**Subject area/course**: Science/Life Science

**Grade level/band**: 7-8

**Task source**: Achieve

**Natural Selection and the Development of Antibiotic Resistance**

**STUDENT INSTRUCTIONS**

1. **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 widespread 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.

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.

1. **Final product**:

Task Component 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 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.

1. 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.
2. 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.
3. 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.

Task Component 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.

1. 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:
2. Discuss whether the data can be modeled by a function, including any features of the function (linear/nonlinear, increasing/decreasing, etc.).
3. Describe any proportional relationships that could be inferred from the data.
4. Discuss the probability that one of the gene variants provides streptomycin antibiotic resistance to bacteria in the population.
5. 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.
6. 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.

Task Component 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.

1. 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.
2. 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.

Task Component 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.

**Additional Information**

1. **Knowledge and skills you will need to demonstrate on this task:**
* Analyzing and interpreting data
* Applying concepts of heredity and natural selection to make sense of data
* Synthesizing information and thinking critically to make a recommendation for responsible use of antibiotics
1. **Materials needed:**
* Access to the Internet and/or a set of articles is necessary for students to research solutions to antibiotic resistance in bacteria.
* 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>
1. **Time requirements:**

This task will take approximately 2 weeks for complete. Your teacher will provide additional details regarding deadlines and due dates.

1. **Scoring:**

Your teacher will provide information regarding scoring for your work.