Natural Selection and the Development of Antibiotic Resistance - Middle School Sample Classroom Task

Introduction

Adaptation by natural selection acts over generations to change the characteristics of a population, particularly in response to new environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not, become less common. As a result, the distribution of traits in a population changes. In this task, students will use their understanding of how natural selection leads to the predominance of certain traits in a population and the suppression of others to explain the frequencies of traits in a bacterial population and to consider the impact an antibiotic has on a bacterial population over many generations. Students calculate the frequencies of traits, and use graphs and scatterplots to describe and interpret the changes in those frequencies. Students also consider the development of antibiotic resistance through natural selection, and develop a list of criteria and constraints for solutions to combat antibiotic resistance in hospitals or other places that see large numbers of sick or elderly people.

This task was inspired by the files on mathematical modeling of natural selection available at: http://home.mira.net/~reynella/selection.htm (accessed April 2014)

Standards Bundle

(Standards completely highlighted in bold are fully addressed by the task; where all parts of the standard are not addressed by the task, bolding represents the parts addressed.)

CCSS-M

MP.2	**Reason abstractly and quantitatively.**
MP.3	**Construct viable arguments** and critique the reasoning of others**.**
MP.4	**Model with mathematics.**
7.RP.A.2	**Recognize and represent proportional relationships between quantities.**
7.SP.A.2	**Use data from a random sample to draw inferences about a population with an unknown characteristic of interest.** Generate multiple samples (or simulated samples) of the same size to gauge the variation in estimates or predictions.
7.SP.C.7	**Develop a probability model and use it to find probabilities of events. Compare probabilities from a model to observed frequencies; if the agreement is not good, explain possible sources of the discrepancy.**
7.SP.C.7a	**Develop a uniform probability model by assigning equal probability to all outcomes, and use the model to determine probabilities of events.**
8.F.A.1	Understand that a function is a rule that assigns to each input exactly one output. **The graph of a function is the set of ordered pairs consisting of an input and the corresponding output.**
8.F.B.5	**Describe qualitatively the functional relationship between two quantities by analyzing a graph (e.g., where the function is increasing or decreasing, linear or nonlinear). Sketch a graph that exhibits the qualitative features of a function that has been described verbally.**

NGSS

MS-LS4-4 **Construct an explanation based on evidence that describe how genetic variations of traits in a population increase some individuals' probability of surviving and reproducing in a specific environment.**

MS-LS4-6 **Use mathematical representations to support explanations of how natural selection may lead to increases and decreases of specific traits in a population over time.**

MS-ETS1-1 **Define the criteria and constraints of a design problem with sufficient precision to ensure a successful solution, taking into account relevant scientific principles and potential impacts on people and the natural environment that may limit possible solutions.**

CCSS-ELA/Literacy

W.7.1 **Write arguments to support claims with clear reasons and relevant evidence.**
W.7.1.a **Introduce claim(s), acknowledge alternate or opposing claims, and organize the reasons and evidence logically.**
W.7.1.b **Support claim(s) with logical reasoning and relevant evidence,** using accurate, credible sources and **demonstrating an understanding of the topic** or text.
W.7.1.c **Use words, phrases, and clauses to create cohesion and clarify the relationships among claim(s), reasons, and evidence.**
WHST.6-8.1 **Write arguments focused on *discipline-specific content*.**
WHST.6-8.1.a **Introduce claim(s) about a topic or issue, acknowledge and distinguish the claim(s), and organize the reasons and evidence logically.**

WHST.6-8.1.b **Support claim(s) with logical reasoning and relevant, accurate data and evidence that demonstrate an understanding of the topic or text, using credible sources.**

WHST.6-8.1.c. **Use words, phrases, and clauses to create cohesion and clarify the relationships among claim(s), counterclaims, reasons, and evidence.**

W.7.7 **Conduct short research projects to answer a question**, drawing on several sources and generating additional related, focused questions for further research and investigation.
WHST.6-8.7 **Conduct short research projects to answer a question** (including a self-generated question), drawing on several sources and generating additional related, focused questions that allow for multiple avenues of exploration.

Information for Classroom Use

Connections to Instruction

This task is aimed at students in the 7th or 8th grade level in math following an instructional unit(s) on percent, frequency, and proportions, and within an instructional unit on natural selection and evolution in Course 3, according to the Conceptual Progressions Model for middle school (NGSS, vol. 2, Appendix K). If the science instructional unit is taught at the 7th grade level, the task can be modified to remove the more detailed description of functions modeling the dataset in Task Component B (keeping the description of proportional relationships) or that component can be used as an extension for high interest/achieving 7th grade students. Also, to save time on a 7th grade task, the students could be provided the plots in Task Component A, rather than be asked to create them. If plots are provided, the

CCSS-M 8th grade standards would no longer be addressed, but the NGSS performance expectations could still be addressed as cited. This task is ideally used within a math and science integrated course or in a science course that includes coordination with the mathematics teacher to ensure students are able to apply their math learning in the science classroom.

The frequency, proportions, and plotting parts of the components could serve as a check for understanding (i.e., formative assessment) of the math standards, and students may need to revisit these skills to successfully complete the task, depending on when that material is covered relative to when the natural selection instructional unit is covered. Task Component A, particularly the description of the patterns of the observed frequencies, allows students to demonstrate their understanding of the basics of natural selection in a population prior to conceptual application in later task components. Given the importance of plotting data for developing the explanation, Task Component B could be used as a formative assessment and allow students to revisit their plots prior to using their plots as evidence. Task Components A-D could be used as formative assessments at various points within a unit, or all together as a check for understanding of all of the included math and science material.

Even though students are asked to compose explanations in this task, overall the writing focus, including making, supporting, and evaluating statements of probability, most closely aligns with the ELA and Literacy standards on writing argument. Task Components A, B, and C can be used to formatively assess writing argument. In addition, Task Component D aligns with the ELA/Literacy standards for conducting short research projects, and students can demonstrate their understanding on those standards through this task component. This task has been aligned to ELA/Literacy standards for 7th grade. If used with 8th grade, teachers should consult CCSS for the alignment with 8th grade ELA/Literacy standards related to writing argument and conducting short research projects.

