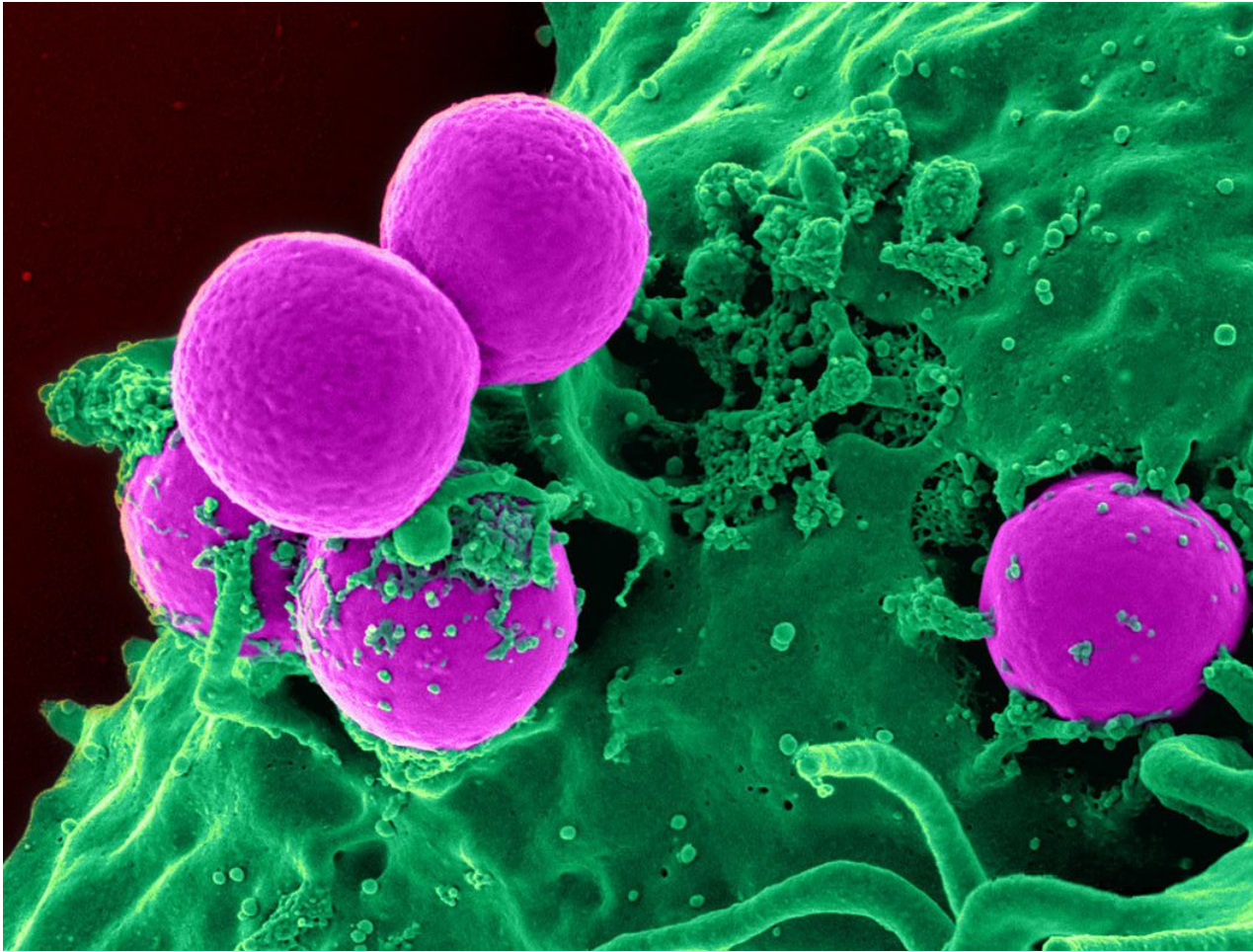


Humans vs. Bacteria - Student Materials

Unit 2

Biology



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Unit Opening

Unit 2 Humans vs. Bacteria

Biology

Student Name:

Tell the Story

Directions:

1. Silently read the texts provided to you.
2. Circle three details that are most important to the phenomenon being described.
3. Share with your group. Each person should identify the details that they circled.
4. Discuss as a group, and determine the overall story. What is the phenomenon?

Text #1

In the 1970s many experts thought that the fight against infectious diseases was over. In fact, in 1970, the Surgeon-General of the United States of America indicated that it was "time to close the book on infectious diseases, declare the war against pestilence won, and shift national resources to such chronic problems as cancer and heart disease".

During the last two decades, this opinion has been reversed, and there is now a renewed appreciation of the importance of infectious disease. The spread of new diseases such as HIV/AIDS, hepatitis C, and dengue haemorrhagic fever, and the resurgence of diseases long since considered under control such as malaria, cholera, and sleeping sickness, have drawn considerable attention.

Over the past 200 years there have been multiple devastating outbreaks of cholera caused by the bacteria, *V. cholerae*. Cholera is an infectious and deadly bacterial disease that affects the small intestine. The infection causes severe vomiting and diarrhea. The infection is typically spread from person to person and through infected food and water.

In 1832, there was a cholera outbreak in New York City that killed 3,515 people or 1.5% of the city's population. New York was struggling to keep up with the growing population, the city was overcrowded, there was a lack of sanitation, and science did not yet recognize the role of germs in disease. Cholera overwhelmingly affected the poorest neighborhoods in the city, hitting African-Americans and immigrant Irish Catholics the most. Many of the high income people from the city were able to leave the city and prevent themselves from getting sick.

In 2010, an outbreak of cholera was confirmed in Haiti for the first time in more than 100 years just ten months after the catastrophic earthquake killed over 200,000 people and left over 1 million people without a secure place to live. In this outbreak there were over 665,000 cases and 8,183 people died. A more recent outbreak of cholera occurred in Kenya in 2017 with 3,967 confirmed cases and 76 deaths. Epidemiologists believe the disease was transmitted during mass gathering events and at refugee camps within the country.

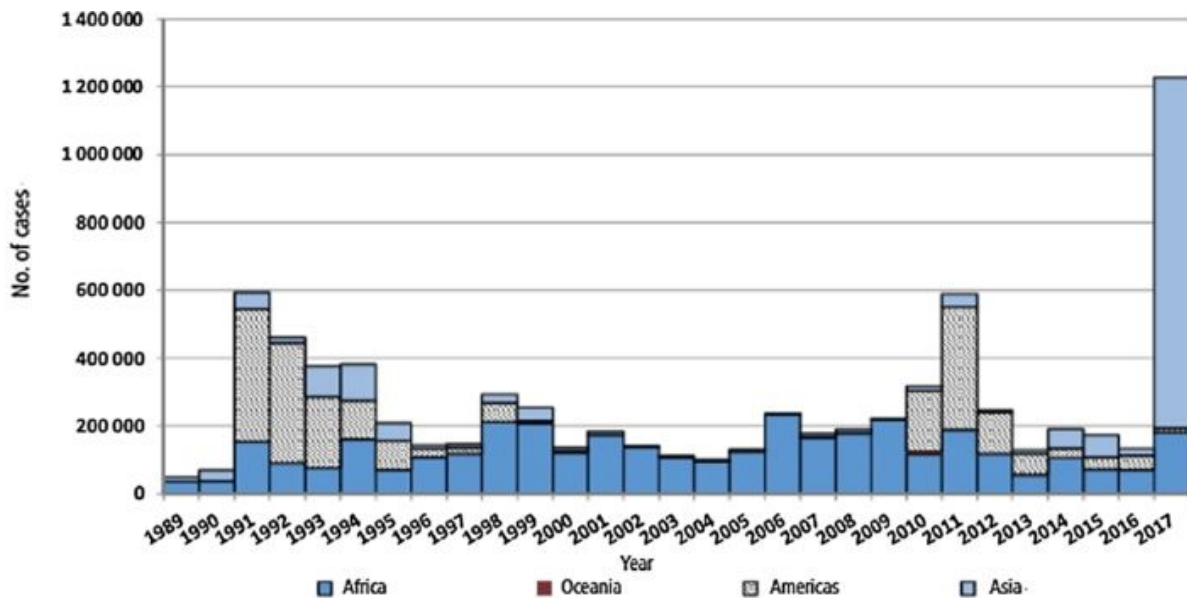
Scientists are concerned because they noticed that some antibiotics used to treat cholera are not working as well as they have in the past. Furthermore, the vaccine for cholera is not always effective in the long term and is not a commonly given immunization by most doctors. Researchers have estimated the bacteria, *V. cholerae* may infect between 1.3 and 4 million people and cause 21,000 to 143,000 deaths worldwide a year. How could we prevent a severe outbreak in the future?

Source: <https://www.who.int/csr/resources/publications/introduction/en/index1.html>

Source: World Health Organization (2019) <https://www.who.int/news-room/fact-sheets/detail/cholera>

Text #2

Number of cholera cases reported to WHO by year and by continent, 1989–2017.



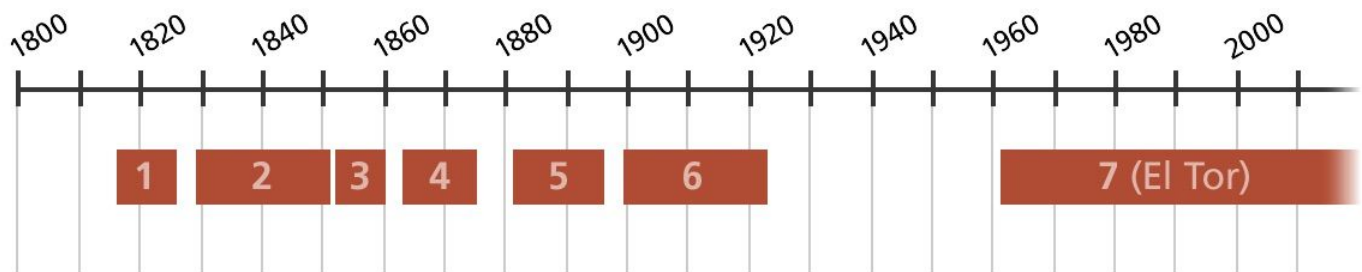
From reference: Cholera, 2017. Wkly Epidemiol Rec 2018; 93(38): 489-500.

Number of cholera cases reported to WHO by year and by continent, 1989–2017.

Text #3

Of the many different strains (types) of *V. cholerae*, only a few cause pandemic disease. A pandemic is an outbreak of a disease that occurs worldwide or over a very large geographical area. There have been six cholera pandemics recorded since 1816. The seventh pandemic was first seen in El Tor, Egypt and continues on to this day.

Cholera pandemics



A timeline showing the seven cholera pandemics throughout history

Humans vs Bacteria

What is the overall story?

Important details our group surfaced (provide at least 5):

1. _____
2. _____
3. _____
4. _____
5. _____

Overall Story of the Phenomenon (based on group discussion):

Use the sentence starters:

- In the past
- Currently
- In the future

Based on the phenomenon, what is an important problem we are facing?

Performance Task Organizer

Unit 2 Humans vs. Bacteria

Biology

Student Name:

What strategies do we have to prevent a future Cholera outbreak?

In this performance task you will develop an argument to support a claim on the best solution we have to deal with *V. cholerae*.

As you engage with investigations, readings, and discussions throughout this unit, you will use this organizer to record your ideas on what is the strongest evidence and scientific reasoning to use in your argument on the best strategy to prevent a future Cholera outbreak.

1. Describe the problem:

2. Why is this an important problem to find a solution to?

Initial Argument

Based on your current understanding of the problem, how would you address the problem? Provide the strongest evidence and scientific reasoning to support your claim.

The Black Death Argument

Our guiding question: How can we learn from past disease outbreaks such as The Black Death?

1. What did we figure out from the investigations and resources that might help us answer our driving question?

Resource: Engage → Historical Documents

What did you figure out?

Investigation: Explore/Explain → Disease Transmission

What did you figure out?

