**Science Instructor Teaching Guide:**

The intent of these activities is to integrate quantitative skills in a scientific concept. These activities provide scaffolding opportunities to help students graph on a semi-log graph and to provide guidance to instructors on how to present this information before completing the science-related activity. In the science activity, students will explore binary fission, generation time, microbial growth, and bacterial growth curves before plotting the data points of *Staphylococcus aureus* over approximately 6 hours. This activity consists of questions addressing the science content and numerical questions, semi-log and arithmetic graphs, and a concept map. Each activity can be completed independently, but flow more efficiently in the sequence provided.

As a result of this project, we became aware of several concepts that need to be addressed to help students integrate quantitative skills in a science classroom. Through discussion between math/science faculty, it was noted that although the concepts of graphing exponential functions and logarithms are in the curriculum for college algebra, the skills needed in a microbiology course are very different from how the content is presented in college algebra. It was also noted that some of the formulas and terminology related to exponential growth models looked different in each discipline. We felt that it is important to discuss these differences and to provide activities that could be used by both biology and math instructors to help students see connections between what is taught in math and how it is used in science. It is suggested that math and science faculty have regular discussions throughout the semester regarding how math concepts are used in science and taught in math.

**Table 1: Example of Summary of Differences**

|  |  |
| --- | --- |
| **Math Context** | **Science Context** |
| Students routinely graph on the coordinate plane using all 4 quadrants. | Students graph data involving the first quadrant. |
| The scale on both axes is linear and data points come from a given data set or an equation. | The scale on either axes may vary. Students collect data or are given data values. |
| Graphs generally do not have a chart title or axis labels other than x and y. | Graphs need to have a title and specific labels on both axes to quantify a variable. |
| Students are shown basic graphs of functions on a graph where both axes are linear. | Semi-log graphs are needed to clearly display data points for exponential growth problems which makes the graph appear to be the model of a linear function if you don’t pay attention to the fact that the y-axis is on a log scale. |
| Students use a function formula to graph a few data points using a table of values. Data points may contain positive and negative values for x.F(x) = 4x | Problems are connected to the real world. Therefore, data values are usually confined to quadrant 1 (usually contain only positive values for x).  |
| Students solve problems involving logarithms.Log 100 = X | Students use the concept of a log to graph on a logarithmic scale. |
| Students reference basic graphs of various functions and learn to associate a math function with the picture of a graph when the x and y-axis are both linear. | Using a semi-log graph to display data from an exponential function makes it easier to see data points that are growing rapidly. But, a math student may assume the data is linear based on the graph. Be sure to address this misconception. |

The terms “Arithmetic” and “Linear” scales are used interchangeably. In this activity, logarithmic scales are presented as a factor of 10, while arithmetic scales can be presented in any scaling value.

The following pages contain guided information on the progression of this activity in three parts and includes copies of the student’s worksheets with instructor notes added in red. Student handouts are located in the resource files along with copies of the graphing paper and concept map.

**Concept: Binary Fission**

The instructor can introduce binary fission and generation time. Binary fission occurs when one cell splits into two cells in prokaryotic organisms. Generation time refers to the amount of time it takes for one cell to double or complete binary fission. The relationship between the number of generations and the concept of a cell doubling can be modeled by the equation N = N0 x 2x, where N represents the number of viable cells, N0 represents the number of viable cells at the beginning of growth, and x represents the number of generations. During the generation time discussion, add an exploratory component using the function, f(x) = 4x, to discuss the arithmetic and semi-log graphs as pictured below. Arithmetic graphs have linear scales on both the x- and y-axis. In a semi-log graph, one axis is linear and the other axis is logarithmic. Keep in mind, this may be the first time that students view data using the concept of a semi-log graph. It will be necessary to explain how this works to students and to show why it is necessary. Students will plot 4x = y as a formative assessment. The graphs below serve as a starting point in the student activity.



**Part 1: Comparing arithmetic and semi-log graphs.**

**Task:**

1. Answer the following questions:
	1. What occurs during binary fission? Binary fission is a form of asexual reproduction that occurs when one cell copies its genetic information and cellular components before splitting to form 2 daughter cells.
2. Use the arithmetic graphing paper to plot y= 4x when x = -2, -1, 0, 1, 2, 3, 4, 5, 6, 8, and 10.
	1. Complete Table for x/y values.

|  |  |
| --- | --- |
| **X** | **Y** |
| -2 | 1/16 |
| -1 | 1/4 |
| 0 | 1 |
| 1 | 4 |
| 2 | 16 |
| 3 | 64 |
| 4 | 256 |
| 5 | 1024 |
| 6 | 4096 |
| 8 | 65536 |
| 10 | 1048576 |

