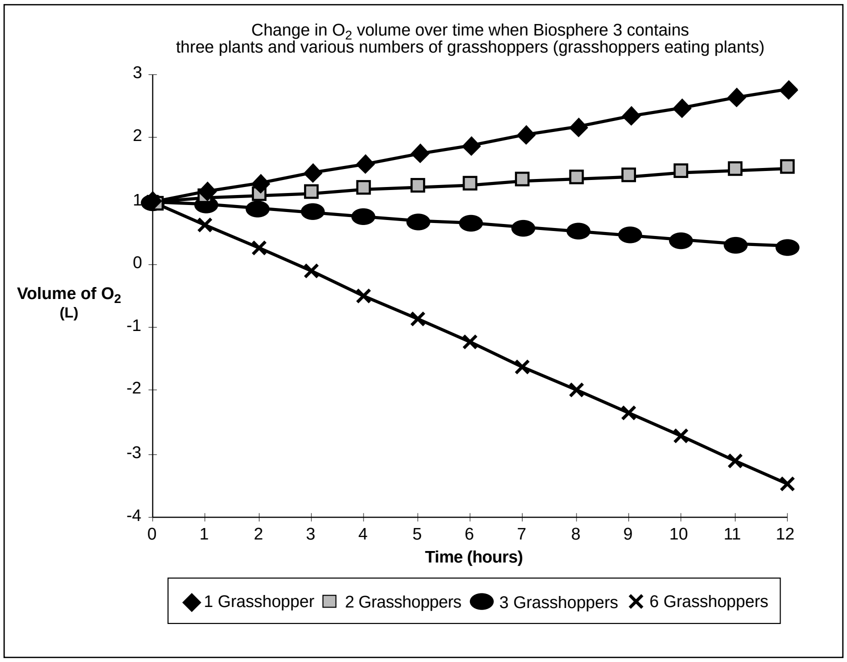
SAMPLE DATA ANALYSIS AND INTERPRETATION

Sample Data

Students should graph change in the volume of O_2 inside Biosphere 3 over a 12-hour period (see Graphs I and J).



Graph I. Change in O_2 volume over time with 3 grasshoppers eating plants and a variable number of plants.



Graph J. Change in O_2 volume over time with 3 plants and a variable number of grasshoppers eating plants.

TEST QUESTION

Based on starting assumptions, what will change inside over time?

Answer to Test Question

Oxygen will be depleted unless the plants outnumber the grasshoppers. When all oxygen is depleted, all plants and grasshoppers will die. Thus, the Graphs I and J do not reflect reality when the volume of oxygen goes below 0.

Biosphere 3 — It's a Small World After All

Directions for Students

INTRODUCTION

Our biosphere consists of many systems that interact with each other. Among the factors that determine what kinds of organisms can survive in a particular place are temperature, rainfall, and light.

All life forms are connected with each other and interact with the non-living or abiotic environment. Photosynthetic bacteria and plants contribute oxygen to the atmosphere and remove carbon dioxide; transforming energy from the sun, they lock it into organic compounds. Animals gain energy by feeding on plants and each other. Together, biotic and abiotic components make up an ecosystem, where nutrients, water, oxygen, carbon, and nitrogen are constantly being recycled.

Change occurs in ecosystems when organisms modify their environment, both over the short and long term. In this experiment, you will develop a mathematical model of an ecosystem and predict CO_2 and O_2 concentrations and the effects of their change on plant or animal populations. Models are useful tools for biology in general and for ecology in particular. Systems as complicated as biospheres are difficult to study without the help of simplified models or simulations.

