DOUBLE TROUBLE

EARTH matters
Studies For Our Global Future

introduction

When modeling **exponential growth** in the science classroom, it is useful to use living organisms whose growth can be easily measured. If a population increases exponentially, with no limits on resources, the graph depicting this growth would look like a **J-curve**. The growth rate of the population accelerates and there are no restrictions.

But in most environments there are restrictions; every environment has a **carrying capacity**. The carrying capacity is reached when the available resources cannot support any additional individuals and the population ceases to grow. In this case, the graph will look like an **S-curve** because the line plateaus and declines.

Vocabulary: carrying capacity, exponential growth, J-curve, limiting factor, S-curve

materials

Part 1

For each pair:

- 20 oz. clear plastic bottle
- Lukewarm water
- 2 sugar cubes
- Packet of yeast
- Party balloon (9-10")
- Cloth measuring tape
- Small funnel
- Graph paper
- Clock or watch

Part 2

For each pair:

- Small bowl
- Lukewarm water
- 2 sugar cubes
- Packet of yeast
- Methylene blue (optional)
- Eye dropper (two if using methylene blue)
- Microscope with slides and coverslips

Part 3

- Graph paper

concept

Populations grow exponentially in environments without limiting factors and eventually reach the carrying capacity of their environment.

objectives

Students will be able to:

- Set-up and conduct a lab experiment on the growth of yeast cultures, making observations and recording data.
- Draw and interpret population J-curve and S-curve graphs.
- Identify limiting factors for populations of living organisms.
- Analyze the growth of a yeast colony as a model for human population growth.

subjects

Biology, Environmental Science (General and AP), Algebra

skills

Lab preparation, scientific modeling, collecting and recording data, graphing and analyzing data, interpreting line graphs, writing

method

Students observe and collect data on the exponential growth of yeast cultures in both a lab experiment and under a microscope, graphing their findings and comparing their results with human population growth.

Part 1: Earth in a Bottle

procedure

1. Divide students into pairs and have each pair bring a 20 oz. clear plastic bottle to class, or collect them at lunch from a recycling bin.

2. Provide students with a little background on yeast:

   "Yeast are simple, one-celled fungi. Yeast microbes are probably one of the earliest domesticated organisms. People have used yeast for fermentation and baking throughout history. Like most fungi, yeast respire oxygen (aerobic respiration), but in the absence of air they derive energy by fermenting sugars and carbohydrates to produce ethanol and carbon dioxide (CO_2). When yeast are supplied with both sugar and oxygen, the colonies grow up to 20 times faster through cell division than without oxygen. The famous microbiologist Louis Pasteur first proposed the production of carbon dioxide from yeast as responsible for raising a loaf of bread in 1859."

3. Explain to the class that they will be measuring the growth of a yeast colony by measuring the growth of its by-product: carbon dioxide (CO_2). A plastic bottle will act as a warm, healthy, resource-rich environment for yeast to grow. As the yeast consumes nutrients, it uses the energy to reproduce through division. The by-products of this division process are alcohol and CO_2. A balloon secured to the top of the bottle will catch the CO_2 and begin to fill as the yeast consumes more and more nutrients.

4. Ask students to hypothesize how they might know when the yeast has consumed all of the available resources.

5. Distribute the experiment materials to each pair and have students do the following:

   a. Mix the sugar (2 cubes or 2 tsp.) and 1 cup lukewarm water in the plastic bottle until the sugar is completely dissolved.
   b. Use the funnel to add the yeast to the sugar water. (Fast-rise yeast works best.)
   c. Place the balloon over top of the bottle, making sure not to tear it.
   d. Gently swirl the yeast mixture for one minute.

6. Students should let the bottle sit and measure the circumference of their balloons every 15 minutes. (Measurements should be made around the widest part of the balloon.) Growth will be slow at first but visible. Measurements should be in metric, rounded to the nearest millimeter, and recorded on paper. The balloon will achieve maximum volume less than two hours after the yeast is added to the nutrient mix. The balloon will begin to deflate once the resources have run out for the yeast colony.

7. Provide each student with a piece of graph paper so they can 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 and even decrease, creating an S-curve as the yeast colonies reach their carrying capacity.

alternate procedure

Add variation to the experiment by allowing several pairs to add different amounts of sugar to their environment. Students can then analyze how different concentrations of the nutrient affect the population.

discussion questions

1. Was the balloon always expanding?

   No, the balloon only expanded during the first part of the experiment.

2. At what time did the yeast consume all of the available nutrients? How do you know?

   The time when the balloon was at its peak circumference. At that time, because there were no more available nutrients for the yeast to consume, it couldn't reproduce. And because it wasn't reproducing, it wasn't creating CO_2 and the balloon stopped inflating.

3. What happened when the yeast ran out of nutrients?

   Without nutrients, the yeast could no longer reproduce so no additional CO_2 was created and the balloon no longer increased in size.

4. Why didn't the balloon stay at its peak circumference? Why did it start to deflate? (You may need to remind students that during reproduction, the yeast created both CO_2 and alcohol.)

   The alcohol produced as waste actually becomes toxic to the yeast, killing it off and causing the population to decrease in size.

5. Is there anything we could have done to prolong the life of the yeast colony?

   Additional nutrients could have been introduced to the environment, or the waste (alcohol) could have been removed.

