CELL SIZE

Background

Virtually every biology student has heard the following statements from his or her teacher, “The cell is the basic unit of all life,” and “A cell’s structure is related to its function.” Both statements are absolutely true and fundamental to understanding biology.

One of the most interesting things about cells is their size. Why are cells so small? How can cells accomplish so many metabolic functions within such a small space? The answers to these questions boil down to two fundamental concepts: (1) Biological membranes regulate traffic into and out of a cell and compartmentalize cellular activities and (2) the ability of a cell to procure nutrients, eliminate wastes, and perform metabolic processes at a sufficient rate is governed by a cell’s surface area (its membrane) relative to its volume (the cytosol enclosed by the membrane). In fact, the SA:V ratio is so fundamental to survival that sizes, shapes, and structures that maximize this ratio are exhibited within all biological systems, from the sub-cellular level to the whole organism. It is a factor that drives adaptations as diverse as the size and shape of a single cell and the size and body shape of animals. It is a factor that explains how the body systems in the large bodies of mammals are adapted to meet the challenge of supplying trillions of cells with their need for nutrients and oxygen.

In this activity you will use potato cubes as models for cells, and investigate how a difference in surface-area-to-volume ratio affects a cell’s interaction with its environment.

Driving Question

Do small and large cells lose heat to the environment at the same rate?

Materials and Equipment

Use the following materials to complete the initial investigation. For conducting an experiment of your own design, check with your teacher to see what materials and equipment are available.

- Data collection system
- PASCO Quad Temperature Sensor
- Fast-response temperature probes (3)
- Metric ruler
- Small knife or scalpel
- Cutting board or other appropriate surface
- Potato
- Plastic containers (for ice water), 24 oz or larger (approximately 700 mL)
- Water, about 500 mL
- Toothpicks (2)
- Permanent marker
- Tape
- Ice, about 100 mL

Safety

Follow these important safety precautions in addition to your regular classroom procedures:

- Wear safety goggles at all times.
- Never eat any materials used in lab activities.
- Use extreme caution when cutting with a knife or scalpel and always cut in a direction away from your body.

Initial Investigation

Complete the following investigation before designing and conducting your own experiment. Record all observations, data, explanations, and answers in your lab notebook.

1. Put on your safety goggles.

2. Connect the Quad Temperature Sensor to your data collection system. Connect three fast-response temperature probes to the temperature sensor.

3. Build graph displays for each temperature sensor. If your data collection system allows you to set an automatic stop condition, set the stop time for two minutes.

   NOTE: During data collection and analysis, make sure you know which temperature probe is associated with each condition: ice bath, large cube, small cube.

4. Set up an ice bath: Half fill a plastic container with water and add two large handfuls of ice to the water.

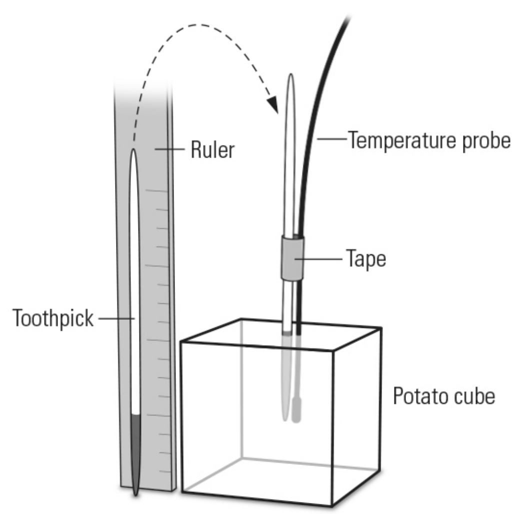
5. Cut small and large potato cubes from a large potato. Cut the cubes from the interior of the potato so the cubes are skinless. One cube should measure approximately 1 cm × 1 cm × 1 cm and the other should measure approximately 2 cm × 2 cm × 2 cm. Copy Table 1 into your lab notebook and record the actual dimensions of the cube in the table.

Table 1: Measurements for the potato cube “model cells”

Potato Cube	Approximate Dimensions *l, w, h* (cm)	Actual Dimensions *l, w, h* (cm)	Surface Area (cm^2)	Volume (cm^3)	SA:V Ratio
Small	1 × 1 × 1	RECORD ANSWERS & DATA IN YOUR NOTEBOOK.			
Large	2 × 2 × 2				

6. Calculate the surface area, volume, and surface-area-to-volume (SA:V) ratio for each cube. Record these values in Table 1. Which has a greater SA:V ratio, a large cube or a small cube?

