INTRODUCTION

In the *Population Dynamics* Click & Learn, you'll explore a powerful tool for learning about populations: mathematical models. As you'll see by doing the Click & Learn and this activity, you can use models to answer questions, solve problems, and make predictions about all kinds of populations — from bacteria in your body, to wildlife across the world, to our own human populations.

PART 1: Introduction to Population Dynamics

Open the *Population Dynamics* Click & Learn and read through the introduction on the first page.

1. Describe a specific question or problem related to population dynamics that interests you.

2. Do you think the question or problem you described could be investigated using a mathematical population model? Why or why not?

PART 2: Exploring the Exponential Growth Model

Open the "Exponential growth model" tab and read the **"Introduction"** section.

3. The end of the "Introduction" describes how you could use a continuous-time, exponential growth model to simulate an *E. coli* population growing in a lab. Describe *another* specific population and situation that you could simulate with this type of model.

4. Complete the following table to explain the *biological* meanings of the symbols in the exponential growth model. For each explanation, give a specific example using the population you described above.

Symbol	Biological Meaning	Specific Example
N		
t		
dN/dt		
r		
N_0		

5. Both dN/dt and r are types of growth rates. What are the differences between them?

   Proceed to the **"Simulator"** section for the exponential growth model.

6. No units are shown for the numbers in the "Settings" section. This is because each of these numbers can have many possible units. Give an example of possible units for each of the following:
   a. N_0
   b. t
   c. r, using the units for t you gave above

7. Examine both Plot 1 and Plot 2.
   a. In Plot 1, what variables do the *x*- and *y*-axes represent?

   b. In Plot 2, what variables do the *x*- and *y*-axes represent?

8. Set N_0 = 50, r = 0.5, and t = 5.
   a. What is the population size at this point?

   b. What is the population growth rate at this point?

9. Set r **=** 0.1, then gradually increase r by clicking the up-arrow to the right of the number. You may need to hover over the number to see the arrow.
   a. Examine Plot 1. As you increase r, what happens to the curve of population size over time?

   b. Examine Plot 2. As you increase r, what happens to the curve of population growth rate vs. population size?

10. Set r = 0.5 and N_0 = 5, then gradually increase N_0 by clicking the up-arrow to the right of the number.
    a. Examine Plot 1. How does the curve of population size over time change if you start with a smaller number of individuals (e.g., N_0 = 5) compared to a larger number of individuals (e.g., N_0 = 100)?

    b. Examine Plot 2. How does the curve of population growth rate vs. population size change if you start with a smaller number of individuals compared to a larger number?

11. List one combination of values for r and N_0 that produces each of the following patterns for population size over time. (There are many possible answers.) Use a time range with a “Min” of 0 and a “Max” of 10.

Pattern	Value of r	Value of N_0
A long period of what appears to be almost no growth. (The curve in Plot 1 looks almost flat.)		
A long period of slow but clearly accelerating growth. (The curve in Plot 1 starts to become steeper at the end.)		
Extremely fast growth from the very beginning.		

PART 3: Exponential Growth in Bacteria

Return to the **“Introduction”** section for the exponential growth model and open the bacteria example linked at the bottom. Read through this example if you haven’t already.

12. The example claims that the population growth rate at 24 hours will be 1.69×10^{26} bacteria per hour. Confirm this result by showing your calculations below. (*Hint*: The example contains the equations and values that you'll need to use.)

Return to the exponential model simulator and fill in the settings using the *E. coli* bacteria example (**N_0 = 2, *r* = 2.45**).

13. Using the simulator, fill in the following table with the population size (*N*) and population growth rate (*dN/dt*) at different time points (*t*, measured in hours).

Time (*t*)	**1**	**2**	**3**	**4**	**5**
Population size (*N*)					
Population growth rate (*dN/dt*)					

14. Use your table above and/or the simulator to answer the following questions. (*Hint:* For the simulator, you may want to change the "Max" values for the axes on Plot 1 to get a better look at the curve. You can use the values of *t* and *N* from your table above to decide what the "Max" values should be.)
    a. Sketch how the population size (*N*) changes over time.

    b. Sketch how the population growth rate (*dN/dt*) changes based on population size (*N*).

    c. The population growth rate (*dN/dt*) depends on the maximum per capita growth rate (*r*). Does *r* also change based on time or population size? Why or why not?