Approximate Duration for the Task

The entire task could take from 5-11 class periods (45-50 minutes each) spread out over the course of an instructional unit, with the divisions listed below:

Task Component A: 2-3 periods
Task Component B: 2-4 periods
Task Component C: 1-2 period(s)
Task Component D: up to 2 periods, depending on whether parts of this component are done outside of the classroom

(Note: the time for the task could be reduced if the students are provided with the graphs and plots; See Connections to Instruction for details on how this may change the assessment of the standards.)

Note that this timeline only refers to the approximate time a student may spend engaging in the task components, and does not reflect any instructional time that may be interwoven with this task.

Assumptions

Students experiencing this task will have already studied concepts related to heredity, natural selection, and evolution; have prior experience with the characteristics of creating and interpreting graphs (linear/nonlinear, increasing/decreasing, etc.); and have experience with calculating and understanding the frequency of a component within a population. It is assumed that students have mastered the 6th grade CCSS-M standards, specifically 6.SP.B.4 and 6.RP.A.3.c.

Materials Needed

- If the teacher asks students to graph variant frequency data using graphing calculators and/or a computer plotting or spreadsheet program, then the students will need access to these resources.
- Access to the Internet and/or a set of articles is necessary for students to research solutions to antibiotic resistance in bacteria.

Supplementary Materials

Information from the CDC and the NIH on antibiotic resistance:
http://www.cdc.gov/drugresistance/threat-report-2013/pdf/ar-threats-2013-508.pdf
http://www.niaid.nih.gov/topics/antimicrobialresistance/documents/arstrategicplan2014.pdf
http://www.niaid.nih.gov/topics/antimicrobialresistance/Pages/default.aspx

Instructors may also find it useful to provide graphic organizers, word banks, translator tools, apps that reproduce verbal language into written language, and opportunities for collaborative group work to aid students as necessary. Worldwide or local information about the prevalence and effects of antibiotic resistance may provide further relevance and context for students.

Accommodations for Instruction and Classroom Tasks

To accurately measure three dimensional learning of the NGSS along with CCSS for mathematics, modifications and/or accommodations should be provided during instruction and assessment for students with disabilities, English language learners, and students who are speakers of social or regional varieties of English that are generally referred to as "non-Standard English".

Classroom Task

Context

When Alexander Fleming discovered penicillin in the 1920s, the field of medicine was revolutionized. Antibiotics like penicillin are chemicals that inhibit the growth of bacteria or cause them to die. While your body naturally contains many different types of helpful bacteria that protect the body and aid digestion, some bacteria are harmful to us; for example, *E.coli* can cause food poisoning, and *Staphylococcus aureus* can cause skin and respiratory infections. Antibiotics are a way to help our immune system fight off bacterial infections that in the past may have resulted in death.

Over time, however, the wide spread use of antibiotics has led to the development of resistant strains of bacteria. Infectious diseases such as staphylococcal infection are becoming increasingly difficult to treat because the bacteria that cause them are becoming resistant, through mutations and natural selection, to the antibiotics used to treat them. New types of antibiotics are being developed, but bacteria continue to develop resistance to these new medicines. This antibiotic resistance makes it difficult to eliminate infections because existing medicines are becoming less effective. Thus, diseases that were once highly treatable are now becoming a problem once again.

People who are infected with antibiotic-resistant bacteria require longer hospital stays and may require more expensive and complicated treatments. The National Institutes of Health estimate that 5-10% of all hospital patients develop some type of infection while in the hospital. In 1992, an estimated 13,300 people died from infections that they developed in the hospital, compared to an estimated 90,000 patients who died for the same reason in 2011. The Centers for Disease Control and Prevention estimate that antibiotic resistance in the United States costs $20 billion each year for additional health care and $35 billion in lost productivity (NIH website- http://www.niaid.nih.gov/topics/antimicrobialResistance/understanding/Pages/quickFacts.aspx- accessed April 2014).

In this task, you will explore how natural selection affects the frequency of traits in a bacterial population, including what conditions cause the increase in frequency of the trait for antibiotic resistance in bacterial populations. You will also consider the criteria and constraints to evaluate solutions for the problem of antibiotic resistance in hospitals, where this problem is compounded by the presence of vulnerable patient populations (elderly and sick individuals) and a contained environment where bacteria can easily spread among patients.

Task Components

A. Consider: Samples of bacteria with different genetic traits are mixed together and added to a petri dish. Some bacteria have a trait that helps them to grow and divide quickly. Some bacteria have a trait that slows down the cell death process*. Other bacteria have a trait that helps them to survive in toxic environments rich in heavy metals. The rest of the bacteria have a trait that helps them to move around more easily. For the sake of this assignment, each bacterial population is dominated exclusively by only one trait. All of these bacteria must

** Usually, bacterial cells die when a population reaches a certain size. If the cells aren't able to die, then the population will grow larger than normal.*

compete with each other for space and food within the petri dish in which they are growing. Because it is difficult to count the number of individual bacteria cells present, the percent of the petri dish covered by the bacteria is used instead. The bacteria mixture starts out taking up a total of 8% of the surface area of the petri dish, equivalent to about 2% coverage for bacteria with each trait. The proportion of the petri dish that each bacteria type covers at the start and at three other points in time was measured and recorded in the table in Attachment 1. Between each time point many generations of bacteria were produced, and by Time 4, the entire petri dish was covered by bacteria.

I. Make a statement of probability that predicts what the frequency of traits would be in the bacterial population at Time 4, if none of these traits provided a reproductive advantage to the bacteria over the other traits within the environment of the petri dish. Describe the reasoning behind your prediction.

II. Complete the table by calculating the actual frequency of each trait within the bacterial population at Time 2, Time 3, and Time 4, using the data in Attachment 1. Create a graphical representation(s) to show the trait frequency of the bacterial population at the different points in time. The representation(s) should include a title, scale, axis labels, unit labels, and legend where appropriate. Representations such as bar graphs, line plots, pie charts, or other data displays should be considered.

III. Compare the probabilities from your prediction (part I) to the observed frequencies (part II). Construct an explanation for why the measured frequencies either match or do not match your prediction. Use your graphical representations and the calculated frequencies to support your explanation. Discuss the role natural selection may have played when explaining why the frequencies of traits in the bacterial population may have changed over many generations within the
environment of the petri dish.