Investigation: Explore/Explain → Natural Selection

What did you figure out?

2. For each of the following claims, identify evidence and associated scientific reasoning that support that claim. Additionally, identify evidence and/or scientific reasoning that might refute the claim. The graphic organizer above may be helpful as you review the investigations and resources you have engaged with throughout the Black Death learning sequence.

Claim#1: Focus on Immunity - Enough people will be immune to cholera

Evidence that supports the claim:

Scientific reasoning that supports the claim (or connects the claim and evidence):

Evidence or scientific reasoning that may refute the claim:

Claim #2: Focus on disrupting transmission - We need to interrupt how cholera is transmitted.

Evidence that supports the claim:

Scientific reasoning that supports the claim (or connects the claim and evidence):

Evidence or scientific reasoning that may refute the claim:

3. How did you figure out which evidence was supportive or not supportive?

4. Which of these BEST relates to how you figured it out?

☐ Patterns ☐ Cause and Effect

5. At this point in the unit how do you think we can prevent another Cholera outbreak? Support your answer using evidence and scientific reasoning from your responses above.

Antibiotic Resistance Argument

Our guiding question: Why are some antibiotics not working as well as they used to?

1. What did we figure out from the investigations and resources that might help us answer our driving question? List out all of the investigations from this learning sequence and what you figured out from completing the investigation.

2. What important scientific concepts did you learn about it in this learning sequence that might help you respond to the guiding question.

3. For the following claim, identify evidence and associated scientific reasoning that support that claim. Additionally, identify evidence and/or scientific reasoning that might refute the claim.

Claim: Focus on Antibiotic Resistance - We need to stop *V. cholerae* from becoming resistant to antibiotics.

4. Evidence that supports the claim:

5. Scientific reasoning that supports the claim (or connects the claim and evidence):

6. Evidence or scientific reasoning that may refute the claim:

7. How did you figure out which evidence was supportive or not supportive?

8. Which of these BEST relates to how you figured it out?

☐ Patterns ☐ Cause and Effect

9. At this point in the unit how do you think we can prevent another Cholera outbreak? Support your answer using evidence and scientific reasoning from your responses above.

The Microbiome Argument

Our guiding question: Why can we treat a bacterial infection with other bacteria?

1. What did we figure out from the investigations and resources that might help us answer our driving question? List out all of the investigations from this learning sequence and what you figured out from completing the investigation.

2. What important scientific concepts did you learn about it in this learning sequence that might help you respond to the guiding question?

3. For the following claim, identify evidence and associated scientific reasoning that support that claim. Additionally, identify evidence and/or scientific reasoning that might refute the claim.

Claim: Focus on The Microbiome - We can leverage a healthy microbiome in order to reduce the chances of a cholera infection.

4. Evidence that supports the claim:

5. Scientific reasoning that supports the claim (or connects the claim and evidence):

6. Evidence or scientific reasoning that may refute the claim:

7. How did you figure out which evidence was supportive or not supportive?

8. Which of these BEST relates to how you figured it out?

☐ Patterns ☐ Cause and Effect

9. How did you evaluate the strength of evidence?

10. At this point in the unit how do you think we can prevent another Cholera outbreak? Support your answer using evidence and scientific reasoning from your responses above.

Our guiding question: How and why do bacteria cooperate, and how does bacteria cooperation impact human infections?

1. What did we figure out from the investigations and resources that might help us answer our driving question? List out all of the investigations from this learning sequence and what you figured out from completing the investigation.

2. What important scientific concepts did you learn about it in this learning sequence that might help you respond to the guiding question?

1. For the following claim, identify evidence and associated scientific reasoning that support that claim. Additionally, identify evidence and/or scientific reasoning that might refute the claim.

Claim: Focus on Disrupting Bacteria Cooperation - We can prevent infections/outbreaks by disrupting bacterial cooperation

2. Evidence that supports the claim:

3. Scientific reasoning that supports the claim (or connects the claim and evidence):

4. Evidence or scientific reasoning that may refute the claim:

5. How did you figure out which evidence was supportive or not supportive?

6. Which of these BEST relates to how you figured it out?

☐ Patterns ☐ Cause and Effect

7. How did you evaluate the strength of evidence?

8. At this point in the unit how do you think we can prevent another Cholera outbreak? Support your answer using evidence and scientific reasoning from your responses above.

Final Argument

The Phenomenon

At the start of the unit, we identified a phenomenon. Identify the phenomenon below, and explain your understanding of the phenomenon, using evidence and ideas from the unit.

The Problem

Describe the problem that we investigated throughout this unit.

Develop Your Final Argument

Develop an argument to support a claim on the best solution we have to address the problem you identified above. Support your answer using evidence and scientific reasoning from the unit and include an explanation of a counterclaim.

Final Argument Rubric

Component	Not Evident	Level 1: Beginning	Level 2: Developing	Level 3: Advancing	Level 4: Proficient
Claim/ Counterclaim	Does not make a claim or counterclaim	A claim is provided, but does not address the problem.	A claim(s) are provided that addresses the problem.	Claim(s) addresses the problem, and a counterclaim is provided, but one or both is inaccurate, inappropriate, or incomplete.	Claim(s) and counterclaim(s) address the problem, are accurate, appropriate, and complete.

Note: All of the suggested claims provided in the performance task organizer can be considered as accurate, appropriate, and complete. Additional claims could also be acceptable. Furthermore, students may combine one or two complementary claims in offering the best solution to the problem. Students should not be expected to address every suggested claim.

Evidence	Does not provide evidence	Only provides inappropriate evidence (evidence does not support the claim)	Provides appropriate, but insufficient evidence to support the claim. May include some inappropriate evidence	Provides appropriate and sufficient evidence to support the claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support the claim
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Note: Appropriate evidence is observations or data collected during an investigation, or secondary data sets from a reputable source.. Scientific ideas or concepts related to the claim are not considered evidence for a claim. To demonstrate sufficient evidence, students should have at least two examples of evidence for each claim discussed. Students are not expected to provide specific examples of evidence for the counterclaim (although it could be included as appropriate).

Reasoning: Science Concepts	Does not include reasoning	Restates evidence and does not include explanation of science concepts	Includes explanation of science concepts but all are inappropriate concepts that do not link evidence to claim	Includes explanation of some science concepts that link evidence to the claim, but are insufficient (one or more concepts that should have been included are not included) or some are inappropriate	Includes explanation of science concepts that link evidence to the claim (concepts are appropriate), and they are sufficient (no omission of key science concepts) and are clearly stated and accurate.
--	----------------------------	--	--	--	---

Note: The scientific concept of natural selection (and/or related ideas such as mutation, competition, etc.) must be discussed to have a sufficient explanation. Depending on the claim, at least one other science concept must be discussed for a sufficient explanation including; disease transmission, ecology, and cooperation.

Reasoning: Logic	Does not include reasoning	Restates evidence or claim and does not include a logic statement that links the evidence to the claim	Attempts to include a logic statement that links the evidence to the claim but does not adequately link the evidence to the claim.	Includes a logic statement that attempts to link the evidence with the claim but needs to be more clearly stated to demonstrate logical reasoning	Includes a logic statement that links the evidence to the claim (including words such as <i>because</i> and <i>therefore</i>) that clearly demonstrates logical reasoning
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Evaluation	Does not include an evaluation	Does not attempt to critique the argument or does not attempt to discuss the use of cause and effect or patterns in developing the argument	Attempts a critique of the argument and a discussion of the use of cause and effect or patterns in developing the argument but both are incomplete.	Includes an incomplete critique of the argument (missing strengths, weaknesses, or additional evidence/concepts needed) or an incomplete discussion of the use of cause and effect or patterns in developing the argument	Includes a complete critique of the argument (including strengths and weaknesses) and suggestions for additional evidence or scientific reasoning and clearly articulates the use of cause and effect or patterns in developing the argument
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Argument Evaluation

Use all of your resources from the unit (Performance Task Organizer, class notes, handouts) to respond to the following reflection prompts.

Part 1: Developing a Scientific Argument

1. How would you describe a scientific argument? How has your thinking changed since the beginning of the unit?
2. Describe how a peer or activity from the unit changed your thinking on what a scientific argument is and how they can be used.
3. What questions do you still have on how to develop or critique a scientific argument?

Part 2: Final Performance Argument Task

1. All arguments have strengths and weaknesses, discuss the strengths and weaknesses of your final argument.
2. In generating your final argument, you made decisions on what claim to support, and which evidence to use. Discuss your decision making process, giving specific examples from your argument.
 - a. How did you differentiate between cause and correlation?
 - b. How did you use evidence to make claims about specific causes and effects in your argument?
 - c. How did you use observed patterns to support evidence for causality in your argument?
3. How could you improve your final argument? What other types of evidence would help support your claim?

The Black Death 5E

Unit 2 Humans vs. Bacteria

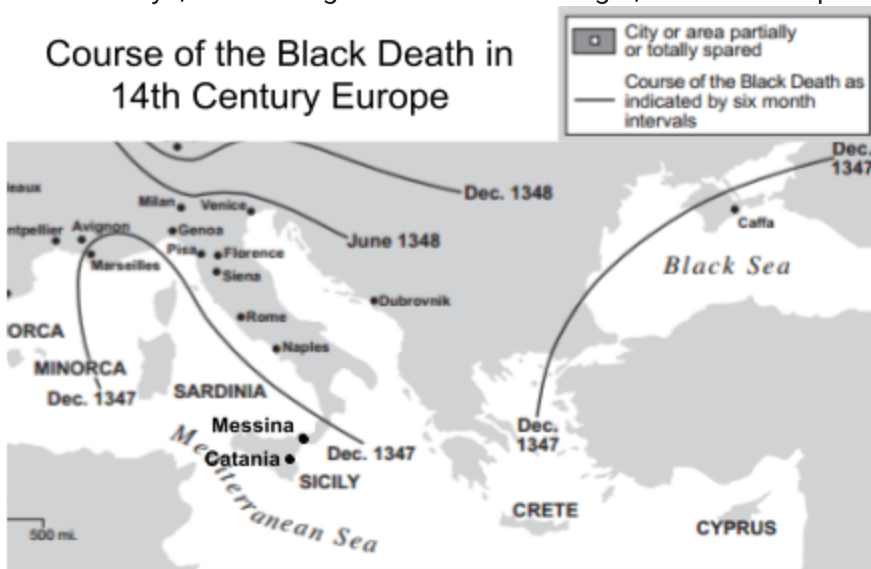
Biology

Student Name:

Black Death Historical Description

Michael Platiensis lived in Messina, the first port city in Europe to feel the effects of the plague. The following document is his description of the arrival and progress of the disease in 1347, though the account was written in 1357.

At the beginning of October, in the year of the incarnation of the Son of God 1347, twelve Genoese galleys [trading ships] . . . entered the harbor of Messina. In their bones they bore so virulent a disease that anyone who only spoke to them was seized by a mortal illness and in no manner could evade death. The infection spread to everyone who had any contact with the diseased. Those infected felt themselves penetrated by a pain throughout their whole bodies and, so to say, undermined. Then there developed on the thighs or upper arms a boil about the size of a lentil which the people called "burn boil". This infected the whole body, and penetrated it so that the patient violently vomited blood. This vomiting of blood continued without intermission for three days, there being no means of healing it, and then the patient expired.



Adapted from the New York State Education Department . January 2011. Global History Exam. Internet. Available [here](#); accessed July 16, 2017.

Not only all those who had speech with them died, but also those who had touched or used any of their things. When the inhabitants of Messina discovered that this sudden death emanated from the Genoese ships they hurriedly ordered them out of the harbor and town. But the evil remained and caused a fearful outbreak of death. Soon men hated each other so much that if a son was attacked by the disease his father would not tend him. If, in spite of all, he dared to approach him, he was immediately infected and was bound to die within three days. Nor was this all; all those dwelling in the same house with him, even the cats and other domestic animals, followed him in death. As the number of deaths increased in Messina many desired to confess their sins to the priests and to draw up their last will and testament. But ecclesiastics [clergy who work for the Catholic Church], lawyers and notaries refused to enter the houses of the diseased.

