

Teacher Preparation Notes for Some Similarities between the Spread of Infectious Disease and Population Growth¹

First, students analyze a hypothetical example of exponential growth in the number of infected individuals. Then, a class simulation of the spread of an infectious disease shows a trend that approximates logistic growth. Next, students analyze examples of exponential and logistic population growth and learn about the biological processes that result in exponential or logistic population growth. Finally, students analyze how changes in the biotic or abiotic environment can affect population size; these examples illustrate the limitations of the exponential and logistic population growth models.

We estimate that this activity will take 1.5-2 50-minute class periods. An alternative activity that provides more in-depth analysis of the exponential and logistic population growth models is “Understanding and Predicting Changes in Population Size – Exponential and Logistic Population Growth Models vs. Complex Reality” (<http://serendipstudio.org/exchange/bioactivities/pop>).

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Learning Goals

In accord with the Next Generation Science Standards²:

- Students will gain understanding of Disciplinary Core Ideas:
 - LS2.A, Interdependent Relationships in Ecosystems:
 - “Growth of organisms and population increases are limited by access to resources.”
 - “Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations.”
 - “Ecosystems have carrying capacities, which are limits to the number of organisms and populations they can support. These limits result from such factors as the availability of living and nonliving resources and from such challenges such as predation, competition, and disease. Organisms would have the capacity to produce populations of great size were it not for the fact that environment and resources are finite. This fundamental tension affects the abundance (number of individuals) of species in any given ecosystem.”

¹ By Drs. Ingrid Waldron and Jennifer Doherty, Department of Biology, University of Pennsylvania, 2018. These Teacher Preparation Notes, the related Student Handout and additional minds-on, hands-on activities for teaching biology are available at http://serendipstudio.org/sci_edu/waldron. We are grateful to Nabeedah Parker, Mary Wang and Jake Zimny for their very helpful input to improve this activity.

² Quotations from <http://www.nextgenscience.org/sites/default/files/HS%20LS%20topics%20combined%206.13.13.pdf>, <http://www.nextgenscience.org/sites/default/files/Appendix%20G%20-%20Crosscutting%20Concepts%20FINAL%20edited%204.10.13.pdf> and <http://www.nextgenscience.org/>

- LS2.C, Ecosystem Dynamics, Functioning and Resilience
“Moreover, anthropogenic changes (induced by human activity) in the environment – including habitat destruction, pollution, introduction of invasive species, overexploitation, and climate change – can disrupt an ecosystem and threaten the survival of some species.”
- Students will engage in several Scientific Practices:
 - Developing and Using Models
“Develop and/or use a model to predict and/or describe phenomena.”
“Develop and/or use a model (including mathematical and computational) to generate data to support explanations, predict phenomena, analyze systems, and/or solve problems.”
 - Analyzing and Interpreting Data
“Analyze and interpret data to determine similarities and differences in findings.”
“Evaluate the impact of new data on a working explanation and/or model of a proposed process or system.”
 - Constructing Explanations
“Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena ...”
- This activity provides the opportunity to discuss the Crosscutting Concepts:
 - Systems and System Models: Models can be used “to predict the behavior of a system, [but] these predictions have limited precision and reliability due to the assumptions and approximations inherent in the models”.
 - Stability and change: “Students understand much of science deals with constructing explanations of how things change and how they remain stable.”
 - Cause and Effect: “Cause and effect relationships may be used to predict phenomena in natural or designed systems.”
- This activity will help students to meet these Performance Expectations:
 - MS-LS2-1, “Analyze and interpret data to provide evidence for the effects of resource availability on organisms and populations of organisms in an ecosystem.”
 - MS-LS2-4, “Construct an argument supported by empirical evidence that changes to physical or biological components of an ecosystem affect populations.”
 - HS-LS2-1, “Use mathematical and/or computational representations to support explanations of factors that affect carrying capacity of ecosystems at different scales.”