B. Bacterial genes are found on one circular chromosome containing a few thousand genes. Bacteria reproduce asexually. Reproduction involves only one parent rather than two parents. The single chromosome is copied and the cell divides into two daughter cells that are genetically identical to the original cell unless a mutation occurs. When a mutation does occur, it can cause a new genetic trait that could equally harm or help the bacteria depending on the environment it is living in. One example of a genetic trait that can provide an advantage to bacteria is the development of antibiotic resistance. Bacteria can die or their growth can be inhibited when they are exposed to an antibiotic. If a mutation causes a trait to develop in a bacterium that blocks an antibiotic, then the bacterium is protected from the harming effects of that antibiotic. There are many different types of antibiotics, so the development of resistance to one type does not guarantee resistance to other types.

The data provided in Attachment 2 show the change in the frequency of different genetic traits within a bacterial population that was exposed to the antibiotic streptomycin. Each trait represents two different variations of the same gene (Variant X and Variant Y) that at the start were equally distributed in the population.

I. Create a scatterplot showing the change in the frequency of the two traits over many generations. The scatterplot should include symbols that distinguish between those bacteria that carry Variant X and those that carry Variant Y as well as include a title, scale, axis labels, unit labels, and legend. Describe how the frequencies of the traits in the population change over the 26 generations due to the change in the environment caused by the introduction of the antibiotic streptomycin. In your description:

a. Discuss whether the data can be modeled by a function, including any features of the function (linear/nonlinear, increasing/decreasing, etc.).
b. Describe any proportional relationships that could be inferred from the data.
c. Discuss the probability that one of the gene variants provides streptomycin antibiotic resistance to bacteria in the population.

II. Construct an explanation for how natural selection is acting over generations in the new environment to lead to a change in the frequency of the genetic traits in the population. Be sure to address how the specific traits may increase some bacteria's chance of surviving in the new environment. Cite the plots and relationships in the data to support your explanation.

III. Consider what would happen to the frequencies of traits in the population if the antibiotic type in the environment was changed. The antibiotic streptomycin is suddenly no longer used and instead the antibiotic tetracycline is introduced into the bacterial population. Tetracycline kills the bacteria with the trait Variant X but does not affect the bacteria with Variant Y. Make a prediction about the change in the frequency of Variant X and Y traits over the next 50 generations. Construct a scatterplot graph similar to the one made previously to show your prediction.

C. When you get sick from a viral infection, your body's immune system focuses on fighting the virus and is less available to keep the bacteria populations in your body in balance. Sometimes when people get infected with a virus, they also can get a bacterial infection, called a secondary bacterial infection. These are commonly treated with antibiotics. The overuse of antibiotics for these types of secondary infections leads to an increase in people's bodies of bacterial populations that have traits for antibiotic resistance.

The data chart and graph in Attachment 3 show the number of people who each developed a secondary bacterial infection from five different populations of bacteria. Each bacterial population is dominated by one of the unknown traits: A, B, C, D, and E. At the time of infection, each person had equal frequencies (20%) for each of the bacterial populations. After infection, one group of people (340 people) was monitored by a doctor but not treated with antibiotics, one group of people (240 people) was treated with Antibiotic 1, and the third group of people (130 people) was treated with Antibiotic 2.

I. Each of the traits listed in Task Component A as well as the trait for antibiotic resistance are represented by one of the unknown traits shown in Attachment 3. Based on your answers from Task Components A and B, make a prediction for which unknown traits (A, B, C, D, and E) corresponds with which of the following traits: grows quickly, less cell death, survives in toxic heavy metal-rich environments, moves around more easily, or resistance to an antibiotic. State the reasoning behind your choice. Given two possible answers, state the probability of one match being more likely or fitting over another.

II. Make a claim for which antibiotic you think the antibiotic resistance traits provides protection from. Describe the reasoning behind your choice. Cite scientific reasoning related to the process of natural selection and use examples from the chart as evidence for your answer.

D. If bacteria become resistant to the antibiotics we have, then there may be no antibiotics left for people to take that will work to fight bacterial infections. For this reason antibiotic resistance in bacteria is a major concern for hospitals, nursing homes, and other people and places that provide care to large numbers of sick or elderly people. Consider the different solutions, found through your research on the topic, that others have proposed for combating antibiotic resistance. Using what you learned about how antibiotic-resistant strains develop and become dominant, make a list of criteria and constraints that you think must be considered when people design a tool, process, or system to reduce or prevent bacterial antibiotic resistance in hospitals and nursing homes. Consider criteria and constraints on long and short time scales that address economic considerations, environmental concerns, issues related to resource availability, societal or cultural concerns and impacts, and technological requirements.

Alignment and Connections of Task Components to the Standards Bundle

Task Component A asks students to calculate and plot the frequency of traits within a bacterial population growing in a petri dish over time. In this component students use the following mathematics skills:

- When the students calculate the frequencies, they are applying the CCSS-M content standard of **6.RP.3.c (***Find a percent of a quantity as a rate per 100*).
- When the students construct a graph showing the frequencies over time, they are using previously learned skills the CCSS-M content standard of **6.SP.4**.

When the students make a prediction of the frequencies of traits assuming that no one trait provides an advantage over another and then compare that prediction to the actual frequencies, they can demonstrate their understanding of parts of the CCSS-M content standards of **7.SP.7** and **7.SP.7a**, and the CCSS-M practices of **MP.2** and **MP.4.** By calculating and plotting frequencies to mathematically represent trends in traits in a changing population of many bacterial cells and using those calculated numbers to discuss how natural selection influenced the change in the frequency of the traits, students are partially addressing the NGSS performance expectation of **MS-LS4-6** and parts (individual bullets from Appendix F) of the associated practice of **Using Mathematics and Computational Thinking,** and parts (bullets from Appendix E) of the core idea of **LS4.C: Adaptation**. This also partially addresses parts of the NGSS core idea of **LS4.B: Natural Selection as it relates to MS-LS4-6**, parts of the NGSS practices of **Constructing Explanations and Designing Solutions** and **Analyzing and Interpreting Data**, and parts (bullet from Appendix G) of the NGSS crosscutting concepts of **Patterns** and **Stability and Change.** The calculation of frequencies and plots are essential evidence for the scientific explanations of natural selection whereas the science data provides a real life context for calculating frequencies, percentages, and making and comparing statements of probability. When students make a statement of probability and describe the reasoning behind their prediction, they are essentially making and supporting a claim and are partially addressing **W.7.1, W.7.1.a, W.7.1.b, W.7.1.c, WHST.6-8.1, WHST.6-8.1.a, WHST.6-8.1.b,** and **WHST.6-8.1.c**.