* 1. Retrieve a sheet of graphing paper with the arithmetic scale. **Plot the values.** See above graphs.
1. Use the semi-log graphing paper to plot y= 4x when x = -2, -1, 0, 1, 2, 3, 4, 5, 6, 8, and 10.
	1. Using the table above, **plot the same values** on the semi-log graphing paper. See above graphs.
2. What are some similarities between the graphs from questions 2b and 3b? These answers may vary, but ideally, students should observe the x-axes are the same.
3. What are some differences between the graphs from questions 2b and 3b? The y-axes have different scales, which creates a different line for each graph. The graph in 2b will appear curved while the graph in 3b will appear linear.
4. Using the equation, N = N0 x 2x, if a bacterial species has a generation time of 15 minutes, how many cells would a single cell produce after an hour?

N = N0 x 2x

N0 = 1

If the cell divides every 15 minutes, there would be 4 divisions after an hour.

x = 4

 N = 1 x 24

N = 24

N = 16

**Concept: Bacterial Growth Curves**

Once students complete the graphing activity, introduce bacterial growth curves. Bacterial growth curves address the exponential growth of bacterial cells over time. There are four phases in the bacterial growth curve: lag phase, log phase, stationary phase, and death phase. In the lag phase, the number of cells are constant. Cells are increasing and decreasing at the same rate, before there is an increase of cells in log phase. During the log phase, there is an exponential increase in the number of cells in the sample. This steep increase occurs until the cells reach the stationary phase. In the stationary phase, cell growth and cell death are equal. Cell growth rate has plateaued. In the death phase, there is an exponential decrease in the number of cells. This activity will focus on the log phase.



Source: <https://openstax.org/books/microbiology/pages/9-1-how-microbes-grow>

Explain how exponential equations can be used to show biological activities. As mentioned previously, students approach mathematical skills differently in a math course as compared to a science course. You can use a Venn Diagram to explore the differences in math and science as it relates to this activity (Use the above table as a guide). Feel free to add items to the Venn Diagram that are not listed in the table.

Be sure to compare and contrast the use of a semi-log graph and a linear scale graph, especially since students have already plotted on both scales. Identify and explain the variables in each graph. Note in the graphs below, the log phase growth is still represented. The graph with an arithmetic scale displays an exponential curve. The semi-log graph has a logarithmic scale and “appears linear,” despite representing exponential data.



Source: <https://openstax.org/books/microbiology/pages/9-1-how-microbes-grow>

**Part 2: Compare and contrast the role of graphing in mathematics and science contexts.**

1. Answer the following questions:
	1. During which phase will the bacterial cells be at equilibrium? Stationary phase
	2. Which two phases show an inverse relationship? Explain. Log phase and death phase have an inverse relationship. Log phase shows an exponential increase while the death phase shows an exponential decrease in the number of living bacterial cells.
	3. Why is the log phase the focal point of this activity? The log phase explores exponential growth of a cell dividing to form two new cells during binary fission.
	4. Which of the following is the best definition of generation time?
		1. The duration of log phase
		2. The time needed for nuclear division
		3. The length of time needed for a cell to divide
		4. The length of time needed for lag phase
	5. From the equation in part 1, y= 4x, the domain includes all numbers from negative infinity to positive infinity (all possible numbers along the x-axis). Find and state the range of y= 4x. In other words, what are the y-axis values of y= 4x ? The range would be (0, infinity) because the y-values of the function have no upper limit. In the context of a real-world problem, we refer to the scientifically relevant domain or range. The domain would consist of the possible values for the independent variable in the context of the experiment and the range would consist of the possible values for the dependent variable in the context of the experiment.
2. Think of how math and science are similar and different in graphing. Use the Venn Diagram to compare and contrast graphing in math and science contexts.



**Concept: Putting Biology into Perspective - Growth of *Staphylococcus aureus***

Now you will introduce and frame the biological question for students to complete the formative assessment.

*Staphylococcus aureus* is a gram-positive bacterium that inhabits the surface of the skin. The term Staphylococcus refers to the circular or spherical morphology (shape) of the bacteria and individual cells divide into formations of clusters rather than form a linear chain. As the bacteria live in the healthy microbial flora of the human skin, it is considered commensal.