Specific Learning Goals

- The spread of infectious disease from person to person in a population can result in exponential increase in the number of infected people. Eventually, the spread of the infectious disease will slow down, e.g. if most susceptible individuals have already been infected or if effective precautions prevent the germs from spreading to uninfected individuals.
- Similarly, when population size doubles repeatedly, this results in exponential population growth. However, population growth is limited by the availability of resources. The maximum population size that an environment can sustain is called the carrying capacity. As population size approaches the carrying capacity, population growth slows and eventually stops, resulting in logistic population growth.
- Real-world populations exist in complex ecosystems that include communities of different types of organisms and their physical environment. Changes in the biotic and abiotic environment can result in changes in population size. The effects of changes in the environment are not included in the exponential or logistic population growth models.

Supplies

For the simulation of the spread of infectious disease, you will need one data strip for each participant. (Note that an even number of students will participate in each class; see page 4.) The last two pages of these Teacher Preparation Notes provide templates for making data strips for 24 students. If a class has more than 24 students, make additional copies of page 13. (For each class, you will want only one data strip that has the number 0 for Time 0, since the simulation begins with only one infected student; all the other data strips for each class should have the number 1 for Time 0.) Put two small sticky notes on the back of each data strip.

General Instructional Suggestions

Before beginning this activity, you may want to coordinate instruction with the students' math teacher who may be willing to include instruction on relevant math concepts.³

If you use the Word version of the Student Handout to make changes, please check the PDF version to make sure that all formatting and figures in the Word version are displayed properly on your computer.

To maximize student learning, we recommend that you have your students answer groups of related questions in the Student Handout individually or in pairs and then have a class discussion of the answers to these questions. In each discussion, you can probe student thinking and help them to develop a sound understanding of the concepts and information covered before moving on to the next part of the activity.

If you would like to have a key with the answers to the questions in the Student Handouts, please send a message to iwaldron@sas.upenn.edu. The following paragraphs provide instructional suggestions and additional background information.

I. The Spread of Infectious Disease – Instructional Suggestions and Background Biology

Infectious diseases are caused by microorganisms such as viruses, bacteria, single cell eukaryotes, and fungi. These diseases can be spread directly from one person to another (contagious diseases) or indirectly (e.g. by insects, food or water). Information to help answer student questions about infectious diseases is available on pages 6-7 of these Teacher Preparation Notes.

Page 1 of the Student Handout engages students in analyzing a hypothetical example of the spread of infectious disease by one-to-one contact. This example shows exponential growth in the total number of infected people. Exponential growth results when the increase during an interval is proportional to the number at the beginning of the interval. (The examples of exponential growth in the Student Handout all involve doubling in each time interval.)

If your students need help with question 2c, you may want to point out that, for each time, the number of arrows indicates the increase in the number of infected people. Notice that, in this hypothetical example, each infected person interacts with an uninfected person during each round of interactions, so the total number of infected people doubles after each round of interactions.

In response to question 5, we hope that some of your students will recognize that the total number of infected people will be limited by the number of people participating in the simulation. Some students may predict linear rather than exponential growth. This will provide the opportunity to contrast linear vs. exponential growth. For example, you could ask students to

³ For the simulation to be successful, each student needs to know that $0 \times 1 = 0$. We hope that this can be taken for granted, but, if not, you may want to have a warm-up activity in which students practice multiplying single digits, including 0.

describe a scenario that would result in linear growth in the number of infected people and ask them how the results of linear growth would differ from the results of exponential growth.

Procedure for Simulation (on page 2 of the Student Handout)

You will want to have an even number of people participate in the simulation in each class. In the simulation, students interact in pairs. If there is an odd number of participants, then in each round one person will not interact; this can cause erratic results, particularly if an infected student doesn't interact during one or more early rounds of the simulation.