Task Component B asks students to plot and describe data showing the frequency of genetic variants in a bacterial population given a change in the environment (addition of antibiotic) and then use those data to explain how the specific traits may increase some bacteria's chance of surviving in the new environment and to make predictions for how the frequencies of traits might change in the future with a different change in the environment. This partially addresses the NGSS performance expectations of **MS-LS4-4** and **MS-LS4-6** and parts of the associated NGSS dimensions, including the practices of **Using Mathematics and Computational Thinking** and **Constructing Explanations and Designing Solutions** and the core ideas of **LS4.C: Adaptation** and **LS4B: Natural Selection**. This also partially addresses parts of the NGSS practice of **Analyzing and Interpreting Data,** and parts of the NGSS crosscutting concepts of **Patterns, Cause and Effect,** and **Stability and Change.** When describing the relationship between the time (generations) and frequency as proportional relationships, as mathematical functions, and by using the patterns in the data and scientific reasoning to make a prediction about the change in frequencies over time, students can partially address CCSS-M content standards of **7.RP.2**, **8.F.1**, and **8.F.5,** and on CCSS-M practices of **MP.2** and **MP.4**. Modeling of the data and using the graphs to predict the changes in the population enhance the performance of the NGSS core ideas and practices whereas the scientific context provides opportunities to use and describe plotted data that show a changing relationship over time. When students discuss probability based on existing data and make predictions about changes in frequency, they are essentially making and supporting claims and are partially addressing **W.7.1, W.7.1.a, W.7.1.b, W.7.1.c, WHST.6-8.1, WHST.6-8.1.a, WHST.6-8.1.b**, and **WHST.6-8.1.c**.

Task Component C asks students to consider plots of population data of frequencies of people with bacterial populations dominated by specific unknown traits and to make conclusions and statements of probability about which unknown trait corresponds with known characteristics of bacteria given the environmental conditions (with and without antibiotics), following the data from Task Component A. This partially addresses the NGSS performance expectation of **MS-LS4-4** and parts of the associated practice of **Constructing Explanations and Designing Solutions,** core idea of **LS4B: Natural Selection**, and crosscutting concept of **Cause and Effect**. This also partially addresses parts of the NGSS core idea of **LS4.C: Adaptation as it relates to MS-LS4-6**, parts of the NGSS practices of **Analyzing and Interpreting Data** and **Engaging in Argument from Evidence,** parts of the NGSS crosscutting concepts of **Patterns,** the **CCSS-M** content standard of **7.SP.2,** and the CCSS-M practices of **MP.2** and **MP.3**. The data present a situation from which students can make inferences about a population to demonstrate their understanding of the math standards, whereas using frequencies and probabilistic reasoning allows a student to understand and describe cause and effect relationships associated with natural selection assessing the crosscutting concept dimension of the science standards. When students make and use scientific reasoning to support claims, they can address **W.7.1, W.7.1.a, W.7.1.b, W.7.1.c, WHST.6-8.1, WHST.6-8.1.a, WHST.6-8.1.b**, and **WHST.6-8.1.c**.

Task Component D asks students to research potential solutions to the problem of antibiotic resistance in bacteria in order to develop a list of criteria and constraints to be considered when people design a tool, process, or system to reduce or prevent bacterial antibiotic resistance in hospitals and nursing homes. The criteria may address factors related to short and long-term consequences of human activities, the positive and negative effects on people and the environment, the uses and limitations of technology, and society's needs, desires, and values. This addresses the NGSS performance expectation of **MS-ETS1-1** through an integration of parts of the core idea of **ETS1.A: Defining and Delimiting Engineering Problems**, parts of the practice of **Asking Questions and Defining Problems**, and parts of the connections to engineering, technology, and applications of science of **Influence of Science, Engineering, and Technology on Society and the Natural World**. By asking students to identify criteria and constraints based on a number of solutions, timescales, and human considerations, students are addressing parts of the NGSS crosscutting concept of **Patterns.** When students conduct research about antibiotic strains and use this researched information to make a list of criteria and constraints, they are addressing **W.7.7** and **WHST.6-8.7**, conducting short research projects.

Together, **Task Components A, B, & C** address the NGSS performance expectations of **MS-LS4-4** and **MS-LS4-6**. The task components address and integrate parts of the core ideas of **LS4.C: Adaptation** and **LS4B: Natural Selection**, parts of the practices of **Using Mathematics and Computational Thinking** and **Constructing Explanations and Designing Solutions,** and parts of the crosscutting concept of **Cause and Effect** by using statements of probability and proportional reasoning and calculations of frequency and models of traits in a bacterial population over time in both stable and changing environments as evidence in explanations for how genetic variations of traits change in the bacterial population over time through natural selection due to the adaptive advantage for increased fitness each trait would give a bacterium in its environment.

Evidence Statements

Task Component A

- I. Students make a statement that includes the following information: if none of the traits provided a reproductive advantage to the bacteria, then the frequency of each trait in the population will be around 25% at Time 4.
- I. Students use the following reasoning to support their statement:
  - Because no one trait provides an advantage to a bacterium that could increase its chances of surviving and reproducing in the environment of the petri dish, the bacteria should increase in number equally.
  - Because the number of bacteria with each trait type should increase equally, the frequency of traits should not change from the starting frequencies.
- II. Students calculate the frequencies of traits for Time 2, Time 3, and Time 4.
- II. Students create a graphical display that is an appropriate method of display for the data; correctly represents the change in frequencies over time; and includes a relevant scale, axis labels, unit labels, legend, and title.
- III. Students construct an explanation that includes that the measured frequencies are different than the predicted frequencies because some traits give the bacteria a higher probability of surviving and reproducing over others. Students connect this specific situation to the concept of natural selection.
- III. Students identify and describe, as evidence, the pattern from the plots that over time the bacterial populations with traits of "grows quickly" and "less cell death" increase in frequency relative to the frequency of the other two traits.
- III. Students logically connect the evidence using the following reasoning:
  - The traits of "grows quickly" and "less cell death" provided an advantage to the bacteria with those traits because those traits helped those bacterial populations increase in number faster, using more food and space.
  - Because the bacteria with traits for "grows quickly" and "less cell death" increased in number faster than the other bacteria, the frequency of the traits for "grows quickly" and "less cell death" in the population increased (greater than 25%) and the frequency of the other traits decreased (less than 25%)

Task Component B

- I. Students create a scatterplot that correctly represents the Variant X and Y frequency numbers for each generation, with symbols distinguishing each variant and a relevant scale, axis labels, unit labels, legend, and title.
- I. Students describe how the frequencies of the traits in the population change according to the data, including at least one of the following descriptions of modeling the dataset:
  - The entire dataset is best modeled by a non-linear function. The data for Variant X is described as increasing non-linearly, and the data for Variant Y is described as decreasing non-linearly.
  - Only part of the dataset could be modeled with a linear function, with parts where the data for Variant X is increasing proportionally and the data for Variant Y is decreasing proportionally.