Commensalism is a type of species relationship in which one member, in this case, *S. aureus*, benefits, while the other member is neither benefited or harmed. Typically, *S. aureus* inhabits the outer skin of humans without causing harm. Occasionally, if a person experiences lowered immune defenses due to illness, *S. aureus* can become an opportunistic pathogen and cause an infection in a compromised host. Due to this, understanding the growth rate of *S. aureus* bacteria is important for human health. Researchers have found that the generation time of a typical *S. aureus* colony is 27 minutes.

It is important to note the semi-log graphs are an estimation of the number of viable cells over time. In a real-world application, the numbers can vary.

**Table 2:** This table shows the maximal growth rates (as stated in generation time) for select microorganisms from the work of M. M. Mason.

|  |  |
| --- | --- |
| **Organism** | **Generation Time (in minutes)** |
| *Streptococcus lactis* (grown in milk and peptone) | 37  |
| *Escherichia coli* (grown in broth) | 17 |
| *Salmonella enteritidis*  | 21.5 |
| *Clostridium botulinum* | 35 |
| *Serratia marcescens* | 37 |

**Part 3: Plotting *Staphylococcus aureus* growth.**

Students will write in the number of generations in the first column of Table 3.

**Table 3: This table shows the maximal growth rates of *S. aureus* over the time it takes to complete a binary fission cycle.**

|  |  |  |
| --- | --- | --- |
|  | Maximal Growth Rates of *Staphylococus aureus* |  |
| **Number of Generations** | Time (Min) | Viable Cell Count |
| **0** | 0 | 1 |
| **1** | 27 | 2 |
| **2** | 54 | 4 |
| **3** | 81 | 8 |
| **4** | 108 | 16 |
| **5** | 135 | 32 |
| **6** | 162 | 64 |
| **7** | 189 | 128 |
| **8** | 216 | 256 |
| **9** | 243 | 512 |
| **10** | 270 | 1024 |
| **11** | 297 | 2048 |
| **12** | 324 | 4096 |
| **13** | 351 | 8192 |
| **14** | 378 | 16384 |

Answer the questions below:

1. Referring to both arithmetic and semi-log graph paper:
	1. What will be the x-axis label on your graph? Time (in minutes)
	2. What will be the y-axis label on your graph? Viable Cell Count (in the arithmetic graph) and Logarithmic Viable Cell Count (in the semi-log graph)
2. How are the x-axis and y-axis scales in the semi-log graph different from the arithmetic graph? Explain. Answers will vary. Students should observe the x-axis scales are the same in both graphs but the y-axis scales are different. The y-axis scale in the arithmetic graph is scaled in increments of 5000, while the y-axis scale in the logarithmic graph is scaled in powers of 10 (i.e. 101, 102, 103, etc.).
3. Use the data table above to plot the growth of *Staphylococcus aureus* on both arithmetic and semi-log graph paper.



Additional Questions

1. What do you estimate the number of viable cells to be after 20 generations? N = N0 x 2x

N0 = 1; x = 20

N = 1 x 220 = 1,048,576

1. Think about decisions scientists often must make concerning data. What do you perceive the benefits to be of graphing on a semi-log vs. a linear (arithmetic) graph? Answers will vary. When the data values are increasing exponentially, the semi-log scale makes it easier to read data points on the graph.
2. Compare the number of cells from the calculated generation time in Part 1 to the actual values from the growth of *Staphylococcus aureus* in Part 3. Students should notice a steeper increase between the two graphs because the first equation has 4x while the equation used in Part 3 has 2x.

Extension

1. Scientists have isolated an unknown microorganism that doubled every 75 minutes in 13 generations. There were 16,384 viable cells produced.
	1. What was the initial number of cells?

 N = N0 x 2x

 Given: N = 16,384 x = 13

 N0 = ?

16,384 = N0 x 213

16,384 = N0 x 8192

16,384 = N0 x 8192

 8192 8192

 2 = N0

1. Assume scientists have a mixed culture of *S. aureus* (generation time of 27 minutes)and *Escherichi coli* (generation time of 20 minutes). There are two initial cells of each bacterial species. How many viable cells should be present after 3 hours and nine minutes?

*S. aureus* = 27 minutes *E. coli* = 20 minutes

N = N0 x 2x N = N0 x 2x

N0= 2 N0= 2

If the cells of *S. aureus*  divide every If the cells of *E. coli* divide every 20

 27 minutes, there would be 7 minutes, there would be 9 divisions after

divisions after 3 hours and nine 3 hours and nine minutes (189 minutes/20

minutes (189 minutes/27). and then rounded down to the nearest

whole generation).

x = 7 x = 9

N = 2 x 27 N = 2 x 29

N = 2 x 128 N = 2 x 512

N = 256 N = 1024

The total number of viable cells is 1,280.