Soon the corpses were lying forsaken in the houses. No ecclesiastic, no son, no father and no relation dared to enter, but they hired servants with high wages to bury the dead. The houses of the deceased remained open with all their valuables, gold and jewels. . . . When the catastrophe had reached its climax the Messinians resolved to emigrate. One portion of them settled in the vineyards and fields, but a larger portion sought refuge in the town of Catania. The disease clung to the fugitives and accompanied them everywhere where they turned in search of help. Many of the fleeing fell down by the roadside and dragged themselves into the fields and bushes to expire. Those who reached Catania breathed their last in the hospitals there. The terrified citizens would not permit the burying of fugitives from Messina within the town, and so they were all thrown into deep trenches outside the walls.

Thus the people of Messina dispersed over the whole island of Sicily and with them the disease, so that innumerable people died. The town of Catania lost all its inhabitants, and ultimately sank into complete oblivion. Here not only the "burn blisters" appeared, but there developed gland boils on the groin, the thighs, the arms, or on the neck. At first these were of the size of a hazel nut, and developed accompanied by violent shivering fits, which soon rendered those attacked so weak that they could not stand up, but were forced to lie in their beds consumed by violent fever. Soon the boils grew to the size of a walnut, then to that of a hen's egg or a goose's egg, and they were exceedingly painful, and irritated the body, causing the sufferer to vomit blood.

The sickness lasted three days, and on the fourth, at the latest, the patient succumbed [gave in; died]. As soon as anyone in Catania was seized with a headache and shivering, he knew that he was bound to pass away within the specified time. . . . When the plague had attained its height in Catania, the patriarch endowed all ecclesiastics, even the youngest, with all priestly powers for the absolution [forgiveness] of sin which he himself possessed as bishop and patriarch. But the pestilence [disease] raged from October 1347 to April 1348. The patriarch himself was one of the last to be carried off. He died fulfilling his duty. At the same time, Duke Giovanni, who had carefully avoided every infected house and every patient, died.

This account is from Michael Platiensis (1357), quoted in Johannes Nohl, *The Black Death*, trans. C.H. Clarke (London: George Allen & Unwin Ltd., 1926), pp. 18-20.

<http://web.archive.org/web/20091001151555/http://www.boisestate.edu/courses/westciv/plague/07.shtml>

Disease Transmission Investigation Part 1

Introduction:

In discussing The Black Death (the Black Plague), you may have noticed that the disease was passed from one person to another. The passing or the transfer of a disease between two people is called **disease transmission**. In this investigation, we will model how disease transmission works in order to better understand why some people became sick with the plague, while others did not.

Research Question:

Predict:

1. Based on your prior knowledge, how do you think disease is transmitted between people?

2. Based on your prior knowledge, under what conditions does disease transmission occur at a faster rate? (in other words, why would a disease be transmitted either faster or slower between people?)

Materials per Individual:

- ☒ Plastic cup (1 per student)
- ☒ Dilute sodium hydroxide
- ☒ Computer access
- ☒ Phenolphthalein pH indicator solution
- ☒ Droppers

Procedure:

Round 1

1. Obtain a clear plastic cup or beaker, containing 20 ml of fluid from the teacher. This represents your bodily fluids (mucus, spit, blood, vomit, etc.). If you have the disease, it would be found in your bodily fluids.
2. Find a partner to exchange bodily fluids (fluid in your cup).

3. Use the dropper to pull up approximately 2-3 ml of fluid from your cup, and deposit in your partner's cup. Your partner will do the same thing, depositing their fluid into your cup.
4. On your data table, indicate who you have exchanged fluids with.

Round 2

1. Repeat steps 2-4, using the same cup and fluid you were given in the beginning
2. Tracking Transmission
3. Your teacher will come by and 'diagnose' your cup, by dropping in an indicator.
4. If the fluid in your cup stays clear, you are healthy (you do not have the disease)
5. If the fluid in your cup becomes pink, you have the disease.
6. Fill in the data table to indicate which cups became infected
7. Using the data collected, generate a graph that best represents your data.

Modeling Disease Transmission:

Using a legend, annotations, and/or diagrams generate a representation of how you are modeling each of the following components in this investigation: bodily fluids, healthy, ill, transmission, diagnosis, time

Data:

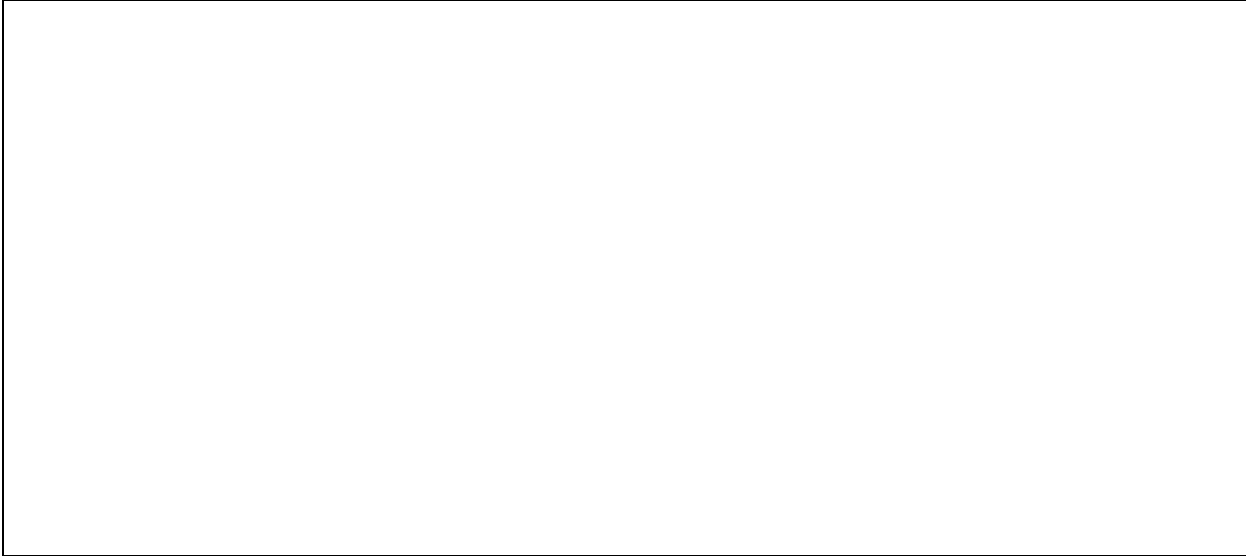
Round 1 partner

Round 2 partner

Name	☒ if sick	Name	☒ if sick

Graph of Class-wide Data:

Title



Data Analysis:

1. Review the data you collected during the investigation. What trends do you notice?

2. How did the probability of becoming infected change over the course of the simulation?

Evaluation:

3. Evaluate the data you collected. Does it address your research question? Be sure to consider:
 - a. Strengths
 - b. Limitations
 - c. Questions you still have about disease transmission
 - d. Suggestions for collecting additional data to address your research question

4. Return to the model you generated in order to represent the different components of the simulation that you carried out. Evaluate the simulation in representing the process of disease transmission. Be sure to consider:
 - a. Strengths
 - b. Limitations
 - c. Suggestions to improve the simulation
 - d. Questions you still have about disease transmission

Disease Transmission Investigation Part 2

In the first part of this investigation, you may have experienced a physical simulation of how infectious disease may spread in a small, enclosed population, when the disease is spread through bodily fluids. In this part of the investigation, you are going to use an online simulator to explore how transmission plays out in real populations. To access the simulation go to:

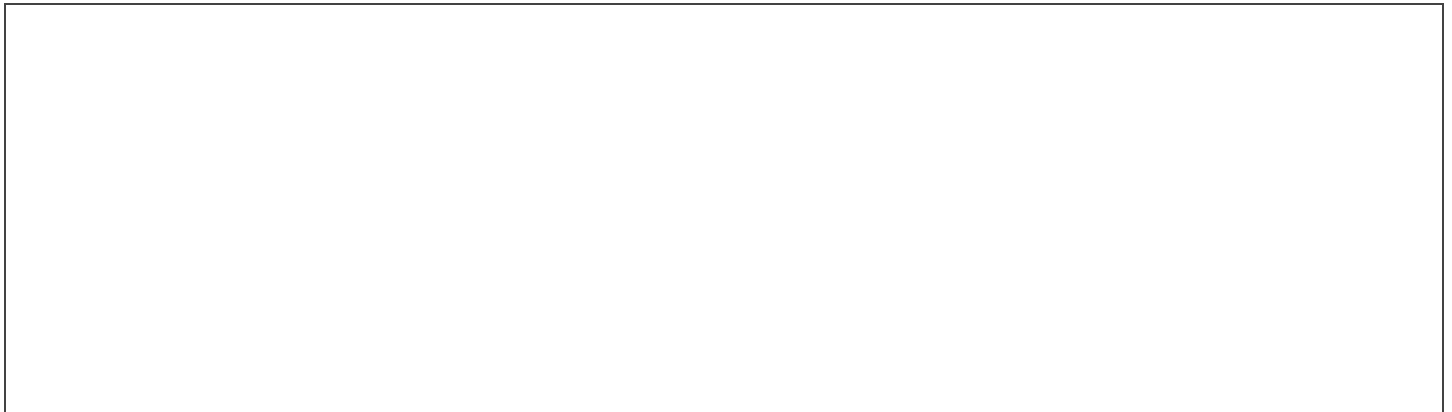
<https://www.learner.org/courses/envsci/interactives/disease/disease.html>

Research Question:

Predict:

Based on the simulation or on your prior knowledge, what variables do you predict will increase the rate of disease transmission in a population? Which of these variables will have the greatest impact on the rate of disease transmission?

Represent your thinking in a graph in the space provided below. Be sure to include each of the variables you identified above.



Procedure:

Explore how to use the simulation.

1. Look over the different settings available in the animation
2. Be aware that the simulation uses a nickname to represent each disease, for example, 'kold' (instead of cold).
3. Run the simulation a few times, using any setting that you would like, paying attention to both the graph and visual representation that demonstrates transmission of the disease, the death rate, the number of

sick days in the population, and the final level of immunity.

4. Reset the animation, by clicking on the green reset button on the upper left hand portion of the screen, and hit the grey 'presets' button to return to all of the original settings.

Use the simulation to generate comparative data on two different types of diseases; the relatively virulent (deadly) disease, **Red Death** and the less virulent disease, '**Impfluenza**'. Additionally, you will use the animation to revise your initial graphical representation of how population density and population mixing impacts the rate of transmission.

5. Set the animation for both diseases at medium for population density and population mixing.
6. Run the simulation and collect the data for both diseases, using the data table below
7. Reset the animation
8. Set the animation for both diseases at high for population density and population mixing.
9. Run the simulation and collect the data for both diseases, using the data table below.

Data Table 1. Comparison at Medium Population Density & Medium Population Mixing

	Red Death	Impfluenza	Graph
Death Toll			
Number of Sick Days			
Percentage chance of survival after 100 days			
Probability that an individual surviving 100 days has become immune			

Data Table 2. Comparison at High Population Density & High Population Mixing

	Red Death	Impfluenza	Graph
Death Toll			
Number of Sick Days			
Percentage chance of survival after 100 days			
Probability that an individual surviving 100 days has become immune			

See-Think-Wonder

Use the graphic organizer below to record your ideas from the investigation.

See Things I see in the data collected	Think Ideas that this data makes me think about	Wonder Questions and wonderings I have about the data
• At which population density is there a greater level of transmission? At which population mixing level? • How did the probability of becoming immune change over time in both cases? • Which disease was more contagious? How does that impact the rate of transmission?	• Why do you see the trends noticed in the 'see' column? • What do you think would happen in the classroom simulation if we had a smaller classroom or a larger class? Why? • What other variables might impact transmission that were not investigated in either simulation?	

