Double Trouble

Student Activity

Method:
In Part One, students observe the exponential growth of yeast cultures by filling a plastic bottle with yeast, sugar, and water, attaching a balloon to the top of the bottle, and watching the balloon inflate with CO₂. In Part Two, students observe the exponential growth of yeast cultures under a microscope and collect data for a graph that will show growth over a period of time. In Part Three, students will conclude by drawing parallels between observed yeast growth and human population growth.

Introduction:
When modeling exponential growth in the science classroom, it is useful to use living organisms whose growth can be easily measured. This activity uses yeast cultures to investigate geometric and logistic population growth. A plastic bottle will represent a warm, healthy environment for yeast to grow with plenty of resources. As the yeast consumes the sugar, it uses the energy to reproduce through division. The by-products of this division process are alcohol and carbon dioxide (CO₂). When contained within a balloon-capped bottle, the CO₂ will fill the balloon and within two hours, all sugar will be digested and the balloon will reach its peak diameter. The rate at which the balloon inflates is proportional to the growth rate of the yeast colony. The yeast will continue to grow as long as there is an ample supply of nutrients. When the balloon begins to deflate or remains constant, this is a sign that the yeast colony has used all available nutrients, and that the alcohol produced as waste by the yeast has actually become toxic to them, causing the population to decrease in size.

If a population increases exponentially, with no limits on resources, the graph depicting this growth would look like a J-curve (also called a geometric curve). The growth rate of the population accelerates and there are no restrictions. Every environment has a carrying capacity, however, which eventually restricts the growth rate of the population. The carrying capacity in the bottle will be reached when all the sugar is gone and there is too much alcohol and CO₂ for the yeast to continue to grow. In this case, the graph will look like an S-curve (also called a logistic curve) because the line evens out and may even go back down as the growth rate slows.

Procedure:

Part One: Earth in a Bottle
*Have students bring in a plastic bottle or collect them at lunch from a recycling bin.
1. Let students know that they will be measuring the growth of a yeast colony by measuring the growth of its by-product: CO₂. They will measure the circumference of the balloon using a tape measure and marking its growth each minute. They will start to see an obvious change about 15-20 minutes after mixing the yeast and sugar. You might like to have the class predict the reproduction rate and size of the balloons.
2. Have the students mix the sugar and warm water together until the sugar is completely dissolved. Now add the yeast (using the funnel) and place the balloon over top of the bottle, making sure not to tear it. Instruct the students to gently swirl the yeast mixture for a minute.
3. Let the bottle sit and have students begin measuring the diameter of their balloons each minute (growth will be slow at first but visible).
4. Have the students graph the results of their balloon’s growth, including a final measurement of depletion. The graph should initially look like a typical J-curve but will eventually level off into an S-curve as the yeast reach their carrying capacity. Discuss with them the nature of the curve and how it displays both growth and limiting factors.

*The balloon will continue to expand for about two hours and then deflate once the resources have run dry for the yeast colony. You may want to make measurements for them at the end of the day or have an example of one bottle that you started earlier—they will see how it deflates over the class period.

Why would most populations of organisms follow the S-curve? Why don’t populations of natural organisms go out of control? Have the students identify natural factors which help control population sizes and introduce the concepts of environmental resistance and limiting factors.

Limiting factors include: climate, food and water availability, space, disease, and predators. Because these natural population stabilizers are present in so many ecosystems, most populations of organisms can not grow exponentially.

Part Two: Microscopic Colonies

Students can closely observe the process that took place in the bottle as the yeast population expanded.

1. Mix the sugar, yeast and water in a bowl.
2. Using droppers, have the students place a drop of the yeast mixture on a microscope slide and place a cover slip over it.
3. Students should put the slides under microscopes and count the amount of yeast cells that they see, recording the information.
4. Students can observe the division of yeast cells under the microscope, re-recording the population that they count or estimate every five minutes.
5. Have the students identify when the slide has reached or when it will reach its carrying capacity.

Part Three: Human J-Curve

Students can now extend the concept of exponential growth into the area of human population growth. Copy the table below onto the chalkboard. Have the students graph human population growth. This graph should stimulate discussions as to why humans do not follow the S-curve.

