STRUCTURED INQUIRY: Investigating Surface Area to Volume Ratio in Cells

Introduction:
All organisms are composed of cells. The size and shape of a cell determines how well it can deliver nutrients to its interior. Since all cells and organisms depend upon the efficient delivery of gases, nutrients, and other important molecules, the relationship between a cell's surface area and its volume is an important regulating concept.

Surface area of a Cube = length x width x number of sides
Volume of a Cube = length x width x height
Ratio of Surface Area to Volume = surface area/volume

Example:
A cube 5 cm on each side:
Surface Area = 5 cm x 5 cm x 6 = 150 cm²
Volume = 5 cm x 5 cm x 5 cm = 125 cm³
Ratio = 150/125 = 1.2:1

Challenge:
Design a biological model that illustrates how the ratio of surface area to volume ratio affects the rate of diffusion into and out of living systems. The goal of your model is to support the hypothesis that cells must stop growing when they reach a certain size, and explain why virtually all cells are about the same size, and finally, how the ratio of surface area to volume affects the way organisms have adapted to their environments!

Materials List:
3 Phenolphthalein agar cubes: 3 x 3 cm, 2 x 2 cm, and 1 x 1 cm;
3 plastic spoons;
3 plastic cups;
1 metric ruler 12”;
100 mL of white vinegar (acetic acid);
1 Timer

Note to Students:
The agar cubes have been prepared with 1% phenolphthalein, which is a pH indicator. The chart below indicates a color scale of pH for phenolphthalein. The blocks are pink because the agar blocks were soaked in 0.01% sodium hydroxide (a strong base).

<table>
<thead>
<tr>
<th>Phenolphthalein Color Indicator Chart</th>
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<tbody>
<tr>
<td>Color</td>
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<tr>
<td>-------</td>
</tr>
<tr>
<td>Colorless</td>
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<tr>
<td>Pink to Red</td>
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</tbody>
</table>

→ In your Lab Notebook:
- Title and Date (2 points)
- Introduction/Background (5 points)
- Question/Hypothesis/Predictions (3 points)
Procedure
1. Obtain agar cubes in a plastic cup from your teacher. Be careful not to scratch any surface of the cubes.
2. Using the metric ruler, measure the dimensions of each agar cube and record the measurements in the table below.
3. Place the three cubes carefully in a plastic cup. Add white vinegar (acetic acid) until the cubes are submerged. Using a plastic spoon, keep the cubes submerged for 10 minutes turning them as needed.
   • Be careful not to scratch any surface of the cubes.
   • Be sure to start the timer once the cubes are submerged.
4. As the cubes soak, calculate the surface area, volume, and surface area to volume ratio for each agar cube.
5. Record this data in the table below.

→ In your Lab Notebook:
• Brief methodology including:
  o Discussion of Independent and Dependent Variables (4 points)
  o Discussion of Constant Variables (6 points)
  o Discussion of Data Collection Strategy...summarized – NOT copied (5 points)

Table 1: Surface Area and Volume of Cells

<table>
<thead>
<tr>
<th>Cube Size (length, width, height of each side in cm)</th>
<th>Surface Area (cm²)</th>
<th>Volume (cm³)</th>
<th>Surface Area/Volume Ratio (cm²:cm³ or 1:cm)</th>
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Formulas
Surface Area = length \times width \times \# \ of \ sides
Volume = length \times width \times height
Surface Area/Volume Ratio = surface area / volume
Extent of Diffusion = \frac{(\text{total cube volume} - \text{volume of cube that has not changed color}) \times 100}{\text{total cube volume}}
6. After 10 minutes has elapsed, use the spoon to remove the agar cubes and carefully blot them on dry paper towel. **DO NOT CUT THE AGAR CUBES UNLESS EXPLICITLY TOLD TO DO SO BY YOUR TEACHER.**

7. Using a metric ruler, measure the distance in centimeters (cm) that the white vinegar diffused into each cube (see Figure below). Record this as the distance from the surface in the table below.

   For each cube, measure the penetration of vinegar into the agar (distance in cm from edge of white edge of cube to edge of pink in the cube).

8. Calculate the rate of diffusion for each cube in centimeters per minute (cm/min). Record your calculations in the table below.

9. Calculate the volume of the portion of each cube which has not changed color (in other words, the portion of the cube that is still pink). Record your calculations in the table below.

10. Calculate the extent of diffusion into each cube as a percent of the total volume. Record your calculations in the table below.