Conclusion:

Based on both simulations, describe how different variables impact the rate of disease transmission.

Evaluation:

1. Compare these two simulations in terms of limitations and how they helped you understand the phenomenon.

	Classroom Modeling of Disease Transmission	Simulation of Disease Transmission in a Population
How this simulation helped me understand disease transmission		
Limitations of this simulation		

2. Which simulation provided the most useful scientific evidence that can be used to make claims about disease transmission? Why?

3. What else do we need to know about why some people survived the Black Death?

Disease Transmission Investigation Rubric

Student Rubric - Disease Transmission Investigation

How did you do in the investigation?

Student Self-Score Circle one			
I know how this investigation connects to our current unit.	No - I need help.	Almost	Yes
I was able to contribute to the See-Think-Wonder and respond to the evaluation questions.	No - I need help.	Almost	Yes
I used my time well in this investigation.	No	Mostly	Yes
I plan to come in for extra help to complete parts of the investigation or ask questions.	No		Yes

What other resources could you have used to get more out of this investigation?

- More time
- More resources
- More information
- More help from my partners
- More help from my teacher
- Other:

Partner Rubric - Disease Transmission Investigation

How did your partners do in the investigation?

Directions: Think back to how your partners participated in the lab. For each of the four categories, write your partner's or partners' names in the appropriate box.

	Unsatisfactory	Pretty Good	Excellent
Contributions	Did not participate.	Did the minimum of what was required.	Provided useful ideas when participating in discussion
Working with Others	Rarely listened to others. Disrupted or discouraged others' attempts to participate.	Usually listened to, shared with, and supported the efforts of others.	Listened to, shared with, and supported the efforts of others.

Time Management

Procrastinated, did not use school time or schedule provided to get work completed.

Mostly used time well and completed investigation on time.

Used time well to ensure things get done on time.

The Black Death

The Black Death, also called Bubonic Plague, was a devastating disease that killed almost 50% of the population of Europe, and nearly one-fifth ($\frac{1}{5}$) of the world's population in the 1300's. At that time, most of Europe was ruled by a feudal system, in which a wealthy upper class owned much of the land, and poorer peasants farmed the land. The population of cities was also increasing at this time, but these Medieval cities did not have modern facilities that help maintain hygienic (clean) conditions for the inhabitants. For example, it was common practice for people to throw garbage and human waste directly into the streets.

Population of Medieval Europe

Year	Population in millions	Percent increase
1100	62.1	10
1200	68	9.5
1300*	78.7	15.7
1400	78.1	-0.8

* The Black Death occurred in the late 1340's

Scientists have studied ancient skeletons from the Medieval period in Europe to better understand what might have happened during the plague. According to one such scientist, Dr. Sharon DeWitte, many of the people that died from the Black Death were elderly, frail, and malnourished. Based on an analysis of over 700 skeletal remains, "the disease apparently removed the weakest individuals on a very broad scale over much of Europe, whether their frailty was due to poor immune systems, prior disease, or malnutrition."^[1]

The Black Death is caused by a **bacterium** called *Yersinia pestis*. Bacteria are microscopic organisms that live everywhere in our environment, as well as on and inside our bodies. Most bacteria are actually harmless, or even beneficial. However, some, like *Yersinia pestis*, are **pathogenic** (cause disease). *Yersinia pestis* is often found in rodents like rats. Rats, which were common in Medieval cities, often had fleas on them. The fleas bit the rats, then jumped onto humans and bit them, which spread the pathogenic bacteria to humans. Once the bacteria took hold and started multiplying inside a person, it caused the disease called the Black Death, which resulted in a failure of homeostasis in their body. The disease caused damage to tissues in the lymphatic and respiratory systems resulting in fever, vomiting, and large boils on the body. The bacteria were often able to spread from person to person through body fluid and coughing, bringing the disease to more people.

Scientists are able to describe how contagious a disease is by measuring the **R₀** (the reproduction number) of a pathogen. This number tells us the average number of people that one infected person will likely infect.

The R₀ of Common Diseases

Disease	Type of Pathogen	R ₀
Common cold	virus	2

Cholera	bacteria	9.5
Influenza (Flu)	virus	1
Rabies	virus	10
Bubonic Plague	bacteria	3.5
COVID-19	virus	2.2 - 5.7

[1] Shipman, Pat Lee. (2014). The Bright Side of the Black Death. *American Scientist* 102 (6), p 410. Retrieved from: <https://www.americanscientist.org/article/the-bright-side-of-the-black-death>.

Black Death Claims

Guiding Question:

Why did the Black Death result in such a high death toll?

Directions:

Below is a list of three possible claims that respond to the guiding question. Find evidence that addresses each claim in the following sources:

1. [Ted-Ed Black Death Video](#)
2. *Black Death Text*
3. *Disease Transmission Investigation P2*

Claim #1:

High population densities increased the rate of transmission.

Evidence for this claim

Claim #2:

The people who died of The Black Death were already sick or unhealthy (had an existing imbalance of homeostasis).

Evidence for this claim

Claim #3:

The bacterium that causes The Black Death is especially contagious, and it is especially virulent (causes severe disease).

Evidence for this claim

Summary Task

Today we completed a class consensus discussion! How did it go?

One thing that went well in the discussion:

One thing we can improve the next time we have a discussion:

One person who helped me learn today:

What did you learn from this person?

One idea that I contributed to my group or my class:

Consider what you've learned to answer these questions:

1. Based on all of the evidence and scientific reasoning you considered, what caused such a high death toll during the Black Death?

2. What other evidence might you need to explain the cause(s) behind why the Black Death had such a high death toll?

3. Why do you think that bubonic plague has not been a big problem in modern-day Europe or the US?

Making Sense of Color Variation Over Time in Rock Pocket Mouse Populations Investigation

Directions:

After collecting and graphing your data (steps 1-6 in the investigation) fill in the See-Think-Wonder graphic organizer below. Use the prompts in the See and Think columns to get you started.

See Things that I see or notice in the data	Think What the data makes me think about, or connections that I can make	Wonder Questions that I have about the data
• What is the variation (difference in the mouse population) that we are investigating? • Which location and time had a higher proportion of light colored mice? Dark colored mice? • How did the probability of a mouse being light or dark change over time in each location? • What caused the environment to change in location B?	• How do the predators find the mice? Why is this important? • Why does the color of the fur change over time in location B but not in location A? • How does color influence the probability of survival for mice in each location? • After a volcanic eruption, which variation of fur color is more advantageous to mice? Why? • How are patterns in the data helpful in understanding the cause(s) behind the fur color change in the mouse population over time?	• Why are there a mix of both light and dark mice in both locations?

Color Variation Over Time in Pocket Mice Populations Investigation Rubric

Student Rubric - Color Variation Over Time in Pocket Mice Investigation

How did you do in the investigation?

Student Self-Score Circle one			
I know how this investigation connects to our current unit.	No - I need help.	Almost	Yes
I was able to contribute to the See-Think-Wonder.	No- I need help.	Almost	Yes
I used my time well in this investigation.	No	Mostly	Yes
I plan to come in for extra help to complete parts of the investigation or ask questions.	No		Yes

What other resources could you have used to get more out of this investigation?

- More time
- More resources
- More information
- More help from my partners
- More help from my teacher
- Other:

Partner Rubric - Color Variation Over Time in Pocket Mice Investigation

How did your partners do in the investigation?

Directions: Think back to how your partners participated in the lab. For each of the four categories, write your partner's or partners' names in the appropriate box.

	Unsatisfactory	Pretty Good	Excellent
Contributions	Did not participate.	Did the minimum of what was required.	Provided useful ideas when participating in discussion
Working with Others	Rarely listened to others. Disrupted or discouraged others' attempts to participate.	Usually listened to, shared with, and supported the efforts of others.	Listened to, shared with, and supported the efforts of others.

Time Management

Procrastinated, did not use school time or schedule provided to get work completed.

Mostly used time well and completed investigation on time.

Used time well to ensure things get done on time.

Natural Selection Text and Sequence Chart

Just like the rock pocket mice, human populations change over time and they possess variations that might become beneficial if the environment changes. Let's look at how variations in the human immune system may have played a role in surviving the black death.

Guiding question: How could genetic variations in the immune system of Medieval humans have contributed to their survival during the Black Death?

1. Read the text **Natural Selection**, identifying information that responds to the guiding question.
2. Use the sequence chart below to develop a sequence chart that addresses the guiding question.

Natural Selection Text

The changes in the rock pocket mice population explored in class is a result of **natural selection**. Evolution by natural selection is a process first described by two scientists, Charles Darwin and his contemporary Alfred Russel Wallace. Both scientists observed that all organisms are engaged in a struggle or competition for resources in their environment. Natural selection is the process by which organisms that are better **adapted** to their **environment** tend to survive and reproduce more offspring that have similar traits. Over time, natural selection can lead to changes in populations. All the diversity on earth that we can see today is ultimately due to populations changing over time due to natural selection.

In the pocket mice, we saw that the mice population had natural variation in their fur color. These variations arise from mutations (changes in DNA sequences) in sex cells (eggs and sperm). These **variations** are found in some individuals, and not others, because of sexual reproduction. In other words, sexual reproduction generates eggs and sperm that contain a variety of possible traits. These genetic variations are **heritable**; they can be passed from one generation to the next.

Humans, as a population, also have variations. Look around at your classmates. Some variations we can easily see, height and eye color are examples. However, many of the differences between people are traits that we cannot see. For example, some people make an enzyme, lactase, as an adult. These people are able to easily digest lactose, the sugar found in milk. Other people do not produce this variation; they are lactose-intolerant and cannot easily digest milk. Another example is blood type. Humans have different blood types, but this trait is not visible just by looking at someone.

Natural Variation and Disease Survival

Humans also possess variations in their immune system. Scientists have been studying variations in the immune system to better understand why some people died during the Black Death, and others did not. One group of scientists have been studying bones from very old cemeteries in London and Denmark. They took genetic samples (DNA samples) from almost 500 people that lived and died during a 100-year window before, during, and after the plague.

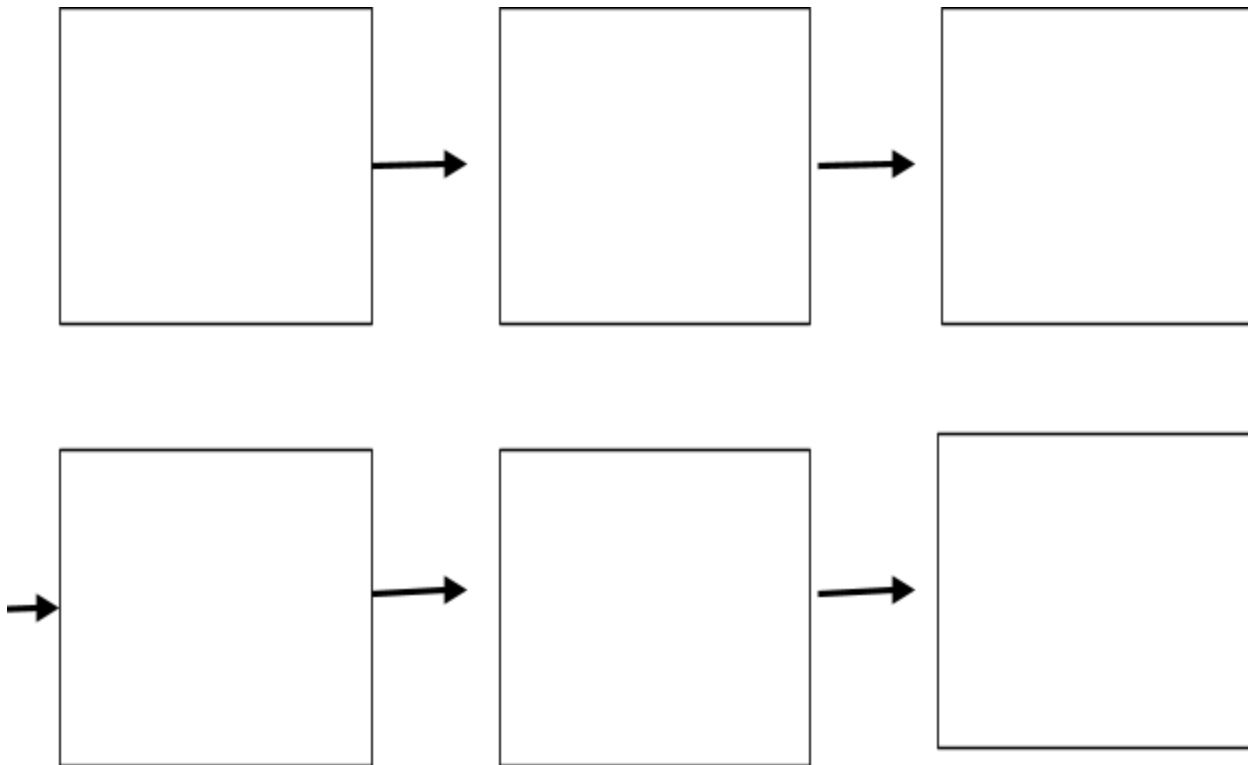
After they extracted and sequenced the DNA from the bones, the team found an astonishing 245 gene variants in immunity genes that rose and fell in frequency before and after the time of the Black Death. Changes in one gene were shown to be the most important, a gene called *ERAP2*. This gene helps immune cells recognize and fight threatening viruses. The scientists confirmed that it can also suppress the bacteria that causes the Bubonic Plague (*Y. pestis*).