<table>
<thead>
<tr>
<th>Year</th>
<th>Population (in millions)</th>
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<tbody>
<tr>
<td>1 A.D.</td>
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<tr>
<td>200</td>
<td>190</td>
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<td>400</td>
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<tr>
<td>1800</td>
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</tr>
<tr>
<td>1850</td>
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</tr>
<tr>
<td>1900</td>
<td>1,625</td>
</tr>
<tr>
<td>1950</td>
<td>2,515</td>
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<tr>
<td>2000</td>
<td>6,073</td>
</tr>
<tr>
<td>2050*</td>
<td>9,587</td>
</tr>
</tbody>
</table>

*Projected


Discussion Questions:

1. How do the yeast population and human population graphs compare?

   The yeast graph looks like a S-curve and the human population graph looks like a J-curve.

2. What could the sugar in the yeast activity represent in the world? What could the CO₂ represent?

   The sugar represents the food, land, and water that are necessary for humans to live. The CO₂ represents the waste that humans create on Earth, such as air pollution and contaminated water.

3. How is the capacity of the bottle similar to the Earth? What factors will influence when the Earth will reach its carrying capacity?

   Every environment has a carrying capacity. The bottle’s carrying capacity for yeast was reached when the balloon reached its peak circumference. The Earth’s carrying capacity will be reached when there are not enough resources such as food, crop land, potable water, and clean air for the human population to continue to grow. The way that humans use the...
4. What is the future for human populations? What decisions must be made? What are the implications of human population growth for future resource use, disease control, and environmental quality?

Follow-up Activities:

Bacteria Bottles

This mind puzzle illustrates the concept of exponential growth using bacteria. Invite students to try it on friends and family.

Bacteria multiply by division. One bacterium becomes two. Then two divide into four, the four divide into eight, and so on. For a certain strain of bacteria, the time for this division process is one minute. If you put one bacterium in a bottle at 11:00 p.m., by midnight the entire bottle will be full.

1. When would the bottle be half-full? How do you know?

The bottle was half full at 11:59 p.m. because the doubling time is one minute and the bottle was full at midnight.

2. Suppose you could be a bacterium in this bottle. At what time would you first realize that you were running out of space?

Answers will vary. To clarify, ask students: “At 11:55 p.m., when the bottle was only 3 percent full and 97 percent empty, would it be easy to perceive that there was a space problem?”

3. Suppose that at 11:58 some bacteria realize that they are running out of space in the bottle, so they launch a search for new bottles. They look far and wide. Finally, offshore in the Arctic Ocean, they find three new empty bottles. Great sighs of relief come from all the bacteria. This is three times the number of bottles they’ve known. Surely, they think, their space problems are over. Is that so? Explain why the bacteria are still in trouble. Since their space resources have quadrupled, how long can their growth continue?

With space resources quadrupled, the bacteria have two more doubling times, or two minutes before they will run out of space.

11:58 p.m.: Bottle 1 is one-quarter full.
11:59 p.m.: Bottle 1 is half-full.
12:00 a.m.: Bottle 1 is full.
12:01 a.m.: Bottles 1 and 2 are full.
12:02 a.m.: Bottles 1, 2, 3, and 4 are all full.

4. Does what you have learned about bacteria suggest something about human population growth?

Paper Fold

Give each student a cocktail napkin or paper towel (regular paper is too thin).

Instruct them to fold the paper in half, then in half again, in half a third time, and then in half a fourth time. At this point, it should be about 1 cm or 0.4 inches thick.

Ask them how thick the paper would be if you folded it in half 29 more times (if this were possible). Estimates may vary widely.

Tell them, “If we were to fold this napkin 29 more times, it would be 3,400 miles thick – the distance from Boston, Massachusetts, to Frankfurt, Germany.”

Use a chart to show the exponential growth of doubling something 33 times, starting from just 1. Explain that since the first human, we have doubled our population about 33 times. Our population is over seven billion. Like in the paper stretching from Boston to Frankfurt, each person in humanity is like one layer of napkin.

Assessment Ideas:

Have the students use the concepts of exponential growth, doubling times, and carrying capacities to write letters to the editor of a local paper, explaining why the city should be concerned about population growth.

Earth in a bottle adapted from the Science@NASA activity, “Planets in a Bottle” (http://science.nasa.gov/newhome/headlines/msad16mar99_1a.htm)

“Paper Fold” was published in the third volume of The Systems Thinking Playbook, co-authored by Linda Booth-Sweeney & Dennis Meadows. The entire book contains 30 short exercises, and it may be purchased from the website of The Sustainability Institute, Hartland, VT 05048: http://www.sustainer.org/tools_resources/games.html.