7. Insert a temperature probe into the center of each cube, as follows:



   a. Place a toothpick against a ruler and use a permanent marker to darken the wood of the toothpick from the tip of the toothpick to a height of 1 cm.

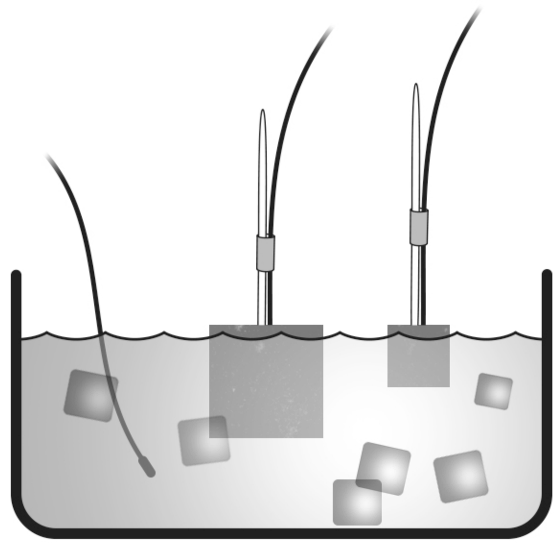
   b. Insert the dark end of the toothpick in the middle of the top surface of the large cube. Gently push the toothpick into the potato just until the black part of the toothpick is no longer showing.

   c. Remove the toothpick and insert a temperature probe into the hole. Reinsert the toothpick into the hole and use tape to secure the wire of the probe to the toothpick.

   d. Repeat the process for the small cube, except darken only 0.5 cm of the toothpick before inserting it into the cube.

8. Place the third temperature probe into the ice bath.

9. Immerse the cubes in the ice water bath but avoid submerging the cubes completely. It is important that water does *not* get into the hole with the temperature sensor. Use the toothpicks to hold the cubes; try to hold the cubes still in the water. Begin recording data.



10. After 2 minutes, end data collection and remove the cubes from the ice bath. Draw or print a record of the temperature data.

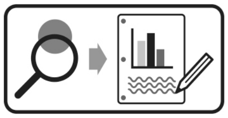
❓ 11. What is the relationship between the cooling rate and the SA:V ratio? Use evidence from the investigation to support your claim.

❓ 12. Cells produce wastes that need to be excreted. Do the results of this investigation suggest that cell size impacts the ability of a cell to excrete wastes? Explain your answer.

❓ 13. The potato cubes are intended to be models for cells; however, cells are rarely cuboidal in shape. Do you think the shape of a cell affects the cell's ability to efficiently exchange substances or heat with its environment? Explain the reasoning for your answer.

Design and Conduct an Experiment

Consider variables, in addition to size, that might affect the SA:V ratio of a cell, structure, or body plan of an organism. Design potato models that vary in one of these variables and determine if the cooling rate is affected by the chosen variable.



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

Design and Conduct an Experiment: Data Analysis

1. From your observations and your data:

   a. Describe how the independent variable you manipulated affected the cooling rate of the "cells." Does the data support your hypothesis? Justify your claim with evidence from your experiment.

   b. Based on the evidence you collected, explain why the results occurred.

2. Is there any evidence in your data or from your observations that experimental error or other uncontrolled variables affected your results? If yes, is the data reliable enough to determine if your hypothesis was supported?

3. Identify any new questions that have arisen as a result of your research.

Synthesis Questions

1. The following table provides the radii of five spheres.

Table 2: Surface-area-to-volume ratios of different sized spheres

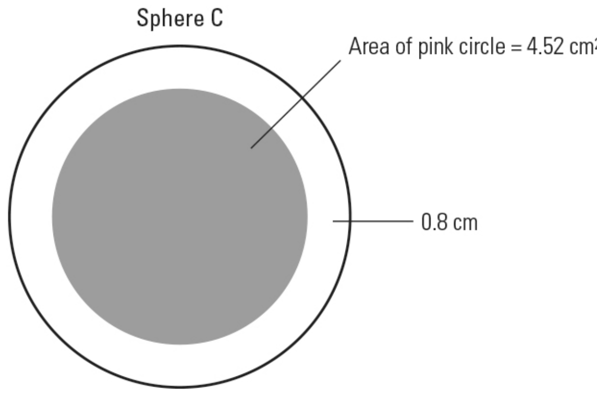
Sphere	Radius (cm)	Surface Area (cm^2)	Volume (cm^3)	SA:V Ratio
A	0.5 cm			
B	1 cm			
C	2 cm			
D	4 cm			
E	8 cm			

RECORD ANSWERS & DATA IN YOUR NOTEBOOK.

   a. Calculate the surface-area-to-volume ratio for each sphere. Then create an appropriately labeled graph to illustrate the relationship between the SA:V ratio and sphere size.

b. A student performed a diffusion experiment to investigate the diffusion of acid through different sized spheres made of agar (a gelatin-like solid). The agar contained an acid–base indicator that caused it to be bright pink. The indicator turns white in an acid.