People that were lucky enough to be born with the protective version of the *ERAP2* gene that gives some immunity to the bacteria were **twice as likely to have survived the plague** as those that inherited the version of the gene that was not as protective. Furthermore, they found that **the percentage of people in London that had the protective version of the gene increased by 10% after the plague, and by approximately 30% in Denmark.**

Therefore, people that had the protective gene were more likely to survive, reproduce and pass the gene for immunity on to their children – increasing the number of people in the population that have that gene. Because this all happened over the course of a couple of generations, this is the fastest example of human evolution ever studied.

Today, the protective variant of *ERAP2* is found in about 45% of the British population. However, having this variant today may have a cost, because it has been associated with auto-immune disorders such as Crohn disease and rheumatoid arthritis.

Sequence Chart



Think-Talk-Open Exchange + Buzzwords Note-catcher**Step 1:**

Think - Respond to the prompt individually, in the space below. Use as many of the buzzwords as possible.

How might natural variations in humans have contributed to their ability to survive diseases such as the Black Death?

Buzzwords: adaptation, variation, differential survival, heritable, therefore

Step 2:

Talk- Share with your group one at a time. Write a tally mark (||||) each time you hear a specific buzzword during the share.

	Adaptation	Variation	Differential survival	Heritable	Therefore
Person 1					
Person 2					

Step 3:

Open Exchange- As a group, discuss the following questions- be sure to use the buzzwords!

- Describe patterns or commonalities between what each group member shared.
- Which buzzwords did you hear the most? Least?
- Are there buzzwords that your group doesn't understand?
- Are there other words you heard a lot? If so, which words?

Step 4:

Reflection - Individually respond to the prompt below.

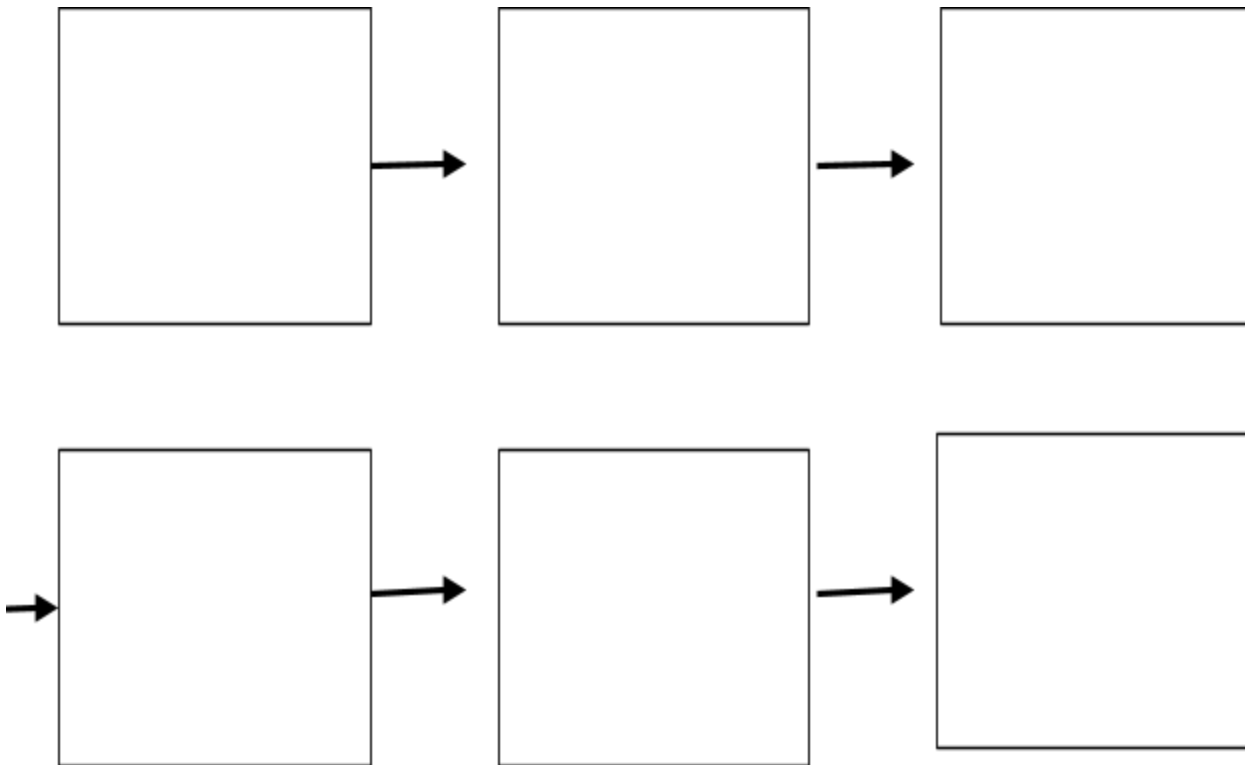
What are some new ideas you heard during your discussion with your group?

Pocket Mice Sequence Chart

Review: How did the rock pocket mice population change over time?

1. Read through the pocket mice cards, and put the cards on your desk in the best sequence. The sequence should represent the story of how the pocket mice population changed over time. Pay close attention to the **bolded** words.
2. Watch the video, [HHMI BioInteractive: Color Variation Over Time in Rock Pocket Mouse Populations Investigation](#) again, and modify the sequence as needed.
3. After you have confirmed the sequence, use the boxes below to describe the sequence of events for the pocket mice.

Sequence Chart



Independent reflection:

How did the probability of survival for mice of each color change over the course of this sequence?

Summary Task

Today we completed a class consensus discussion! How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

4. What did you learn from this person?

5. One idea that I contributed to my group or my class:

6. Many people died during The Black Death; however, some people were able to survive. Why did some people survive?

7. In the pocket mice investigation, what patterns in the data did you observe? Does the pattern in the data support the conclusion that the changes in the ratios of fur colors were caused by natural selection? Why or why not?

8. In the [The Making of the Fittest: Natural Selection and Adaptation](#) video, you observed how changes at the individual level of the mouse lead to changes in its fur color. How did observing that pattern help you understand what was causing the fur color change at the mice population level? How did both of these phenomena help you understand patterns of change in human traits at the population level?

9. In both cases of the mouse fur color and the human resistance to the Black Death, not every individual at the end of the sequence had the advantageous trait. Using the concepts of probability and proportion, explain why the final populations in both scenarios still had variation.

The Immune System

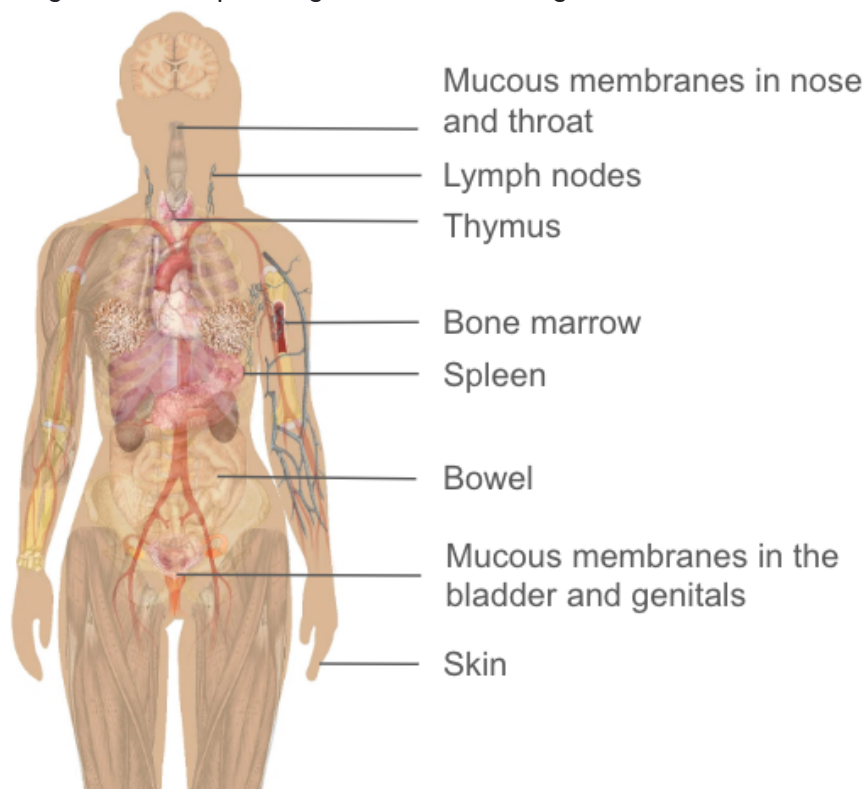
Guiding Question: How did the ERAP2 gene variant A protect some people from the Black Death?

As you just learned, ERAP2 is an example of a trait that you cannot see but that it has been selected by the environment we live in. There is a variant of this ERAP2 gene (variant A) that we inherited from the Neanderthals that makes our immune system more effective in fighting both viral and bacterial infections. Over the course of the last 10,000 years, humans have been exposed to many infectious diseases, like the bacteria that caused the black death. Humans carrying the ERAP2 variant A were more able to survive the viral or bacterial disease, survive, and pass the trait to their offspring. But how does this ERAP2 protein work? ERAP2 synthesizes a protein that helps the immune system find the threat by presenting a piece of the pathogen to the immune system. To make an analogy, this ERAP2 variant is like a fast photographer: it takes a quick picture of the pathogen and shows it to the immune system.

How does the immune system work?

There are many different parts of the immune system. Some parts work to block pathogens, and some have a more complex role to fight pathogens inside our bodies.

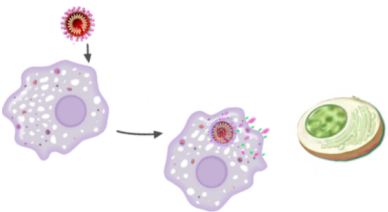
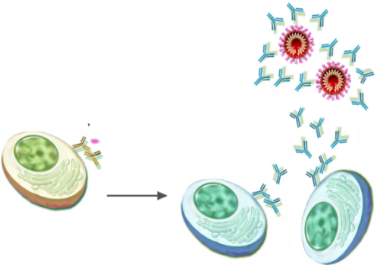
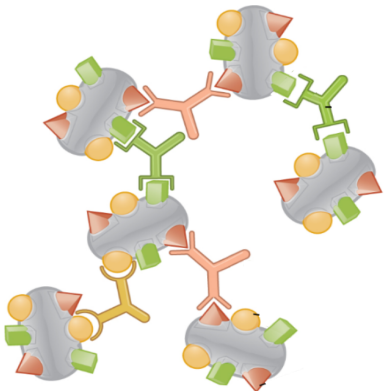
Directions: In the image below, circle or underline which parts of the body you think prevent pathogens from entering, and which parts fight infections that get inside.