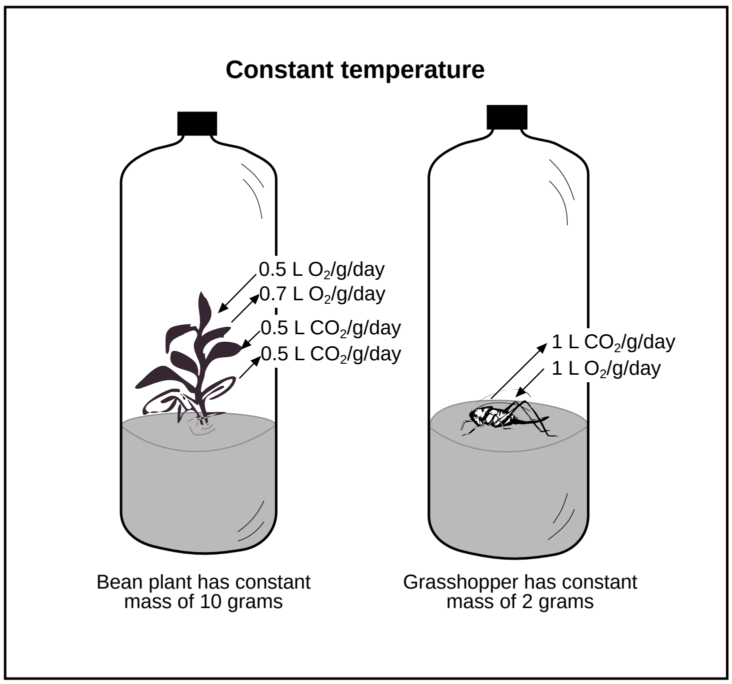


Figure 1. Biosphere 3.

OBJECTIVES

At the end of this lab, you should be able to:

- Develop a simple mathematical model that investigates the complicated processes and systems of an artificial ecosystem.
- Describe the role each biotic and abiotic variable plays within the ecosystem.
- Observe, record, and interpret how different components of the ecosystem change as they interact with each other and the environment.
- Discuss how models are used to investigate complicated processes and systems.
- Discuss the difficulties of controlling all variables in a complicated system.

STUDENT LITERATURE SEARCH SUMMARY WITH REFERENCES

Do a literature search on the topic of potential nutritional mutants. Summarize your findings and cite your references. Your teacher may be able to suggest some references.

MATERIALS NEEDED

You will need the following for each group of two students in a class of 24:

- 4 sheets of graph paper
- 1 calculator
- 1 number cube or die
- 1 or more class "closed bottle" systems (*optional*)

HYPOTHESIS GENERATION

From the information you have on this topic, develop a hypothesis that could be tested by a mathematical model which generates quantitative data. Explain the reasoning behind your hypothesis.

Answer the following questions:

1. What is the question you are investigating?
2. How are variables controlled in your experiment?
3. What assumptions are built into your model?
4. How do you know whether your assumptions are good ones?

PLAN OF INVESTIGATION

Below, write the equation for the mathematical model you will use in your experiment. Briefly describe what it means. Use your model to generate data that will test your hypothesis. Analyze your data and discuss the results with the class.

You must have your teacher approve this protocol before you begin the experiment.

QUESTIONS AND ANALYSIS

Once you have collected and analyzed your data and graphed your results, answer the following questions:

1. What conclusions can you reach about your hypothesis?
2. How do the predictions made by your model apply to the real world?
3. Judging from how complicated the Biosphere 3 model becomes when just a few variables are included, comment on the difficulties of writing a computer program that will predict the weather or model global warming.
4. Predict the effect of temperature change in Biosphere 3 on respiration rates.
5. Compare software such as *BioBlast*™ to mathematical models developed in this activity.

DESIGN OF VARIATIONS OF CORE EXPERIMENT

After collecting and analyzing the data from the Core Experiment and sharing the results and conclusions with the class, brainstorm ideas for models that you could do next. Think of questions that occurred to you as you conducted the Core Experiment. Questions other students have studied include the following:

- What is the relationship between oxygen supply in a closed system and the survival of plants?
- What will be the oxygen consumption when both beans and grasshoppers are sealed in Biosphere 3?
- What will be the oxygen consumption when both beans and grasshoppers are sealed in Biosphere 3 and grasshoppers can eat plants?