To begin the simulation, give each participant a data strip with two small sticky notes on the back (see the section on Supplies on page 2). Only one student should receive a data strip that has the number 0 for Time 0; you may want to ensure that this data strip is given to a student who is reliable about following directions.

We have found that, for the simulation to work well, you need to be very clear about the instructions for the simulation. We recommend that you have a pair of students demonstrate how to do the interaction. In this demonstration, it will be helpful to clarify that their first secret number is located in the Number column next to the Time 0. Also, emphasize that, after a pair of students have interacted with each other, they should go back to their seats. The instruction for students to return to their seats after having interacted with one partner only has two purposes. It prevents students from rushing ahead to their next interaction before other students have completed the current round of interactions. It also makes it easier for any students without a partner to find each other.

For each round of interactions, announce “Begin your interaction for Time ____.” Remind your students to move to a different part of the classroom and interact with a different student. It is important for the students to mix and mingle; otherwise, the infected students may repeatedly interact with each other so the infection does not spread. You may need to give explicit instructions to get groups of students to move out of their comfortable social groups. Occasionally, there is a problem that everyone has paired off except two students who have already interacted with each other in a previous round of interactions; when this happens we recommend that you let them repeat their interaction.

After the first round of interactions, you may want to double check that each person has interacted with exactly one partner. This is a good time to make sure that all students are following the procedure and to catch any problems that will distort the results of the simulation. Also, remind the students that if their secret number has changed, they need to write the new secret number on another sticky note and put that sticky note on top of the sticky note with their previous secret number.

When students are interacting, they should take care not to let anyone else know their “secret number”. If a student develops a hypothesis about which number represents infection, ask them not to share it until after the simulation is done. If students learn that another student is infected, they may avoid interacting with that student or may purposely interact with that student, either of which can distort the results.

If your class size is small, you may find that you do not need all 10 rounds of interaction. However, you should be sure to have enough rounds of interaction so the number of infected people clearly levels off for the later rounds of interaction.

After the students have finished all the rounds of interaction, you can ask for their hypotheses about what represents infection, and then confirm their hypothesis or explain that 0 represents

infection and multiplying 0 by 1 represents the spread of infection. To collect the data from the simulation, we recommend that you use this table to summarize when each student first had 0 as their secret number. Once this happens, a student will have 0 as his or her secret number from then on. Therefore, you can calculate the total number of infected students at each time by adding the number newly infected to the number previously infected.

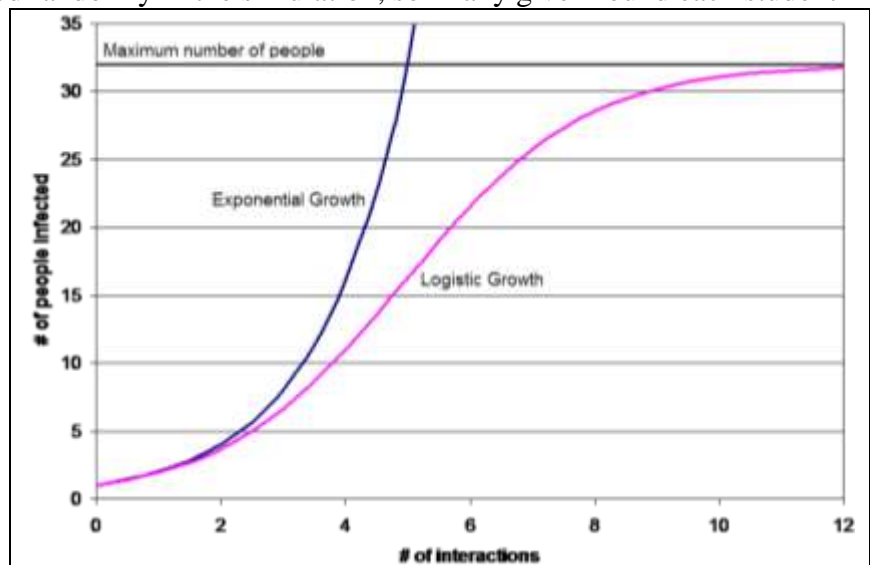
Time	0	1	2	3	4	5	6	7	8	9	10	Students who never had 0
Initials of students who first had 0 as their secret number at this time = newly infected												
# students who have 0 = total # infected people	1											

Display the data for the number of infected people at each time, so students can complete the table in question 6 in the Student Handout.