6. What does this tell us about the relationship between the yeast colony and the available resources?

   *The yeast population will continue to grow as long as there is an ample supply of nutrients. A scarcity of the nutrient acts a **limiting factor** in the yeast's population growth.*

7. What limiting factors kept the yeast population from continuing to grow?

   Limiting factors for the yeast included the size of the plastic bottle, the amount of nutrients available, and the presence of waste.

8. What are some limiting factors that keep populations of organisms from growing indefinitely?

   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 cannot grow exponentially.

Part 2: Microscopic Colonies

procedure

1. Still working in pairs, students add the sugar (2 cubes or 2 tsp.), yeast (1 packet) and lukewarm water (1 cup) in a bowl and mix until combined.
2. Using droppers, students place a drop of the yeast mixture on a microscope slide, then add a drop of methylene blue on top of the yeast, and cover with a coverslip over the top.
3. Allow time for each pair to put their slide under a microscope and count the amount of yeast cells that they see, recording the information. Dead yeast cells will appear dark blue.
4. Soon students will observe the division of yeast cells under the microscope. Every five minutes they should count and record the number of cells. Further into the time, they may need to estimate the number of cells if there are too many to count.
5. Have the students identify when the slide has reached its carrying capacity.

discussion questions

1. How did you know when the population on your slide had hit carrying capacity?

   The population stopped growing and experienced some die-off.

2. What were the limiting factors in this part of the experiment?

   The size of the slides, the available nutrients, and the amount of waste (alcohol) present all prevented the yeast population from growing indefinitely.

3. Which method of observing the yeast's growth (the balloon inflation or counting under the microscope) did you prefer and why? What pros and cons were associated with each method?

   Answers will vary. Some students might mention that counting the yeast through the microscope was more accurate, but once the population reached a larger size, estimation was required. Others may say that measuring the balloon provided a better sense of exactly when the yeast hit carrying capacity, as well as when they began to die off because the balloon's inflation clearly showed the byproducts of the yeast's growth.

Part 3: Human J-Curve

procedure

1. Display the table below, showing the human population growth over the past two millennia.

Year	Population (in millions)
1 C.E.	170
200	190
400	190
600	200
800	220
1000	265
1100	320
1200	360
1300	360
1400	350
1500	425
1600	545
1700	610
1750	760
1800	900
1850	1,211
1900	1,625
1950	2,536
2000	6,145
2050	9,772*

Source: United Nations, Department of Economic and Social Affairs, Population Division. (2017). *World Population Prospects: The 2017 Revision.*

*projected

2. Distribute a piece of graph paper to each student and allow them time to graph the data on human population over time.

discussion questions

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

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

2. What are the similarities between the yeast experiments and human population, as well as other organisms' population?

   Similar to the bottle and slide, the Earth is a finite size. Both humans and yeast rely on nutrients to survive and without them will die. The presence of waste negatively impacts the well-being of both humans and yeast.

3. How do yeast and humans differ in the way they reproduce?

   Yeast are one-celled fungi that reproduce asexually, while humans reproduce sexually.

4. What could the sugar in the yeast activities represent in the world in regards to the human population? What could the CO_2 and alcohol represent?

   The sugar represents the food, land, and water that are necessary for humans to live. The CO_2 and alcohol represent the waste that humans create on Earth, such as air pollution and contaminated water.

5. Analyze the bottle as a model of the Earth.

   Both the Earth and the bottle are environments with a finite amount of space and both have some (but in the case of the Earth, not all) resources that are finite. In both cases, these serve as limiting factors. Additionally, both the bottle and the Earth have a carrying capacity.

6. What factors will influence when the Earth will reach its carrying capacity?

   The bottle's carrying capacity for yeast was reached when the sugar had all been consumed (which we saw when the balloon reached its peak circumference). The Earth's carrying capacity will be reached when there are not enough resources such as food, potable water, and clean air for the human population to continue to grow.

7. Do you think it's possible to determine how many people the Earth can support? What would be some of the considerations?

   The Earth's carrying capacity for humans depends on how people use resources. What kind of diet do we eat? How much water and other resources are needed to grow different kinds of food? How do humans use energy? Is it an energy source with a lot of waste by-product or not? So, the question isn't so much "How many people can the Earth support?" but "How many people can the Earth support given certain lifestyles?"

assessment

Students select a living organism inhabiting a finite space (such as duckweed plants in a pond or squirrels in a wooded area), then write 1-2 paragraphs explaining:

- What conditions would need to exist for the population to continue to grow steadily?
- What limiting factors would keep the species' population from growing indefinitely?
- How would you determine the carrying capacity for that species within the specified area?

follow-up activities

1. 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.

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

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

   b. 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?"

   c. 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?

      Answer: 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.

   Or have your students conduct this as an experiment using lactobacillus (or acidophilus). These bacteria are available in many stores in the health supplement section.

2. 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 one. Explain that since the first human, we have doubled our population about 33 times. Our population is over 7 billion. Like in the paper stretching from Boston to Frankfurt, each person in humanity is like one layer of napkin.

Part 1 adapted from the Science@NASA activity, "Planets in a Bottle" (science.nasa.gov). Follow-up Activity, "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 Academy for Systems Change, http://donellameadows.org/systems-thinking-book-sale/