- I. In their description, students cite a low probability that bacteria with Variant Y display antibiotic resistance to streptomycin because the numbers are decreasing while there is a high probability that bacteria with Variant X are antibiotic resistant because the numbers are increasing.
- II. Students construct an explanation that includes the idea that there is a change in the frequency of the traits in the population because the new environmental conditions provide bacteria with Variant X with an advantage over bacteria with Variant Y, and therefore natural selection is acting on the bacterial populations.
- II. Students identify and describe the increase in the frequency of Variant X and the decrease in Variant Y on the plot over time in response to the new environmental conditions (added antibiotic) as evidence in support of the explanation.
- II. Students use reasoning to logically connect the evidence, including:
    - Because bacteria with Variant Y are not resistant to the antibiotic, they will die and create fewer offspring in the new environment causing their numbers and the frequency of Variant Y in the population to decrease.
    - Because bacteria with Variant X are antibiotic resistant to streptomycin, they will continue to multiply and thrive in the new environment causing their numbers and the frequency of Variant X in the population to increase.
    - If there are fewer bacteria with Variant Y because they are dying and not reproducing and if bacteria with Variant X are unaffected and multiply, then the frequency of Variant Y will decrease and the frequency of Variant X will increase as seen in the plot.
- III. Students construct a scatterplot that shows Variant Y increasing non-linearly to frequencies near 98-99% and Variant X decreasing non-linearly to frequencies near 1-2% following the shape of the data in the plot created previously.

Task Component C

- I. Students make a prediction that includes the following connections and lines of reasoning:
    - Unknown B and D most likely correspond with "grows quickly" and "less cell death" (with B more likely to be "grows quickly") because B and D had the highest frequencies in the group without antibiotics (with B slightly higher) and these traits also had the highest frequency in the data from Task Component A (with grows quickly slightly higher).
    - Unknown C and E most likely correspond with "survives in toxic, heavy metal-rich environments" and "moves around more easily" (with equal likelihood that each trait is C or E) because C and E had the lowest frequencies in the group without antibiotics (nearly equal) and these traits also had the lowest frequency in the data from Task Component A.
    - Unknown A most likely corresponds with antibiotic resistance because it is only high in frequency in a population given antibiotics (Antibiotic 1).
- II. Students make a claim that includes that the trait for antibiotic resistance provides protection from Antibiotic 1.

- II. In support of their claim, students identify and describe evidence, including the increased frequency in Trait A for antibiotic resistance in the population given Antibiotic 1.
- Students evaluate the evidence for relevance and sufficiency, including any limitations their evidence may pose (e.g., correlational).
- II. Students synthesize the relevant evidence using reasoning, including:
  - Cause and effect relationships between environmental conditions and population growth. Specifically, students identify that because the antibiotics kill all the other bacteria types except the one with the trait for antibiotic resistance, people that take that antibiotic will be creating an environment in their bodies where those bacteria will preferentially thrive and the trait will increase in frequency within the population over time.
  - Because only the people with Antibiotic 1 have high numbers of bacteria with that trait and because Trait A is only uniquely prevalent in a group given antibiotics, Trait A must provide antibiotic resistance to Antibiotic 1.

Task Component D

- The list of criteria and constraints:
  - Collectively define the problem of antibiotic resistance in hospitals and nursing homes.
  - Addresses a solution(s) such as an object, tool, process, or system that prevents or combats antibiotic resistance in hospitals and nursing homes.
  - Is based on sound scientific reasoning related to natural selection and the change in trait frequencies in response to the bacteria's environment.
  - Addresses long and short term economic considerations, environmental concerns, issues related to resource availability, societal or cultural concerns and impacts, and/or technological requirements related to the problem of antibiotic resistance places that provide care for the sick and elderly.

Attachment 1: Data Table for the Frequency of Traits in a Bacterial Population Growing in a Petri Dish Over Time

	Time 1- Start		**Time 2**		**Time 3**		**Time 4**	
Trait	Percent of Petri Dish Covered by Bacteria	Frequency of the Trait in the Bacterial Population	Percent of Petri Dish Covered by Bacteria	Frequency of the Trait in the Bacterial Population	Percent of Petri Dish Covered by Bacteria	Frequency of the Trait in the Bacterial Population	Percent of Petri Dish Covered by Bacteria	Frequency of the Trait in the Bacterial Population
grow quickly	2	25	9		26		43	
less cell death	2	25	8		21		33	
can grow in toxic, heavy metal-rich environments	2	25	5		8		11	
can move around more easily	2	25	4		9		13	
Total % of Petri Dish Covered	8		26		64		100	

Attachment 2: Comparison of the Frequency of Genetic Traits in Bacteria Over Time