There are two reasons why the results of the simulation differ from the exponential growth observed in the hypothetical example on page 1 of the Student Handout.

- The simulation continues for more rounds of interaction. In the hypothetical example on page 1 of the Student Handout, everyone in the population was infected by time 4. Clearly, a fifth round of interactions would not have led to continued exponential growth in the number of infected people.
- The hypothetical example has a very precise pattern of interactions, so each infected person interacts with an uninfected person in each round of interactions. In contrast, in the simulation, two infected people may interact with each other. That type of interaction does not spread the infection, so the increase in number of infected people will be less than a doubling for that round of interactions. Interactions between infected people are increasingly likely as more of the students in the class have been infected. Therefore, in the later phases of the simulation, the rate of increase in the number of infected people will be less than the doubling required for continued exponential growth.

Suppose that students interacted randomly in the simulation, so in any given round each student had the same probability of interacting with an infected person. This would result in logistic growth, as shown in this figure. In our experience, the results of the simulation often do not follow a logistic growth curve because students do not interact randomly. This is one reason that the term logistic is not introduced in the Student Handout until the next section.



You may want to point out that the analyses on pages 1 and 2 of the Student Handout are concerned with the cumulative number of people infected. For most types of infectious disease, the number of people with an active infection would be less, as people recovered from the infectious disease.

Additional Questions and Information about Infectious Diseases

You may want to discuss some or all of the following information with your students. Both the ways of preventing the spread of infectious disease and the concept of herd immunity have practical implications for their behavior.

- In your simulation the infection spread very rapidly. In real life, infections do not spread this rapidly. What are some reasons why the spread of infectious disease is slower in real life?
 - The rate of interactions with other people is typically slower in real life.
 - Even when an infected person has contact with an uninfected person, the infected person doesn't always transmit any germs or enough germs to start an infection.
 - If a susceptible person does get enough germs to start an infection, it takes a while for the germs to reproduce to a large enough population size for the person to become contagious or have symptoms. (For many types of infection, a person may be contagious before they feel sick. Bacterial population growth is analyzed in section II of the Student Handout.)
 - Some people may be immune to the infection (e.g. if they have been vaccinated – see the next page).

- What are some ways that infectious diseases are transmitted from one person to another?
 - physical contact with an infected individual (e.g. pinkeye, herpes, Ebola, sexually transmitted diseases)
 - droplets in the air (e.g. cold, flu, tuberculosis)
 - via food or water (e.g. Salmonella or other types of food poisoning)
 - via mosquitoes or ticks (e.g. malaria, Zika, West Nile virus, Lyme disease)
 - indirect contact (e.g., you can catch an infectious disease by getting germs on your hands and then touching your mouth or eyes or by eating food you have touched with unwashed hands.)

- What are some ways you can prevent the spread of an infectious disease?
 - Avoid close contact with people who are infected.
 - Use tissues if you have a cold or flu and throw them away. If you do not have a tissue, cough or sneeze into your elbow.
 - Wash hands thoroughly, especially before eating, after using the toilet, or after contact with someone who has an infection.
 - Avoid touching your eyes, mouth or other mucous membranes where infection may occur.
 - Don't touch other people's body fluids (e.g. avoid touching soiled tissues from someone who has a cold).
 - Don't share toothbrushes, eating utensils, etc.
 - Get recommended vaccinations (see below).