When agar spheres were submerged in an acidic solution, diffusion of acid into the agar caused the color to change from pink to white. The diagram below shows the results obtained when Sphere C was soaked in a cup of vinegar for five minutes and removed. The sphere was cut in half and the student measured the depth of white and the area of pink in the cross-section of the cut sphere.



Predict the results of soaking Sphere A in vinegar for 5 minutes. Sketch a diagram to illustrate your prediction and use evidence from the graph to help explain your predication.

2. Surface-area-to-volume ratio relates not only to cells but also to the bodies of animals. Animals have adaptations that either maximize or minimize SA:V ratio.

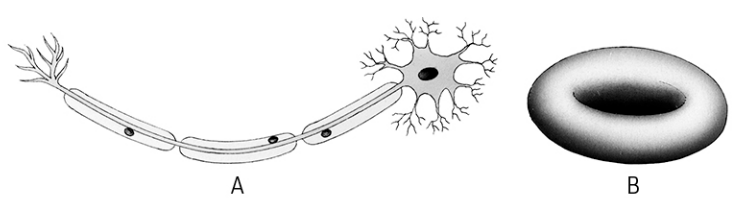
   a. The largest penguin on earth is the Emperor penguin with an average height of 1.1 m and a body mass of 27–41 kg. Emperor penguins live in the very cold climate of Antarctica. Galapagos penguins live in a much warmer climate and average 0.5 m in height, and 1.7–2.6 kg in body mass. Based on their body size and the relationship between SA:V ratio and cooling, explain why a Galapagos penguin is ill-adapted to live in the frigid weather of Antarctica.

   b. African elephants have much larger ears than Asian elephants. African elephants are adapted to the hot savannah while Asian elephants live in cool forests. Explain the advantage of larger ears in animals living in hot biomes.

3. Surface-area-to-volume ratio (SA:V) is important to living things at many levels: from the sub-cellular to the cellular to the system level.

   a. Identify one organelle present in eukaryotic cells that has a structure with a high surface-area-to-volume ratio and explain how the organelle's SA:V ratio facilitates the function carried out by the organelle.

   b. Identify each of the cells pictured below. For each cell, describe the cell's function and explain how the SA:V ratio of the cell relates to the efficiency of its function.

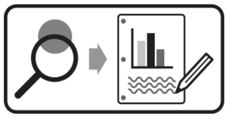


c. The respiratory, circulatory, digestive, and excretory systems of mammals all contain specialized structures that are highly branched to maximize their membrane surface area relative to their volume. Describe two examples of highly branched structures in these systems and explain how the SA:V ratio of these structures facilitates their functions.

NAME PERIOD DATE

Design and Conduct an Experiment Worksheet

Consider variables, in addition to size, that might affect the SA:V ratio of a cell, structure, or body plan of an organism. Design potato models that vary in one of these variables and determine if the cooling rate is affected by the chosen variable.



Develop and conduct your experiment using the following guide.

1. Based on your knowledge of the relationship between the SA:V ratio and cooling, what variables could affect the rate of cooling in organisms?

2. Create a driving question: choose one of the factors you've identified that can be controlled in the lab and develop a testable question for your experiment.

3. What is the justification for your question? That is, why is it biologically significant, relevant, or interesting?

4. What will be the independent variable of the experiment? Describe how this variable will be manipulated in your experiment.

5. What is the dependent variable of the experiment? Describe how the data will be collected and processed in the experiment.

6. Write a testable hypothesis (If…then…).

7. What conditions will need to be held constant in the experiment? Quantify these values where possible.

8. How many trials will be run for each experimental group? Justify your choice.

9. What will you compare or calculate? What analysis will you perform to evaluate your results and hypothesis?

10. Describe at least 3 potential sources of error that could affect the accuracy or reliability of data.

11. Use the space below to create an outline of the experiment. In your lab notebook, write the steps for the procedure of the lab. (Another student or group should be able to repeat the procedure and obtain similar results.)

12. Have your teacher approve your answers to these questions and your plan before beginning the experiment.