**Vocabulary**

The table below explains the definitions of terms as it applies to math and science.

|  |  |  |
| --- | --- | --- |
| **Term** | **Math Application** | **Science Application** |
| Arithmetic scale | Always used for graphing of all functions | Graphing linear data |
| Domain | The set of all values of the independent variable | The set of all values of the independent variable |
| Range | The set of all values of the dependent values that occur | The set of all values of the dependent values that occur |
| Semi-log graph | Not typically used for math purposes but has value in scientific and engineering contexts for data with exponential relationships. | Used on a single scale for plotting bacterial cell growth |
| Experiment | Stated in general terms in math | Using observations, forming predictions and hypotheses, and collecting data to form conclusions |

**Files Included**

* Science Instructor Teaching Notes
* Science Student Handout
* Supplementary Venn Diagram document
* Supplementary mathematical graphing functions document
* Learning Environment Modeling Flowchart - This resource can be used to structure the lesson and show the actions of the instructor, represented by dotted arrows, and the learner, represented by solid arrows.

**Considerations**

Textbooks utilize different formats for calculating the number of viable cells in a population. Examples are provided below with the attributed source.

|  |  |
| --- | --- |
| **Textbook (edition and editors/authors)** | **Calculating Number of Viable Cells** |
| Foundations in Microbiology (10th/11th edition by Kathleen Talaro and Barry Chess) | Nf = (Ni)2n  |
| OpenStax Microbiology (1st edition, Rice University) | Nf = (Ni 2n)  |
| Microbiology: An Introduction (12th edition by Tortora, Funke, and Case) | Number of cells = Initial number of cells x 2number of generations |
| Brock Biology of Microorganisms (15th edition by Michael T. Madigan, Kelly S. Bender, Daniel H. Buckley, W. Matthew Sattley, and David A. Stahl) | N = N02n |

**Recommendations**

Mason (1934) provides a comparison table for the maximal growth rates of different bacterial species. This resource can be provided to students as a pre-reading assignment. This can provide students with insight on the variable growth rates for bacteria.

**Additional Resources**

[A Beginner’s Guide to Graphing Data (Math: 10 min 37 sec)](https://youtu.be/9BkbYeTC6Mo)

<https://youtu.be/9BkbYeTC6Mo>

Paul Andersen from Bozeman Science explains graphing and charts as a means of visually representing data. Specifically, experimental data is represented as line graphs, scatter plots, bar graphs, histograms and pie charts. The independent variable is displayed along the x-axis, correlated to the dependent variable on the y-axis.

[Graphing a Basic Function (Math: 5 min 35 sec)](https://youtu.be/2-dUHLHeyTY)

<https://youtu.be/2-dUHLHeyTY>

A Khan Academy guide to graphing an algebraic function. A demonstration of creating a table and graph of the function f(x) = 5x-4 using real numbers.

[CoronaVirus Maths: Logarithmic Scale-What? (Math: 6 min 1 sec)](https://youtu.be/FNAnPvncwWY)

<https://youtu.be/FNAnPvncwWY>

OReilly Maths plots the same data on two separate graphs, one with a linear y-axis and another with a logarithmic y-axis. The linear scale y-axis increases in sequential order while the logarithmic y-axis increases by multiples of 10, creating a semi-log graph. Evaluating points along the plotted lines demonstrates that both graphs represent the same data along different y-axes.

[What’s a Log Scale?? Pandemic Plots Explained! (Math: 12 min 56 sec)](https://youtu.be/eJF9hiv3c-A)

<https://youtu.be/eJF9hiv3c-A>

Zedstatistics covers the usage of the log scale graphs to represent COVID-19 case data. Consecutive marks on a linear scale represent an increase of one unit per mark while the log scale marks represent a multiplication of units from the previous mark.

[Bacterial Growth Full Animation Video (Microbiology: 2 min 44 sec)](https://youtu.be/DfA-MHgi2ws)

<https://youtu.be/DfA-MHgi2ws>

Bacterial cultures grow by a cell doubling process known as binary fission. During binary fission, a parental cell divides into 2 daughter cells. As bacterial cultures are inoculated into a new media, they undergo growth phases described as lag (exponential) phase, log phase, stationary phase, and death phase. Log phase is represented on a logarithmic graph as the cell doubling is occurring each generation.

**References:**

Mason, M. M. (1934). A Comparison of the Maximal Growth Rates of Various Bacteria Under Optimal Conditions. *Journal of Bacteriology, 29(2),* 103 - 110.

Openstax Rice University. *Microbiology*. Rice University, 2016.