- What defenses does your body have that can prevent you from getting sick, even when you have been exposed to germs?
 - Important first defenses include barriers such as the skin, chemicals such as acid in the stomach, inflammation and phagocytic cells.
 - If viruses or bacteria get past the first defenses, your immune system is stimulated to produce specific immune system cells that can fight that specific type of virus or bacteria.

This response takes time, especially the first time you are exposed to a specific virus or bacteria.

- For many types of infection, your body will produce memory cells which can produce a rapid defense if you are exposed to the same type of virus or bacteria a second time, so you are able to fight off a second infection rapidly and effectively; consequently, the levels of virus or bacteria are kept low and you may never even feel sick. A vaccination provides a controlled exposure that induces the production of memory cells, so when a person is later exposed to the virus or bacteria, these memory cells can mount a rapid defense which prevents illness.
- Susceptibility may be increased by a weak immune system due to age, inadequate nutrition, previous illness, etc. Babies, the elderly, and cancer patients may be particularly vulnerable to infection. These individuals can be protected by herd immunity, which occurs when ~90% of the population has been vaccinated, so the infection does not spread in the population and susceptible individuals are unlikely to be exposed.

Good sources of additional information on infectious diseases are:

- <http://www.mayoclinic.org/diseases-conditions/infectious-diseases/symptoms-causes/dxc-20168651>
- <http://www.mayoclinic.org/healthy-lifestyle/childrens-health/in-depth/childrens-conditions/art-20044109?p=1>
- <https://wwwnc.cdc.gov/travel/page/infectious-diseases>
- <https://www.usatoday.com/story/news/2017/01/11/vaccines-breaking-down-and-debunking-10-myths/96454552/>

The spread of infectious disease is revisited in question 17 on page 4 of the Student Handout (and see the next page of these Teacher Preparation Notes).

II. Exponential and Logistic Population Growth – Instructional Suggestions and Background Biology

A doubling time of 30 minutes is realistic for bacterial population growth. Researchers have found that under optimal conditions bacteria can divide as often as every 20 minutes for even more rapid population growth.

Questions 9-11 help students to understand that the rate of increase in population size accelerates over time because the increase in population size is proportional to the size of the population (more bacteria dividing → more increase in population size). Your students should compare their guesses in question 9b with the calculated result in question 10a. You may want to mention that, if population size continued to double for ten hours, the original single bacterium would increase to a population of over one million bacteria.

Exponential population growth occurs when the rate of population growth is proportional to the size of the population, similar to the hypothetical example of spread of infectious disease on page 1 of the Student Handout. Exponential population growth is observed in nature when resources are abundant relative to the size of the population, e.g.:

- when a population is first introduced to a new environment with abundant resources or
- during recovery after a population has been drastically reduced (e.g. by a natural calamity or human hunting).

As discussed in questions 14-15, exponential population growth cannot continue forever. The exponential population growth model assumes unlimited resources to support exponential increases in population size. In contrast, the logistic population growth model takes account of

the effects of competition for resources (e.g. food, water, nesting sites, and/or sunlight). As population density increases, increased competition results in increased mortality and/or decreased reproduction. As a result, population growth slows down and the logistic population growth curve deviates more and more from the exponential population growth curve.

Question 17 helps students to see the similarities between logistic population growth and logistic growth in the cumulative number of infected individuals. Essentially, logistic growth occurs when:

- initially, the increase during each time interval is proportional to the number at the beginning of the interval (e.g. number of organisms or number of infected people), and
- the process runs out of something (e.g. food for paramecia or people who have been newly exposed to the Ebola virus in the graphs in question 17 or uninfected students in our simulation).

The logistic growth model may be relevant for other processes with similar characteristics, e.g. the spread of a rumor or a computer virus.

