The Ratio of Surface Area to Volume

Strand Life at the Molecular and Cellular Level

Topic Investigating the structure and function of cell membrane

Primary SOL BIO.3 The student will investigate and understand relationships between cell structure and function. Key concepts include
- e) the impact of surface-area-to-volume ratio on cell division, material transport, and other life processes.

Related SOL BIO.1 The student will demonstrate an understanding of scientific reasoning, logic, and the nature of science by planning and conducting investigations in which
- e) conclusions are formed based on recorded quantitative and qualitative data;
- f) sources of error inherent in experimental design are identified and discussed;
- g) validity of data is determined;
- h) chemicals and equipment are used in a safe manner.

BIO.4 The student will investigate and understand life functions of Archaea, Bacteria, and Eukarya. Key concepts include
- b) maintenance of homeostasis.

Background Information

The cell is highly organized, having many functional units or organelles. Most of these units are limited by one or more membranes. Each membrane is specialized in that it contains specific proteins and lipid components that enable it to perform its unique role(s) for that cell or organelle. Membranes are essential for the integrity and function of the cell.

Materials

- Fresh onion or a container of an odorous substance (e.g., perfume) acceptable for classroom use
- Scented oil
- Balloon
- Unflavored gelatin
- Water
- Loaf pans
- Phenolphthalein
- Knives
- Plastic cups
- 4% NaOH
- Paper towels
- Metric rulers
- Calculator (optional)

Vocabulary

phenolphthalein, surface area, validity, volume

Student/Teacher Actions (what students and teachers should be doing to facilitate learning)

This lesson is a four-part study. In Part 1, students use materials, to construct their own models of the parts of the cell membrane. In Part 2, they model a function of a semi-permeable membrane. In Part 3, they conduct experiments based on the principles of osmosis. In Part 4, they investigate the effect of surface-area-to-volume ratio on the rate of diffusion.

Prepare for this lesson by preparing gelatin as directed. While it is still a liquid, slowly add several drops of phenolphthalein. *(CAUTION: Phenolphthalein solutions are flammable, and vapors can explode when mixed with air. Make sure there are no flames or sources of ignition when conducting this experiment.)* Phenolphthalein is an acid-base indicator: it turns bright pink in the presence of a base and is clear in the presence of an acid. Allow gelatin to cool and harden in a deep dish, such as a loaf pan, so that it can be cut into cubes of different sizes.

Prior to engaging in this lesson, students should complete the lesson entitled "The Parts of an Experiment: Introduction to Inquiry and the Scientific Process" in order to gain more experience in designing experiments and writing lab reports. That lesson also includes generic differentiation strategies for general inquiry lessons.

1. Slice an onion, or open a container of an odorous substance, such as perfume, and let the fumes diffuse throughout the classroom. Next, add one drop of scented oil to the inside of a balloon before inflating it. Inflate it, pass it around the room, and ask students to smell the balloon and hypothesize why they can smell the oil even though it was placed *inside* the balloon.
2. Hold a discussion on diffusion, osmosis, and associated concepts such as kinetic energy and Brownian motion. Discuss the importance of being able to control what goes out (e.g., keeping the onion odor in one place) and what comes in (e.g., getting water into your body when you need it). This will lead to a differentiation between osmosis and diffusion. Relate the discussion to the diffusion of the fumes throughout the room. Segue into the following experiment to test the effect of cube (cell) size on the rate of diffusion.
3. Have students cut the gelatin into different size cubes—i.e., 1-cm, 2-cm, and 3-cm cubes. (This works best when students do not know why they are creating these cubes.)
4. Have students estimate or calculate the surface area, volume, and surface-area-to-volume ratio of each cube.
5. Direct students to place each cube in a plastic cup and add enough 4% NaOH to completely cover the cube. Direct them to stir *around* the cubes gently for 10 minutes, being careful not to scratch the surface of the cubes. While stirring, have them predict the results and explain their predictions.
6. After 10 min., instruct students to remove the cubes, place them on paper towels, and blot them gently with additional paper towels.
7. Instruct students to determine how close in millimeters the 4% NaOH moved to the center of each size cube, using metric rulers.

8. Have students record their observations, draw conclusions, identify sources of error, and evaluate the validity of the data collected. Guide them in relating their observations and conclusions to the functioning of their small intestines, their kidneys, or a fish's gills.
9. Discuss with students what would happen if a substance could not diffuse fast enough. Relate the concept of surface-area-to-volume ratio by asking the question, "Why does ground beef cook faster than a thick T-bone steak?"

Assessment

- **Questions**
  - Which cube showed the greatest diffusion rate over 10 minutes? Why?
  - As cells increase in size, what happens to their surface-area-to-volume ratio?
  - Write a generalized statement about the relationship between diffusion rate and cell size.
  - Is NaOH an acid or base?
- **Journal/Writing Prompts**
  - Explain how the cell membranes of some living organisms' cells could be modified to be more efficient. Consider what the pros and cons of greater movement would be.
  - Explain the importance of surface area in your small intestine and kidneys.
- **Other**
  - Provide students with 27 wooden cubes to be assembled into one large cube. Have them calculate the surface-area-to-volume ratio of the large structure as if it were one large cube (cell) instead of 27 individual cubes (cells).

Extensions and Connections (for all students)

- Have students research another structure whose function depends on its surface area.
- Have students design an experiment to illustrate the effect of surface area on diffusion, using the following materials:
  - Sandwich baggie
  - Dialysis tubing
  - Iodine
  - Cornstarch
  - Water

  Be sure students observe what occurs when iodine and starch are combined, or provide discovery time prior to their designing the experiment. This lesson can also be used to segue into the concept of semi-permeability.

Strategies for Differentiation

- Employ flexible groupings of students by grouping them according to common readiness levels, shared interests, or diverse strengths.