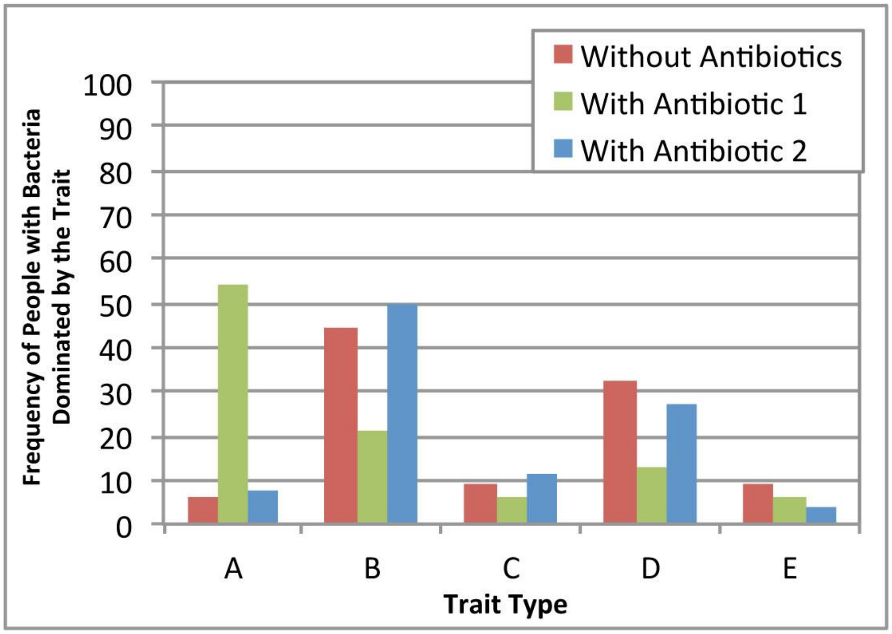
Generation	Frequency of Variant X in the Population	Frequency of Variant Y in the Population
1	51	49
2	55	45
3	60	40
4	64	36
5	68	32
6	72	28
7	75	25
8	79	21
9	82	18
10	84	16
11	86	14
12	88	12
13	90	10
14	92	8
15	93	7
16	94	6
17	95	5
18	96	4
19	96	4
20	97	3
21	98	2
22	98	2
23	98	2
24	99	1
25	99	1
26	99	1

The data above were collected from a study examining the effect of streptomycin on a bacterial population over a span of time. The bacterial population consisted of organisms carrying one or the other of two variants of a single gene.
Sources:
Mathematics: http://home.mira.net/~reynella/selection.htm
Excel Data: http://home.mira.net/~reynella/selec_pub.xls

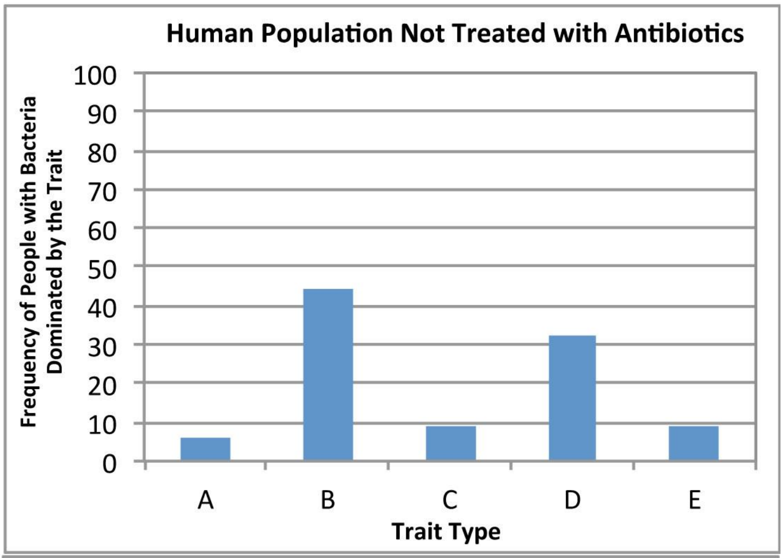
Attachment 3: Data Table for the Frequency of People with Bacterial Populations Dominated by Certain Traits, after Observation and Treatment with Antibiotics.

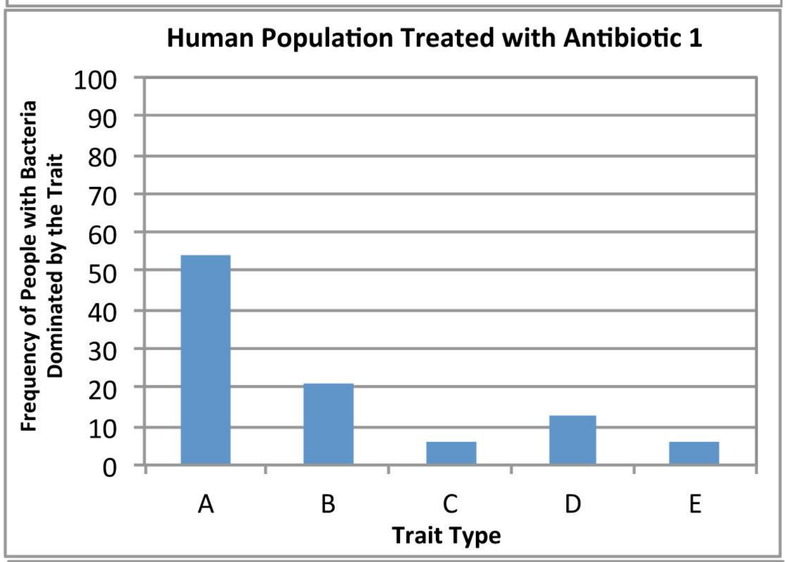
	Without Antibiotics		With Antibiotic 1		With Antibiotic 2	
Trait	Number of People with a Bacterial Population Dominated by Each Trait	Frequency of People in the Population with Bacteria Dominated by the Trait	Number of People with a Bacterial Population Dominated by Each Trait	Frequency of People in the Population with Bacteria Dominated by the Trait	Number of People with a Bacterial Population Dominated by Each Trait	Frequency of People in the Population with Bacteria Dominated by the Trait
A	20	6	130	54	10	8
B	150	44	50	21	65	50
C	30	9	15	6	15	12
D	110	32	30	13	35	27
E	30	9	15	6	5	4
Total	340		240		130	

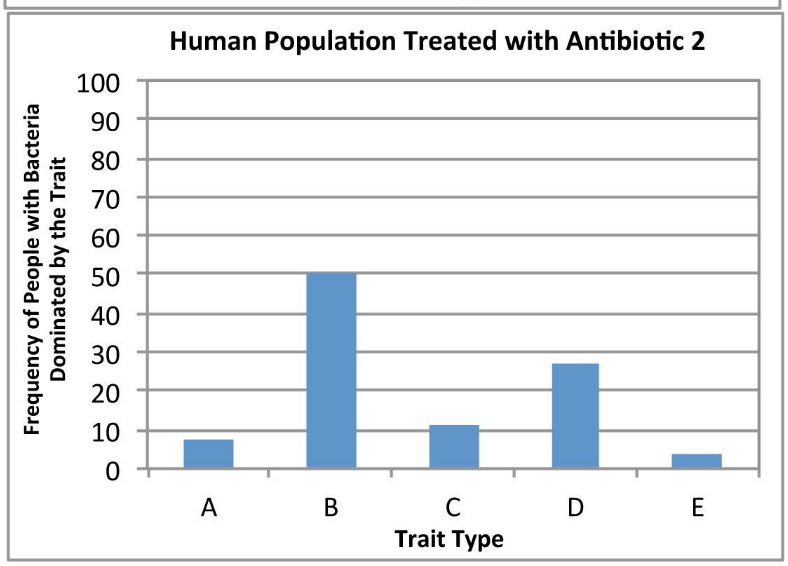
Attachment 4: Data Charts for the Frequency of People with Bacterial Populations Dominated by Certain Traits