For your discussion of question 17, it may be helpful to know that this population of paramecia received the same amount of bacteria for food each day, so the amount of food per capita decreased as population size increased. You may notice that the population growth curve for this population of paramecia does not exactly match the logistic population growth curve. The paramecia did not respond promptly to increased competition for food, so population size exceeded the carrying capacity and then decreased. Further examples of this phenomenon, including a larger overshoot of carrying capacity followed by an abrupt, dramatic crash in population size, are described in the Student Handout and Teacher Notes for “Understanding and Predicting Changes in Population Size – Exponential and Logistic Population Growth Models vs. Complex Reality” (<http://serendipstudio.org/exchange/bioactivities/pop>).

Ebola is spread by contact with the bodily fluids of an infected person or corpse. The spread of Ebola in West Africa was eventually reduced and the epidemic was ultimately ended by preventive measures such as isolation wards for infected individuals, extreme sanitary precautions for healthcare workers, and safe burial practices. Additional information about Ebola is available at <http://www.mayoclinic.org/diseases-conditions/ebola-virus/basics/definition/con-20031241>. A student-friendly description of the West African Ebola epidemic is available at <http://infectiousdiseases.edc.org/content/article/ebola>, and additional information is available at https://en.wikipedia.org/wiki/West_African_Ebola_virus_epidemic.

During the discussion of questions 15-17, we recommend that you bring in the Crosscutting Concept, Stability and change: “Students understand that much of science deals with constructing explanations of how things change and how they remain stable.” Ask students why, during logistic population growth, population size changes initially and then becomes stable.

III. Population Growth Models vs. Complex Reality – Instructional Suggestions and Background Biology

A model is a simplified representation of reality that highlights certain key aspects of a phenomenon and thus helps us to better understand and visualize the phenomenon. Many students tend to think of a model as a physical object and may not understand how a graph or simulation can be a useful model. It may be helpful to introduce the idea of a conceptual model. “Conceptual models allow scientists... to better visualize and understand a phenomenon under investigation... Although they do not correspond exactly to the more complicated entity being modeled, they do bring certain features into focus while minimizing or obscuring others. Because all models contain approximations and assumptions that limit the range of validity of

their application and the precision of their predictive power, it is important to recognize their limitations."⁴

To help your students understand conceptual models, you can give examples of conceptual models that students may have used, e.g. a map, a diagram of a football play, a concept map, or an outline for an essay that a student plans to write. Then, you can ask them about the strengths and weaknesses of these conceptual models to elicit student ideas that will lead to the Crosscutting Concept, “Models can be used to predict the behavior of a system, but these predictions have limited precision and reliability due to the assumptions and approximations inherent in models”. We recommend that you include these ideas as you introduce and discuss section III of the Student Handout.

To help your students understand the limitations of the exponential and logistic population growth models, you may want to compare the exponential and logistic population growth curves with the changes in population size for rabbits in question 18. The exponential population growth model assumes abundant resources; when resources are not abundant relative to increasing population size, then logistic population growth may be observed. The logistic population growth model assumes a constant carrying capacity, with population growth culminating in a stable population size at the constant carrying capacity. When carrying capacity varies due to changes in the environment, logistic population growth is not observed. For example, seasonal changes in weather affect population growth for many populations of short-lived animals and plants. During the growing season, population size may increase exponentially and then, during the cold and/or dry season, the carrying capacity of the environment drops dramatically and population size decreases correspondingly.

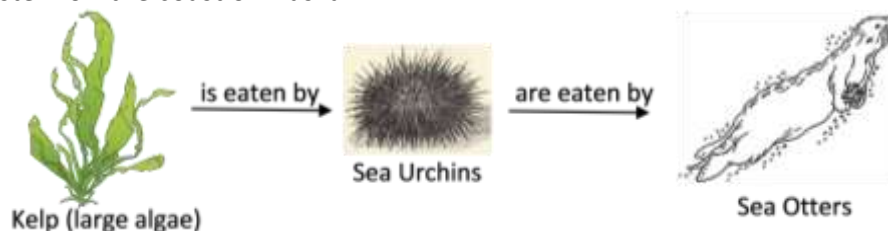
In Alaska and other coastal areas of the northern Pacific, changes in human hunting have directly affected population size for sea otters, which in turn have affected population size for sea urchins, which in turn have affected the abundance of kelp. Kelp include several types of algae which are anchored to rocky areas near the coast and can grow up to 45 m long. When sea otters are absent and sea urchins are abundant, sea urchins eat the bases of the kelp, so the rest of the kelp floats away. This can destroy a kelp forest, which provides shelter and food for many types of marine animals. In addition, kelp forests take up a significant amount of carbon dioxide, which is a greenhouse gas. Thus, human hunting of sea otters had multiple harmful effects on ecosystems and contributed to global warming.