Now we can zoom in and look at some examples of immune cells to understand more about how they work inside the body to fight infections.

Directions:

1. Examine the images below, then predict the role the illustrated immune cell or molecule has in fighting a pathogen
2. Use the text and the video [How your Immune System Works](#) to revise your ideas.

Image	Initial Predictions before reading the text	Revised Explanations after reading the text
		
		
		

Immune System Text

The immune system is a complex and fascinating part of our body that keeps us constantly safe from all the pathogens we encounter (bacteria, viruses, fungi, parasites). The immune system is composed of several organs, like the thymus and bone marrow (where the immune cells are produced), and also the spleen, tonsils, and lymph nodes.

The first line of defense are barriers that keep pathogens out, like skin and mucus (the jelly stuff in your nose). Many of the strategies we use to avoid getting sick work by preventing pathogens from crossing our barriers, like washing hands, avoiding sick people, and making sure food is safely cooked. But, if these barriers are breached, then the immune system kicks in and it is activated to fight off any pathogen that gets inside your body. The immune system has several types of cells that patrol every single inch of your body (like your own personal army of soldiers). These are few of the immune cells that protect you:

Macrophages/ Phagocyte: a specialized group of cells that patrol your body and, when they detect the enemy, like a foreign substance from the virus or bacteria, they engulf (eat) it and destroy the pathogen. Once they've engulfed the pathogen, they hold onto a piece of it called the antigen, which they show to the B cells to teach the B cells what the pathogen looks like.

B-Cells: these specialized cells produce antibodies, molecules that are secreted like arrows with flags that will cover the pathogen and make it visible to other cells so it can be destroyed. To do so, they look at the antigen presented by the macrophage, and build an antibody that matches it.

Long Lived Plasma cells (memory B-Cells): these cells retain information about prior infections and remember how to make antibodies to fight them. They help us stay immune to infections we have fought off before.

How do antibodies work?

Antibodies are proteins that stick to the surface of pathogens, telling our cells to destroy them. Antibodies are highly specific, meaning the immune system has to make new antibodies for every new pathogen it encounters. Every pathogen has unique proteins on its cell membrane, called antigens. Antigens are like little personal IDs, and each one is shaped differently. This is where ERAP2 comes in. The protein encoded by ERAP2 helps immune cells learn exactly what the pathogen's antigen looks like, so the B cells can produce antibodies that match their shapes properly. The protein synthesized from ERAP2 variant A may be better at isolating and presenting the antigen for the black death than other variants, resulting in a more effective immune response in people carrying that gene.

Read-Generate-Sort-Solve

Guiding prompt:

How has the environmental pressure of malaria resulted in the evolution of the sickle cell trait? How is this phenomenon similar or different to the other examples of natural selection we have discussed in class?

Step 1:

Read and/or watch the information sources.

Step 2:

Generate ideas with others in your group, adding information into the graphic organizer below.

How has the environmental pressure of malaria resulted in the evolution of the sickle cell trait?

Generate Ideas.

Name:	Name:
Name:	Name:

Step 3:

Sort - Discuss each solution or idea and ✨star the ideas that seem the most useful

Step 4:

Solve - Independently respond to the prompt incorporating the most useful ideas from the sorting process! In your argument, be sure to include how the evidence you are using supports your cause-and-effect claim.

What do we know about cholera immunity and transmission?

Since 1817 there have been 7 big cholera pandemics, and one persists until today. In 2017 there have been 1.2 million cholera cases with almost 6 thousands deaths worldwide. *V. cholerae* is a bacterium that can be naturally present in some aquatic environments and its transmission can happen through contaminated water, contaminated food, and even flies! Even today, some cases of cholera are reported each year in New York City. What can we learn from past pandemic outbreaks and the biology of traits so that we can prevent and survive a future outbreak?

How did big cities react to these outbreaks?

One major factor that increases cholera spreading is mass gathering (weddings, funerals, pilgrimage, prisons, and camps) with insufficient safe water and poor sanitation. Cholera is hyperinfective (highly infective) in fresh stools, that is why highly populated cities can be heavily impacted. In 1892 the city of Hamburg, in Germany, was the 4th largest port in the world. When cholera “arrived”, authorities decided to stop the outbreak by imposing restrictions on people's movements and disinfecting homes (similar to what is happening with COVID19 today). Even in the 1832 New York City cholera outbreak, 250 thousands people left the city to avoid getting in contact with this deadly disease. Indeed, as you also experienced in the disease transmission lab, reducing or avoiding contact with other people is the most effective and best way to stop the spread of any type of infectious disease. Also keep in mind that cholera is not a disease from the past.....in 2011, during a large wedding in Dominican Republic, people were infected with cholera after eating contaminated shrimp.

How can our traits protect us from cholera?

As you have practice with the pocket mice lab, traits can be beneficial and allow the individual to survive and reproduce. Some traits are visible (like the color of the fur of the mice), while some are not (like your blood type or your immune system). Some studies have shown that cholera is more infectious in people with the group O blood type, while people with A and B blood type are at lowest risk. Your genetics can play a big role in the fight against infectious diseases and “help” you survive (as you might have observed when investigating the black death).

For example, people with HIV, whose immune system is compromised, showed a higher infection rate of cholera. However, people who have been infected with cholera and survived, showed a stronger immune system and a future protection against cholera. This means that if you get infected with cholera and you survive, your immune system is stronger and ready to fight a future “attack” from cholera. Based on these findings, scientists believe that cholera is having a role in the natural selection process: people who show a variation in the immune system might survive and pass their traits to the next generation. Like in the pocket mice, if you have the type (variation) of the immune system that can fight against cholera, you have more chances to survive, reproduce, and pass this trait to your offspring.

Is there a vaccine?

You might wonder....why not use a vaccine to protect people from getting cholera in the first place? To answer that, we need to think about what vaccines are and how they work. Vaccines are usually made of weakened or dead pathogens, which stimulate an immune response in the body. Once the body has been exposed to the vaccine, B cells remember the pathogen as if they'd been infected with it, so the body is ready to fight an infection if they encounter it in real life. But, vaccines are not perfect. They rely on the immune system remembering the vaccine, and on it being very similar to the pathogen circulating in the population. As a result, some vaccines work better than others.

Unfortunately, even where cholera vaccines are an option, they do not protect for life and the efficacy is low (less than 60%). The length of the protection varies between 6 months to 3 years with efficacy dropping to less than 50% after the first year. This means that even if you get the vaccine, you can still be infected. This is why it is important to think about treatments that are effective in saving lives, such as using antibiotics to treat cholera infections. We need to find out more about cholera to see if we can avoid another deadly outbreak.

Black Death Mini-Rubric

Claim #1- Focus on Immunity - People will be immune to cholera

Component	Developing	Proficient
Evidence	Effectively and clearly provides evidence that includes some of the elements below: - At least 2 examples of evidence are provided - Provided evidence is data from an investigation completed in the learning cycle - Evidence supports the claim(s) - If appropriate, evidence that refutes the claim is included and clearly indicated	Effectively and clearly provides evidence that includes all of the elements below: - At least 2 examples of evidence are provided - Provided evidence is data from an investigation completed in the learning cycle - Evidence supports the claim(s) - If appropriate, evidence that refutes the claim is included and clearly indicated
Scientific Reasoning & Logic	Effectively and clearly provides scientific reasoning and logic that includes some of the elements below: - An accurate explanation of the concept of natural selection is used to link the evidence to the claim(s) including: - Human variation in immune systems - Immunity as an advantageous trait - Differential reproduction & changes in populations based on immunity - Includes a logic statement that links the evidence to the claim (including words such as because and therefore) - If appropriate, an idea or concept is used to refute or question the claim	Effectively and clearly provides scientific reasoning and logic that includes all of the elements below: - An accurate explanation of the concept of natural selection is used to link the evidence to the claim(s) including: - Human variation in immune systems - Immunity as an advantageous trait - Differential reproduction & changes in populations based on immunity - Includes a logic statement that links the evidence to the claim (including words such as because and therefore) - If appropriate, an idea or concept is used to refute or question the claim
Evaluation of claims, evidence, and reasoning	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with some of the following components: - Cause and Effect or Patterns is checked off - An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with all of the following components: - Cause and Effect or Patterns is checked off - An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.
Student Self-Evaluation Circle one		Teacher/Peer Evaluation Circle one
Evidence	Developing Proficient	Evidence Developing Proficient
Reasoning	Developing Proficient	Reasoning Developing Proficient
Evaluation	Developing Proficient	Evaluation Developing Proficient

Glow

Glow

Grow

Grow

Claim #2- Focus on Transmission - We need to interrupt how cholera is transmitted

Component	Developing	Proficient
Evidence	Effectively and clearly provides evidence that includes some of the elements below: • At least 2 examples of evidence are provided • Provided evidence is data from an investigation completed in the learning cycle • Evidence supports the claim(s) • If appropriate, evidence that refutes the claim is included and clearly indicated	Effectively and clearly provides evidence that includes all of the elements below: • At least 2 examples of evidence are provided • Provided evidence is data from an investigation completed in the learning cycle • Evidence supports the claim(s) • If appropriate, evidence that refutes the claim is included and clearly indicated
Scientific Reasoning & Logic	Effectively and clearly provides scientific reasoning and logic that includes some of the elements below: • An accurate explanation the concept of disease transmission is used to link the evidence to the claim(s) including: • The role of density-dependent factors in transmitting disease and/or other factors including poverty and hygiene • The effect of the level of contagiousness of a disease and its' transmission • Includes a logic statement that links the evidence to the claim (including words such as because and therefore) • If appropriate, an idea or concept is used to refute or question the claim	Effectively and clearly provides scientific reasoning and logic that includes all of the elements below: • An accurate explanation the concept of disease transmission is used to link the evidence to the claim(s) including: • The role of density-dependent factors in transmitting disease and/or other factors including poverty and hygiene • The effect of the level of contagiousness of a disease and its' transmission • Includes a logic statement that links the evidence to the claim (including words such as because and therefore) • If appropriate, an idea or concept is used to refute or question the claim
Evaluation of claims, evidence, and reasoning	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with some of the following components: • Cause and Effect or Patterns is checked off • An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with all of the following components: • Cause and Effect or Patterns is checked off • An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.
Student Self-Evaluation Circle one	Teacher/ Peer Evaluation Circle one	

Evidence	Developing	Proficient	Evidence	Developing	Proficient
Reasoning	Developing	Proficient	Reasoning	Developing	Proficient
Evaluation	Developing	Proficient	Evaluation	Developing	Proficient
Glow			Glow		
Grow			Grow		

Antibiotic Resistance 5E

Unit 2 Humans vs. Bacteria

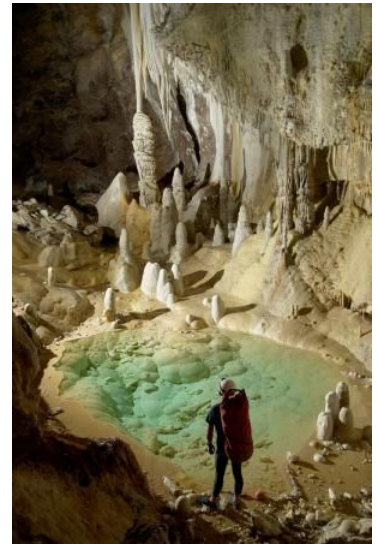
Biology

Student Name:

Scientists find ancient, cave-dwelling resistant bacteria in New Mexico

A thousand feet under the ground, in one of the deepest caves in the country, scientists have found an ancient bacterium that is resistant to many of the antibiotics that we use in medicine today. Luckily, the bacterium is non-pathogenic, meaning that it will not make us sick. However, it is puzzling that an organism that has been sealed off from human or even animal contact for more than 4 million years is able to resist modern antibiotics.