Attachment 4 (continued)**: Data Charts for the Frequency of People with Bacterial Populations Dominated by Certain Traits**

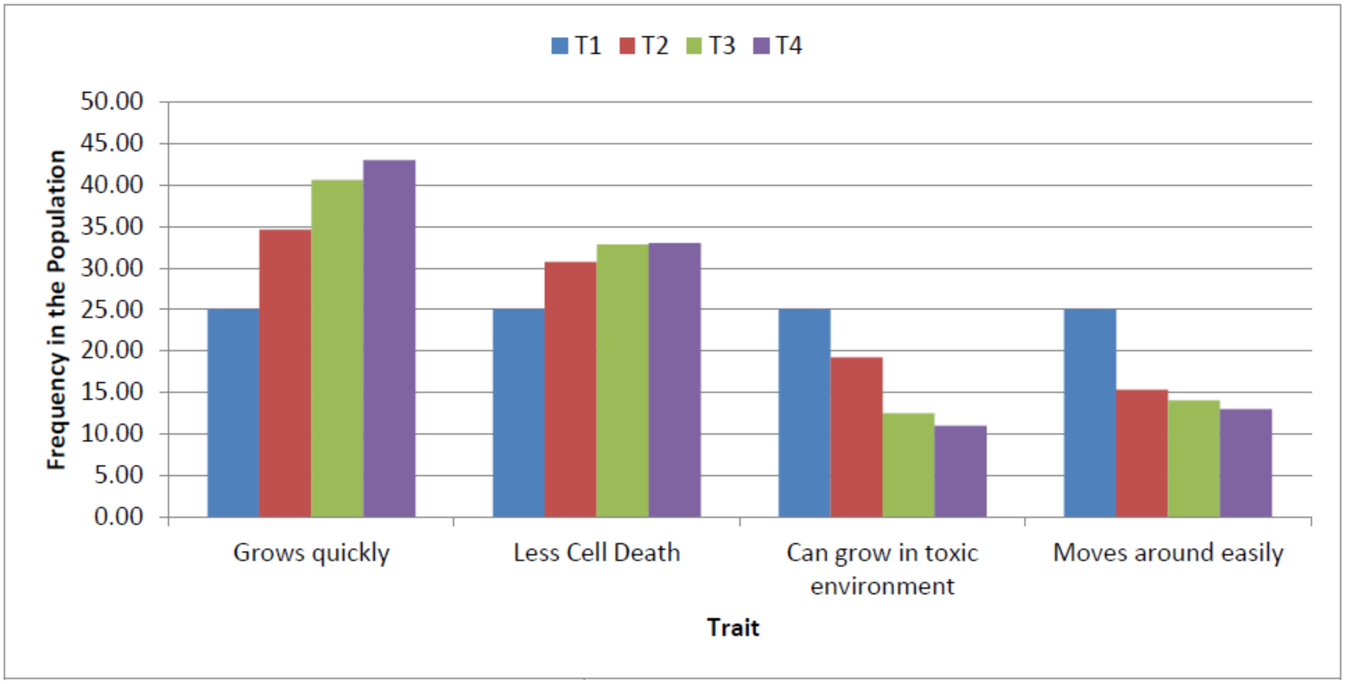


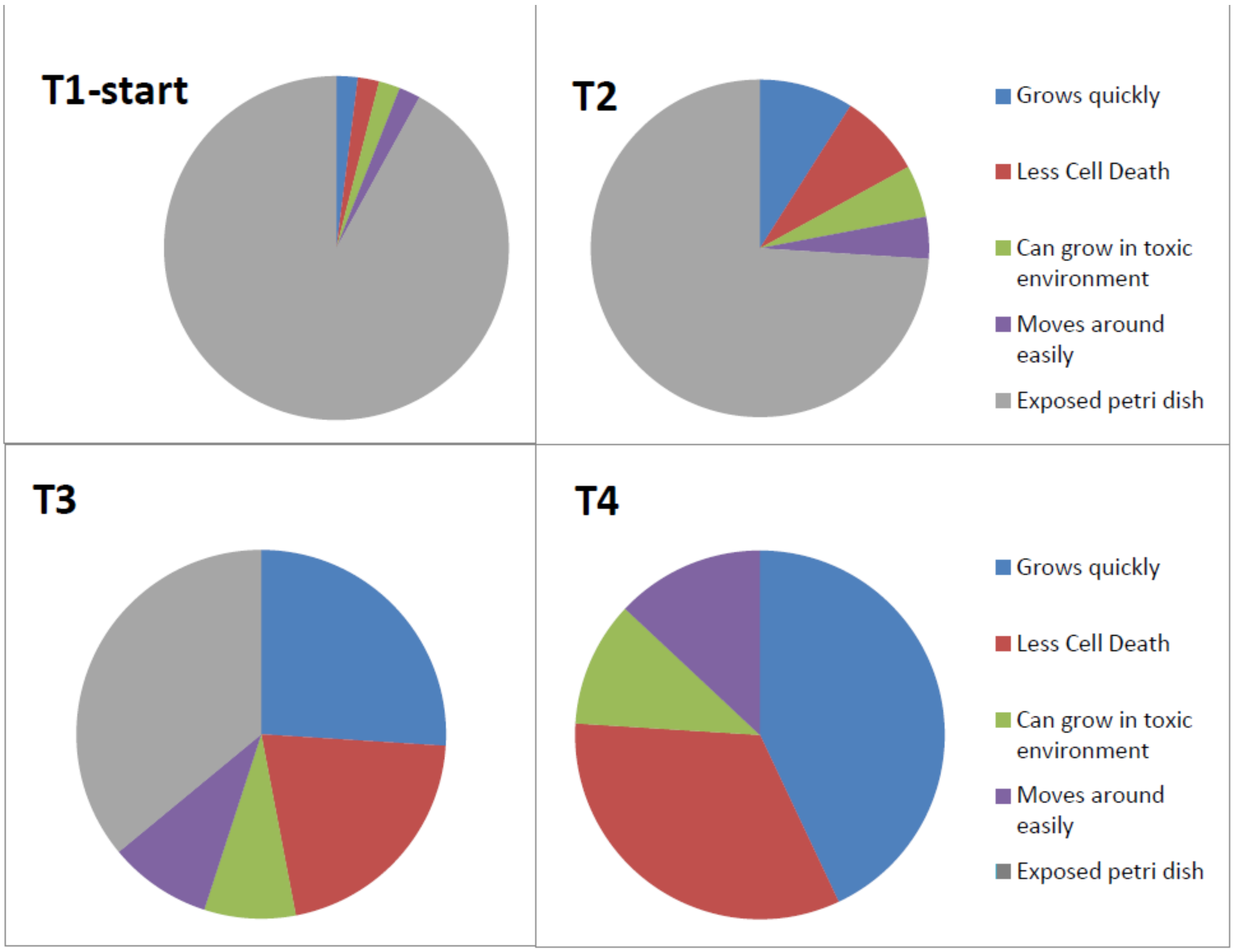


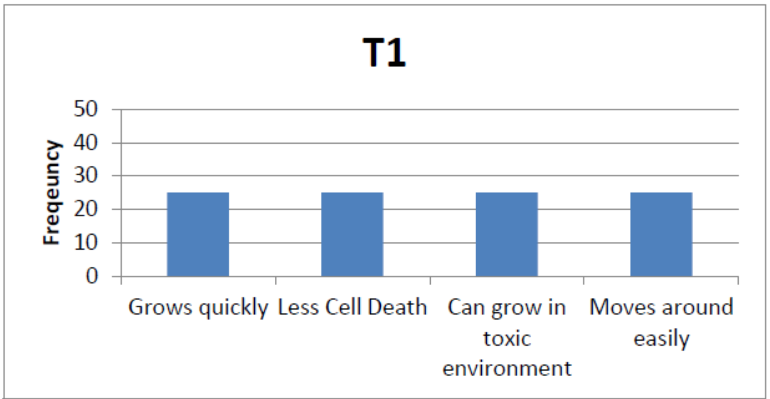


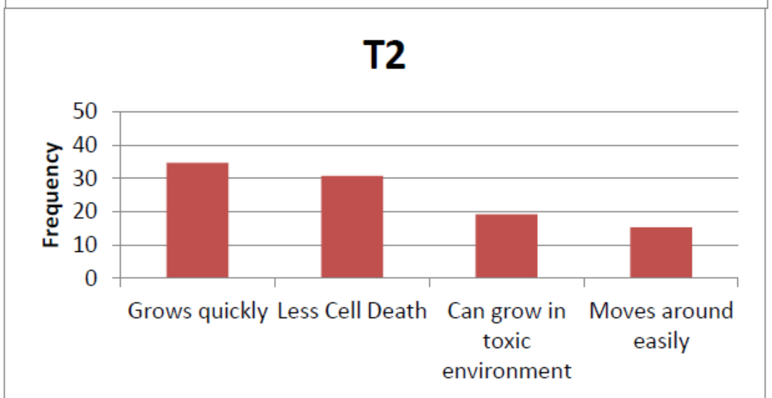
Sample Answers:

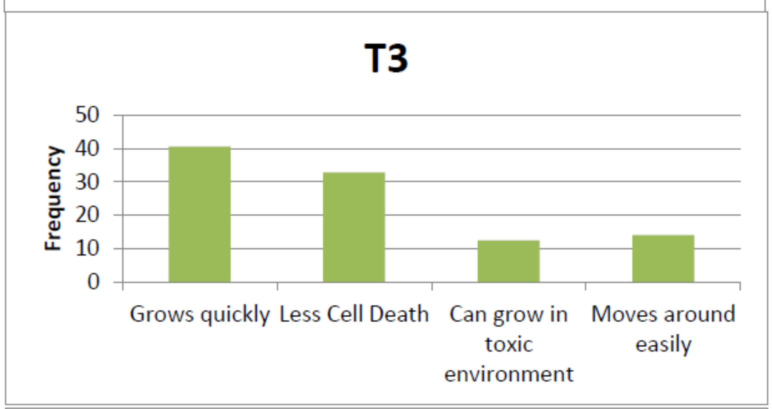
Examples of different plot types showing the change in frequency of traits in the bacterial population of a petri dish over time (Task Component A)

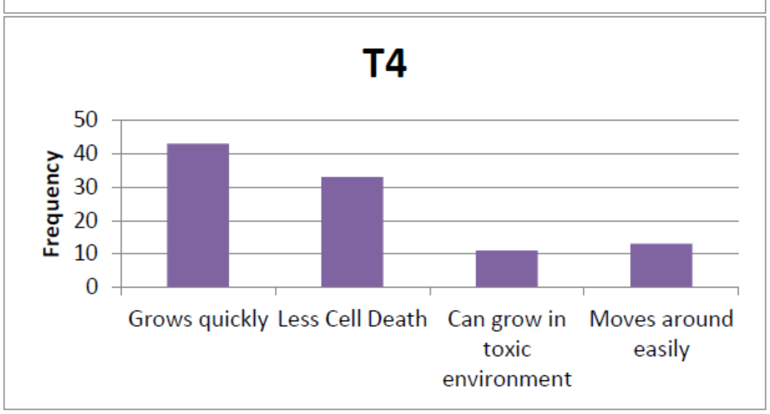



T1-start
T2
Grows quickly
Less Cell Death
Can grow in toxic environment
Moves around easily
Exposed petri dish
T3
T4
Grows quickly
Less Cell Death
Can grow in toxic environment
Moves around easily
Exposed petri dish


T1
Freqeuncy
50
40
30
20
10
0
Grows quickly
Less Cell Death
Can grow in toxic environment
Moves around easily


T2
Frequency
50
40
30
20
10
0
Grows quickly
Less Cell Death
Can grow in toxic environment
Moves around easily


T3
Frequency
50
40
30
20
10
0
Grows quickly
Less Cell Death
Can grow in toxic environment
Moves around easily


T4
Frequency
50
40
30
20
10
0
Grows quickly
Less Cell Death
Can grow in toxic environment
Moves around easily

Examples of the scatterplots showing the change in frequency of Variant X and Y in the bacterial population over time (Task Component B)