(http://urchinsandkelpforests.blogspot.com/2015/03/introduction_11.html)

If you either prefer not to or can't show your students the video at <https://ww2.kqed.org/quest/2014/02/25/balancing-act-otters-urchins-and-kelp/>, you can use the following alternative which does not require the video.

⁴ Quotation from A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas (available at http://www.nap.edu/catalog.php?record_id=13165).

A real world population is part of a complex **ecosystem** that includes the physical environment and communities of different types of organisms. This figure shows the food chain for three species in a marine ecosystem off the coast of Alaska.



19a. As a result of human hunting, sea otters were rare at the beginning of the twentieth century. Then, hunting was restricted, and sea otters became abundant. When the number of sea otters increased, the sea urchin population size _____.

(increased / decreased)

19b. As a result of the change in sea urchin population size, the kelp population size _____. Explain your reasoning.

(increased / decreased)

The examples on page 5 of the Student Handout illustrate how population size is affected by abiotic environmental factors (seasonal changes in weather) and biotic environmental factors (changes in the size of predator or herbivore populations). Question 20 focuses student attention on the progression from the exponential population growth model (which includes increases in population size as a result of reproduction) to the logistic population growth model (which adds the effects of competition for limited resources) to a more complete description of the causes of changes in size for real-world populations (which adds the effects of changes in the environment).

Related Activities and Resources

- “Exploring Infectious Diseases” (<http://infectiousdiseases.edc.org/>)
- “How does an infectious disease spread? HIV simulation” (<http://www.seplessons.org/node/226>)
- “e-Bug” (http://www.e-bug.eu/lang_eng/primary_pack/downloads/UK%20Junior%20Pack%20Complete.pdf)
- "Role-Playing in a Vaccination Debate Strengthens Student Scientific Debate Skills for Various Audiences" (<https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4858372/>)
- “Understanding and Predicting Changes in Population Size – Exponential and Logistic Population Growth Models vs. Complex Reality” (The Student Handout includes a section on human population growth and the Teacher Notes include relevant sources.) (<http://serendipstudio.org/exchange/bioactivities/pop>)

Sources for Figures in Student Handout

(This includes figures we have modified, but does not include figures we have made.)

Page 4

- <http://swh.schoolworkhelper.netdna-cdn.com/wp-content/uploads/2011/12/exponential-vs-logistic-growt.jpg?x37075>
- <http://www.nature.com/scitable/knowledge/library/how-populations-grow-the-exponential-and-logistic-13240157>
- <https://www.cdc.gov/vhf/ebola/outbreaks/2014-west-africa/cumulative-cases-graphs.html>

Page 5

- https://populationeducation.org/sites/default/files/pop_ecology_files.pdf

- http://ian.umces.edu/imagelibrary/albums/userpics/12789/normal_ian-symbol-enteromorpha-intestinalis.png
- <http://freepages.rootsweb.ancestry.com/~wakefield/history/41395-h/images/illus022.jpg>
- <https://s-media-cache-ak0.pinimg.com/originals/6b/76/ed/6b76ed639ea3f800524de36f77850de0.gif>

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0	1		0	1		0	1	
1			1			1		
2			2			2		
3			3			3		
4			4			4		
5			5			5		
6			6			6		
7			7			7		
8			8			8		
9			9			9		
10			10			10		