In fact, they found one strain of this bacteria that is resistant to 26 of 40 antibiotics tested. Even brand new and powerful antibiotics were not able to kill all of these bacteria.



Researcher Hazel Barton, PhD, in New Mexico's Lechuguilla Cave (Photo, Max Wisshak)

Adapted from <http://www.cidrap.umn.edu/news-perspective/2016/12/scientists-find-ancient-cave-dwelling-resistant-bacteria>

Simulating Repeated Exposures to Antibiotics Investigation

Introduction:

In this investigation, we will simulate how repeated exposure to antibiotics impacts bacteria, in order to better understand how the trait of antibiotic resistance is found in cave dwelling bacteria.

Research Question:

How does repeated exposure to antibiotics impact bacteria?

Predict:

Like all organisms, bacteria have variation in their traits. One type of variation is their ability to resist antibiotics. Imagine a mix of populations of bacteria that are living in an area together:

- The parent population, population 0, is not resistant to antibiotics at all
- Population 1 descends from a bacteria that randomly had a variant that makes them able to partially resist antibiotic "A",
- Population 2 has a variant that makes them able to fully resist another antibiotic "B"
- Population 3 has both variations, and is resistant to both antibiotics A and B.

If the population is being repeatedly exposed to different antibiotics, predict how each of these types of bacteria will respond over time.

Draw a graph below to demonstrate your ideas. The graph should represent what might happen to each of the four populations of bacteria over approximately one year if they encounter recurrent exposures to antibiotics "A" and "B". Be sure to include a title and label each axis in your graph.



Hypothesis:

Procedure:

Today you are going to simulate what happens when bacterial populations are repeatedly exposed to antibiotics.

Bacteria are constantly reproducing in their environment, whether that is an infected organism or a habitat like a cave. Every time reproduction takes place, there is the possibility that a mutation will occur. At times, those mutations create variations that give antibiotic resistance to the individual.

In this activity, you and your group mates will work together to simulate the impact of antibiotics on the survival of a population of bacteria experiencing mutation.

1. You will get a set of 75 tokens (chips, beads, anything similar), a 6-sided die, and a placemat. The tokens represent bacteria, and the placemat shows what variations the bacteria have.

Scenario 1: No antibiotic Use

2. Begin with 15 tokens in the “No Resistance” section of the placemat. This represents a population of 15 bacteria that have no variations that confer antibiotic resistance. This population is about to reproduce. Record the number 15 in the [Antibiotic Resistance Data Table](#) for the “start” line, in the “No Resistance” column.
3. When bacterial populations reproduce, they double. For each reproducing bacterium, there is the opportunity for mutation to occur. Simulate bacterial reproduction by doubling the number of tokens. In this case, since you have 15 bacteria “parents” in the “No Resistance” box, you will add another 15. However, for each new token you add, there is the possibility that a mutation has taken place. Each time you add a new token, roll the die to see if a mutation has occurred according to the rules below:

Die Roll	Mutation
1, 2, 3	No mutation occurs. The token goes in the same box as its “parent”
4	A mutation makes the bacterium resistant to Antibiotic A. The token goes in the “Resistant to A” box.
5	A mutation makes the bacterium resistant to Antibiotic B. The token goes in the “Resistant to B” box
6	A mutation makes the bacterium resistant to Antibiotic C. The token goes in the “Resistant to C” box

Record the total number of tokens in each box in your data table.

*Note: the number of tokens recorded in the “Total” column on the right should be double the number that you had before.

4. The bacteria reproduce again. Each token already in a box is a “parent.” For each token that is already in a box, add one more, using the die to figure out where to put the new token according to the rules below:

Die Roll	Mutation
1, 2, 3	No mutation occurs. The token goes in the same box as its “parent”

4	A mutation makes the bacterium resistant to Antibiotic A. The token goes in the "Resistant to A" box. If the bacterium that is reproducing already has resistance to Antibiotic B, it moves to the "Resistant to AB" box. If the bacterium that is reproducing already has resistance to Antibiotic C, it moves to the "Resistant to AC" box. If the bacterium that is reproducing already has resistance to Antibiotics B and C, it moves to the "Resistant to ABC" box.
5	A mutation makes the bacterium resistant to Antibiotic B. The token goes in the "Resistant to B" box If the bacterium that is reproducing already has resistance to Antibiotic A, it moves to the "Resistant to AB" box. If the bacterium that is reproducing already has resistance to Antibiotic C, it moves to the "Resistant to BC" box. If the bacterium that is reproducing already has resistance to Antibiotics A and C, it moves to the "Resistant to ABC" box.
6	A mutation makes the bacterium resistant to Antibiotic C. The token goes in the "Resistant to C" box If the bacterium that is reproducing already has resistance to Antibiotic A, it moves to the "Resistant to AC" box. If the bacterium that is reproducing already has resistance to Antibiotic B, it moves to the "Resistant to BC" box. If the bacterium that is reproducing already has resistance to Antibiotics A and B, it moves to the "Resistant to ABC" box.

Scenario 2: Repeated Antibiotic Use

- Begin the game again, repeating steps 2 and 3 from Scenario 1. You should end up with 30 bacteria, where at least 15 of them are in the "no resistance" box, and the other 15 are located based on the dice rolls.
- The population will now be hit with a dose of Antibiotic A. When the antibiotic strikes, any population that has resistance to that antibiotic will not be affected, but any population without resistance will lose 75% of its population. If there are fewer than 4 bacteria in a non-resistant population, the whole population will die.

For example: if the populations before the antibiotics are as follows:

	No Resistance	Resistant to A	Resistant to B	Resistant to C	Resistant to AB	Resistant to AC	Resistant to BC	Resistant to ABC
Start	21	3	5	1	0	0	0	0

Then after a dose of Antibiotic A, the numbers would be:

	No Resistance	Resistant to A	Resistant to B	Resistant to C	Resistant to AB	Resistant to AC	Resistant to BC	Resistant to ABC
Dose with Antibiotic A	5	3	1	0	0	0	0	0

When this happens, remove dead bacteria from your placemat.

7. After the antibiotic dose, the remaining population will reproduce.

For each population, the tokens currently sitting in the boxes are the “parents,” and each one will have an offspring. However, each time a new bacterium is added, it is possible that a mutation occurs that confers antibiotic resistance.

Following the same rules as in step 3, when you add a token for reproduction, roll the die to see what box that bacterium will go in.

For example:

*If there are 5 tokens in the “none” box, 5 more will be added. But each time you add a new token, roll the die to see if it stays in the none box or moves to a different box. The 5 “parent” tokens remain in the none box.

*If there were 3 tokens in the “A” box, you will add 3 more, rolling the die each time to see if it stays in the A box or moves to a different box. The 3 “parent” tokens remain in the A box.

8. You will repeat the cycle of antibiotic dose followed by reproduction and mutation and observe how the bacteria change after repeated exposures to antibiotics. Follow your teacher’s instructions to figure out what order to give the antibiotics in. Each time you give an antibiotic dose, be sure to record which antibiotic the bacteria were exposed to.

9. Continue until you have done 9 total rounds of antibiotics and reproduction/mutation

Simulating a Bacterial Infection Investigation (Scaffolded Version)

Simulating Repeated Exposures to Antibiotics Investigation

Introduction:

In this investigation, we will simulate how repeated exposure to antibiotics impacts bacteria, in order to better understand how the trait of antibiotic resistance is found in cave dwelling bacteria.

Research Question:

How does repeated exposure to antibiotics impact bacteria?

Predict:

Like all organisms, bacteria have variation in their traits. One type of variation is their ability to resist antibiotics. Imagine a mix of populations of bacteria that are living in an area together:

- The parent population, population 0, is not resistant to antibiotics at all
- Population 1 descends from a bacteria that randomly had a variant that makes them able to partially resist antibiotic "A",
- Population 2 has a variant that makes them able to fully resist another antibiotic "B"
- Population 3 has both variations, and is resistant to both antibiotics A and B.

If the population is being repeatedly exposed to different antibiotics, predict how each of these types of bacteria will respond over time.

Draw a graph below to demonstrate your ideas. The graph should represent what might happen to each of the four populations of bacteria over approximately one year if they encounter recurrent exposures to antibiotics "A" and "B". Be sure to include a title and label each axis in your graph.



Hypothesis:

Procedure:

Today you are going to simulate what happens when bacterial populations are repeatedly exposed to antibiotics.

Bacteria are constantly reproducing in their environment, whether that is an infected organism or a habitat like a cave. Every time reproduction takes place, there is the possibility that a mutation will occur. At times, those mutations create variations that give antibiotic resistance to the individual.

In this activity, you and your group mates will work together to simulate the impact of antibiotics on the survival of a population of bacteria experiencing mutation.

1. You will get a set of 75 tokens (chips, beads, anything similar), a 6-sided die, and a placemat. The tokens represent bacteria, and the placemat shows what variations the bacteria have.

Scenario 1: No antibiotic Use

2. Begin with 15 tokens in the “No Resistance” section of the placemat. This represents a population of 15 bacteria that have no variations that confer antibiotic resistance. This population is about to reproduce. Record the number 15 in the [Antibiotic Resistance Data Table - Scaffolded Version](#) for the “start” line, in the “No Resistance” column.
3. When bacterial populations reproduce, they double. For each reproducing bacterium, there is the opportunity for mutation to occur. Simulate bacterial reproduction by doubling the number of tokens. In this case, since you have 15 bacteria “parents” in the “No Resistance” box, you will add another 15. However, for each new token you add, there is the possibility that a mutation has taken place. Each time you add a new token, roll the die to see if a mutation has occurred according to the rules below:

Die Roll	Mutation
1, 2, 3	No mutation occurs. The token goes in the same box as its “parent”
4	A mutation makes the bacterium resistant to Antibiotic A. The token goes in the “Resistant to A” box.
5	A mutation makes the bacterium resistant to Antibiotic B. The token goes in the “Resistant to B” box
6	A mutation makes the bacterium resistant to Antibiotic C. The token goes in the “Resistant to C” box

Record the total number of tokens in each box in your data table.

*Note: the number of tokens recorded in the “Total” column on the right should be double the number that you had before.

4. The bacteria reproduce again. Each token already in a box is a “parent.” For each token that is already in a box, add one more, using the die to figure out where to put the new token according to the rules below:

Die Roll	Mutation
1, 2, 3	No mutation occurs. The token goes in the same box as its “parent”

4	A mutation makes the bacterium resistant to Antibiotic A. The token goes in the "Resistant to A" box. If the bacterium that is reproducing already has resistance to Antibiotic B, it moves to the "Resistant to AB" box. If the bacterium that is reproducing already has resistance to Antibiotic C, it moves to the "Resistant to AC" box. If the bacterium that is reproducing already has resistance to Antibiotics B and C, it moves to the "Resistant to ABC" box.
5	A mutation makes the bacterium resistant to Antibiotic B. The token goes in the "Resistant to B" box If the bacterium that is reproducing already has resistance to Antibiotic A, it moves to the "Resistant to AB" box. If the bacterium that is reproducing already has resistance to Antibiotic C, it moves to the "Resistant to BC" box. If the bacterium that is reproducing already has resistance to Antibiotics A and C, it moves to the "Resistant to ABC" box.
6	A mutation makes the bacterium resistant to Antibiotic C. The token goes in the "Resistant to C" box If the bacterium that is reproducing already has resistance to Antibiotic A, it moves to the "Resistant to AC" box. If the bacterium that is reproducing already has resistance to Antibiotic B, it moves to the "Resistant to BC" box. If the bacterium that is reproducing already has resistance to Antibiotics A and B, it moves to the "Resistant to ABC" box.