11. Graph the rate of diffusion (cm/min, Y-axis) relative to the surface area to cell volume ratio (1/cm, X-axis).

12. Graph the extent of diffusion (Y-axis) relative to cell volume and surface area (X-axis).

**In your Lab Notebook:**
- Results including:
  - Data Tables 1 and 2 (2 points)
  - Graphs for Rate of Diffusion and Extent of Diffusion (10 points)
  - Interpretation of Graphs for Rate of Diffusion and Extent of Diffusion (3 points)
Table 2: Rate & Extent of Diffusion

**Show All Calculations**

<table>
<thead>
<tr>
<th>Cube Size (length, width, and height of each side in cm)</th>
<th>Total Volume of Cube (cm³)</th>
<th>Distance from Surface (cm)</th>
<th>Rate of Diffusion (cm/min)</th>
<th>Volume of Undiffused Area (Still Pink) (subtract distance from surface – both sides from length of 1 side to get 2. Now cube this number to get area of pink)</th>
<th>Volume of Diffused Area (White Area) (subtract volume still pink from total volume of cube)</th>
<th>Extent of Diffusion (divide volume of white area by total volume of cube and multiply by 100)</th>
</tr>
</thead>
</table>
Graph: Rate of Diffusion

Graph: Extent of Diffusion
Analysis of Results:
1. Compare your calculations of surface area and volume (Data Table 1). Discuss the changes in the surface area to volume ratio as the potato blocks get larger.
2. How does the ratio of surface area to volume explain the efficiency of cells?
3. Examine your data (Data Table 2). What dimensions supported the fastest rate of diffusion? Why?
4. What dimensions supported the greatest diffusion percent total volume (Data Table 2)? Why?
5. Compare the rate of diffusion for each cell size to the extent of diffusion for each cell size (Graphs 1 and 2). Discuss the significance of the data.

→ In your Lab Notebook:
- Analysis Including:
  - Write out or summarize questions #1-5 for Analysis of Results (5 points; 1 point each)
  - Completely and thoroughly answer each question (15 points; 3 points each)

Conclusions - Biological Connections:
1. The size of some human cells is 0.01mm. Using the formulas in this activity, calculate the surface to volume ratio of such a cell (assume 0.01 mm cube). Describe the extent of diffusion into this living cells as compared to the smallest agar cube. Explain.
2. Using what you observed, explain why cells stop growing when they reach a certain size and why all cells are about the same size?
3. What prediction can you make about the efficiency of a very small cell in: getting oxygen, getting rid of wastes, keeping water in a dry environment, keeping heat in a cold environment?
4. What prediction can you make about the efficiency of a very large cell in: getting oxygen, getting rid of wastes, keeping water in a dry environment, keeping heat in a cold environment?
5. Compare the appearance of a rabbit that lives in a desert and a rabbit that lives in the arctic. Explain their appearances using the ratio of surface area to volume.
6. What are some modifications that animals have evolved to increase their surface area for food absorption, exchange of gases, or getting rid of wastes?
7. Compare the ear shape and size of an African and Indian elephant. What advantages does each have to the respective animal?
8. In many science fiction movies and books, a misguided scientist is determined to use a device to enlarge an organism to gigantic proportions. Use what you know about the surface area to volume ratio to explain the biological impossibility of such a scenario.

→ In your Lab Notebook:
- Conclusion Including:
  - Write out or summarize questions #1-8 for Biological Connections (4 points; .5 points each)
  - Completely and thoroughly answer each question (26 points; 3.25 points each)
INQUIRY – Taking Your Ideas Further:
Regardless of cell size, external factors may affect the rate of diffusion into and out of cells. Choose a variable from the list below. Using the concepts examined in the structured portion of this lab, design an experiment to test the effect of this variable on the rate of diffusion into or out of the cell.

Factors that Affect the Rate of Cellular Transport:
- Temperature
- Size of Particles
- Diffusion Medium (solid/liquid/gas)
- Molecule Charge

In your Lab Notebook:
- Experimental Design Including:
  o clearly stated question or problem and biologically supported hypothesis (1 point)
  o clearly described independent and dependent variables (1 point)
  o clearly described control group and how it is used to show comparison (1 point)
  o clearly described constant variables (at least 3) with proper discussion (1 point)
  o clearly described sample size (1 point)
  o clearly described methodology that uses QUANTITATIVE terminology and technique (1 point)
  o clearly described # of trials repeated with proper discussion (1 point)
  o clearly described time limit per trial (1 point)
  o clearly described mathematical or statistical approach to determine validity of results (1 point)
  o clearly described expected results including a graph of expected outcome (1 point)