15. All models have strengths and limitations. A *strength* of a model could be something that the model simulates very well or something that makes it easy to use. A *limitation* could be something that the model does not simulate as well or an important process that it does not include.
    a. What is one *strength* of the exponential growth model you explored?

    b. What is one *limitation* of the exponential growth model you explored?

PART 4: Exploring the Logistic Growth Model

Go to the "Logistic growth model" section and read the introduction.

16. Summarize the main differences between the exponential and logistic growth models.

17. Explain what the carrying capacity (*K*) is in your own words.

Proceed to the **"Simulator"** section for the logistic growth model.

18. Set N_0 = 1, r = 0.6, and K = 1000. Also set the "Max" value for t on the x-axis of Plot 1 to 25.

    a. Examine Plot 1. What happens to the population size over time?

    b. Examine Plot 2. For what values of N is the population growth rate almost zero (for example, 0.01 or lower)?

    c. Set N_0 = 1500. What happens to the population size over time now? For what values of N is the population growth rate almost zero?

    d. In general, for what values of N and K is the population growth rate almost zero?

19. Set N_0 = 1 again. Gradually increase r by clicking the up-arrow on its box.

    a. Examine Plot 1. As you increase r, what happens to the curve of population size over time?

    b. Examine Plot 2. As you increase r, what happens to the curve of population growth rate vs. population size? (*Hint:* Pay attention to the numbers on the y-axis of Plot 2.)

PART 5: Logistic Growth in Bacteria

Return to the **"Introduction"** section for the logistic growth model and open the bacteria example linked at the bottom. Read through this example if you haven't already.

Optional Question: The example claims that the population growth rate at 240 hours will be about 16,300 bacteria per hour. Confirm this result by showing your calculations below.

Return to the logistic model simulator and fill in r and N_0 using the *E. coli* bacteria example (**N_0 = 2, r = 0.05**). For the following questions, we'll imagine that the bacteria are growing in an environment with fewer resources, so the carrying capacity (K) is 10,000 bacteria instead of 10^{13} bacteria. So, set **K = 10,000** instead of 10^{13}.

20. Using the simulator, fill in the following table with the population size (N) and population growth rate (dN/dt) at different time points (t, measured in hours).

Time (t)	**100**	**200**	**300**	**400**	**500**
Population size (N)					
Population growth rate (dN/dt)					

21. Use your table above and/or the simulator to answer the following questions. (*Hint:* For the simulator, you may want to change the "Max" values for the axes on Plot 1 to get a better look at the curve. You can use the values of *t* and *N* from your table above to decide what the "Max" values should be.)
    a. Sketch how the population size (*N*) changes over time.

    b. Sketch how the population growth rate (*dN/dt*) changes based on population size (*N*).

    c. How do your answers above compare to your answers for the exponential growth model (Question 14)?

22. Complete the following table to explain why the population growth rate (*dN/dt*) is small in certain situations. The first row is filled out for you as an example.

The population growth rate (*dN/dt*) is small when…	**Mathematical explanation**	**Biological explanation**
the population size (*N*) is close to 0	The equation for the population growth rate is $dN/dt = rN(1–N/K)$. When N is close to 0, both rN and N/K are small, which makes dN/dt small too.	When the population size is small, the population has only a few individuals to produce offspring. This means the population can't grow very quickly, so the population growth rate is small.
the population size (*N*) is close to the carrying capacity (*K*)		

23. Like all models, the logistic growth model has both strengths and limitations.
    a. What is one *strength* of the logistic growth model you explored?

    b. What is one *limitation* of the logistic growth model you explored?

    c. How do your answers above compare to your answers for the exponential growth model (Question 15)?

PART 6: Modeling Other Populations

The exponential and logistic growth models aren't just for bacteria. They can be applied to many other types of populations, including human populations.

24. Do you think the global human population is experiencing exponential growth or logistic growth? Why?

25. Find a graph of the global human population over time and sketch it below.

26. Based on the graph you found, would you change your answer to Question 24? Why or why not?

27. What do you think will happen to the size of the global human population in the long run? Why?

28. Think of a population from a species *not* yet discussed that you are familiar with or have learned about.

    a. Propose a specific question about this population that you could investigate using a mathematical population model.

    b. What kind of model, exponential or logistic, would you use to simulate this population and why?

    c. Is there anything you would need to add to the model you chose in Part B in order to answer your question in Part A? If so, what?