Scenario 2: Repeated Antibiotic Use

- Begin the game again, repeating steps 2 and 3 from Scenario 1. You should end up with 30 bacteria, where at least 15 of them are in the "no resistance" box, and the other 15 are located based on the dice rolls.
- The population will now be hit with a dose of Antibiotic A. When the antibiotic strikes, any population that has resistance to that antibiotic will not be affected, but any population without resistance will lose 75% of its population. If there are fewer than 4 bacteria in a non-resistant population, the whole population will die.

For example: if the populations before the antibiotics are as follows:

	No Resistance	Resistant to A	Resistant to B	Resistant to C	Resistant to AB	Resistant to AC	Resistant to BC	Resistant to ABC
Start	21	3	5	1	0	0	0	0

Then after a dose of Antibiotic A, the numbers would be:

	No Resistance	Resistant to A	Resistant to B	Resistant to C	Resistant to AB	Resistant to AC	Resistant to BC	Resistant to ABC
Dose with Antibiotic A	5	3	1	0	0	0	0	0

When this happens, remove dead bacteria from your placemat.

7. After the antibiotic dose, the remaining population will reproduce.

For each population, the tokens currently sitting in the boxes are the “parents,” and each one will have an offspring. However, each time a new bacterium is added, it is possible that a mutation occurs that confers antibiotic resistance.

Following the same rules as in step 3, when you add a token for reproduction, roll the die to see what box that bacterium will go in.

For example:

*If there are 5 tokens in the “none” box, 5 more will be added. But each time you add a new token, roll the die to see if it stays in the none box or moves to a different box. The 5 “parent” tokens remain in the none box.

*If there were 3 tokens in the “A” box, you will add 3 more, rolling the die each time to see if it stays in the A box or moves to a different box. The 3 “parent” tokens remain in the A box.

8. You will repeat the cycle of antibiotic dose followed by reproduction and mutation and observe how the bacteria change after repeated exposures to antibiotics, alternating antibiotics A, B, and C, as indicated in the data table.
9. Continue until you have done 9 total rounds of antibiotics and reproduction/mutation

Data Analysis

Using the data, generate a multi-line graph of the changing population levels by following the steps below

1. Starting with the "No Antibiotics" tab of the data sheet, highlight columns B-I
2. In the toolbar across the top of the spreadsheet, select "Insert" and then "chart"
3. Make sure that the chart is showing up as a Line Chart
4. Repeat this process for the "With Antibiotics" tab of the spreadsheet

Analysis:

1. Use the space below to sketch (or insert) the set of graphs.

2. At the beginning of the investigation, what was the probability of finding a bacterium that had no resistance to any antibiotic? What was the probability of finding an individual that was resistant to all three antibiotics?

3. How did that change by the end of the investigation?

4. Use the space below to describe any further analysis you did (beyond a graph), as well as the results of the analysis.

Summary

1. Explain the relationship between bacterial variation (their ability to resist antibiotics) and the ability to control a population using antibiotics.

2. Suppose the population was exposed to a new antibiotic. What impact do you think that would have on the types and proportions of bacteria present in the population?

-
-
-
-
3. Why was it important to look at the population level for this investigation, and not a single bacterium? How do you think the investigation would have changed if we'd been able to look at even larger scales, like a community of different species of bacteria?

-
-
-
-
4. Describe the limitations of this simulation to represent bacterial populations, like those found in caves. How could you improve this simulation to better demonstrate what happens when a population is exposed to repeated rounds of antibiotics?

-
-
-
-
5. Describe the limitations of the data collected and/or how it was analyzed. How could you improve the data collection, procedure, or data analysis to better understand what happens when a population is exposed to repeated antibiotics?

Simulating a Bacterial Infection Investigation Rubric

Student Rubric - Simulating Repeated Exposures to Antibiotics Investigation

How did you do in the investigation?

Student Self-Score Circle one			
I know how this investigation connects to our current unit.	No - I need help.	Almost	Yes
I was able to contribute to the Data Analysis and respond to the Summary questions.	No- I need help.	Almost	Yes
I used my time well in this investigation.	No	Mostly	Yes
I plan to come in for extra help to complete parts of the investigation or ask questions.	No		Yes

What other resources could you have used to get more out of this investigation?

- More time
- More resources
- More information
- More help from my partners
- More help from my teacher
- Other:

Partner Rubric - Simulating a Bacterial Infection Investigation

How did your partners do in the investigation?

Directions: Think back to how your partners participated in the lab. For each of the four categories, write your partner's or partners' names in the appropriate box.

	Unsatisfactory	Pretty Good	Excellent
Contributions	Did not participate.	Did the minimum of what was required.	Provided useful ideas when participating in discussion
Working with Others	Rarely listened to others. Disrupted or discouraged others' attempts to participate.	Usually listened to, shared with, and supported the efforts of others.	Listened to, shared with, and supported the efforts of others.

Time Management

Procrastinated, did not use school time or schedule provided to get work completed.

Mostly used time well and completed investigation on time.

Used time well to ensure things get done on time.

Antibiotic Resistance: Evaluating a Claim

Guiding Prompt: *How have bacteria become resistant to antibiotics at the population level?*

Directions:

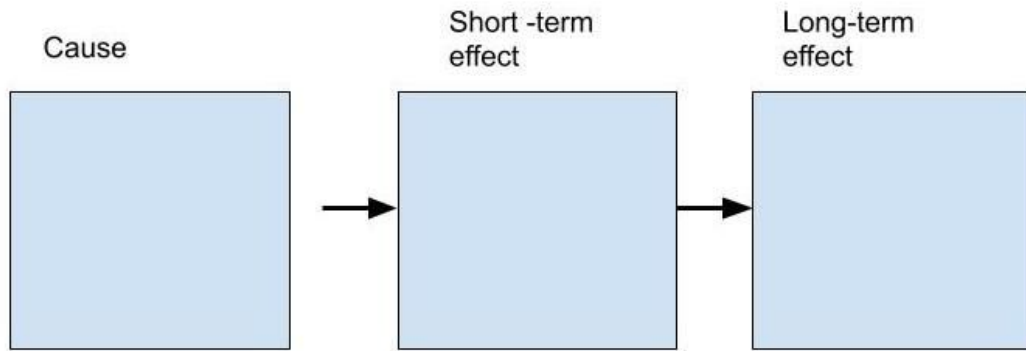
1. After discussing the cause and effect of antibiotic resistance in an example population with your class, let's explore how this happens in the specific example of agricultural populations. As you watch the [Antibiotic Use in Agriculture](#), evaluate the claim: The overuse of antibiotics in agriculture has caused antibiotic resistance. Identify evidence that supports the claim and ideas that refute or contradict the claim. Note down information in the space provided below.
2. Based on the video, fill in the cause and effect chart. This demonstrates what happens at the population level, if one agrees with the claim.
3. Respond to the summary question.

Claim: At the population level, antibiotic resistance is being caused by the overuse of antibiotics in agriculture

Evidence that supports the claim:

Ideas or evidence that refute or act as a critique of the claim or evidence

If we agree with the claim:



Cause and effect chart

Summarize your ideas.

1. What is a possible counterclaim?

2. Summarize why some people in the video state that the overuse of antibiotics in agriculture **causes** antibiotic resistance, and others say that there is only a **correlation**, or possible relationship between the two.

How do bacteria populations develop antibiotic resistance at the population level?

Millions of harmless bacteria naturally live on and inside of your body. These bacteria are the good guys helping us in digesting food and fighting other bacteria (the bad guys). When harmful bacteria appear on the scene, your body's immune system can usually keep a small population of them under control. If, however, these bacteria reproduce too quickly, you suffer consequences—and this is called an infection. Antibiotics help your body fight off an infection by killing off these harmful bacteria.

Introducing antibiotics into the environment of a population, like in agricultural settings, places additional stress on bacteria. Like all organisms, bacteria are competing for resources and trying to avoid being killed by other bacteria or other organisms (like our immune systems!). Through random mutations, some bacteria in a population just happen to possess traits that confer some resistance to an antibiotic. When antibiotics are found in their environment, those with the resistance traits are more likely to survive and reproduce. The resulting offspring inherit resistance, therefore the population over time evolves to be resistant because of this selective pressure.

In natural occurring environments like caves, bacteria are also under stress and they compete with each other for resources. Just like with resistance, random mutations may confer the ability to produce antibiotics that kill off competing bacteria. These bacteria benefit from this trait, outcompeting other bacteria, reproducing more, and passing this trait on to offspring.

At the same time, bacteria can evolve antibiotic resistance to the antibiotics being sent out into their environment by other bacteria. This is like an *arms race* where competing species of bacteria try to kill each other and to evade their enemies at the same time. Thus, both bacteria that we encounter everyday and those that we have never come into contact can evolve to become resistant to antibiotics. However, humans may be increasing the speed at which this occurs through activities like the overprescription of antibiotics in humans and animals.

Natural Selection Comparison Chart

Natural Selection Comparison Chart

Component	Fur Color in Pocket Mice	Antibiotic Resistance in Bacteria (agriculture)	Antibiotic Resistance in Bacteria (Caves)
variation			
pressure in the environment / change in the environment			
adaptation			
differential survival & reproduction		Reminder: bacteria reproduce asexually	
change in population			

C-E-R Graphic Organizer

1. Prewriting:

What is your question?

Support for your explanation

Claim based on the evidence (What is the answer to your question based on your evidence?)	Evidence (Observations/data that answers your question)	Scientific Reasoning (Why you think this happened based on background research)

2. Peer Review

Have a peer read your work and provide comments on what you plan to write.

3. Drafting

Write your explanation in paragraph form.

Scientific Explanation = Claim + Evidence + Science Reasoning

My claim is (fill in with above claim) because (evidence and science reasoning).

C-E-R Rubric

Component	Not Evident	Level 1: Beginning	Level 2: Developing	Level 3: Advancing	Level 4: Proficient
Claim	Does not make a claim	Claim does not answer the question (i.e., describe the relationship between the 2 variables)	Claim does answer the question but it is inaccurate.	Claim answers the question, and is accurate, but is incomplete	Claim answers the question, is accurate, and is complete. Completely describes the trend in the relationship between the IV and DV where appropriate.
Evidence	Does not provide evidence	Only provides inappropriate evidence (evidence does not support the claim)	Provides appropriate, but insufficient evidence to support the claim. May include some inappropriate evidence	Provides appropriate and sufficient evidence to support the claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support the claim
Reasoning: Science Concepts	Does not include reasoning	Restates evidence and does not include explanation of science concepts	Includes explanation of science concepts but all are inappropriate concepts that do not link evidence to claim	Includes explanation of some science concepts that link evidence to the claim, but are insufficient (one or more concepts that should have been included are not included) or some are inappropriate	Includes explanation of science concepts that link evidence to the claim (concepts are appropriate), and they are sufficient (no omission of key science concepts) and are clearly stated and accurate.

**Reasoning:
Logic**

Does not include
reasoning

Restates evidence
or claim and does
not include a logic
statement that
links the evidence
to the claim

Attempts to
include a logic
statement that
links the evidence
to the claim but
does not
adequately link the
evidence to the
claim.

Includes a logic
statement that
attempts to link
the evidence
with the claim
but needs to be
more clearly
stated to
demonstrate
logical
reasoning

Includes a logic
statement that
links the evidence
to the claim
(including words
such as *because*
and *therefore*) that
clearly
demonstrates
logical reasoning

Summary Task

Today we completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

4. What did you learn from this person?

5. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today.

1. Describe one example of evolution by natural selection that we have discussed in class.

2. How can we evaluate a claim about the cause behind a phenomenon?

3. How can we use evidence to differentiate between cause and correlation? Discuss one example from class.

4. When discussing the evolution of antibiotic resistance what patterns did you observe? How did those patterns help you understand the possible causal relationships between using antibiotics in agriculture and widespread antibiotic resistance?

Have you ever wondered why bacteria can become resistant to antibiotics? Bacteria go through the process of natural selection quicker than other species because of their fast reproduction cycle. This means they also adapt faster to different environments. In each population, some bacteria carry genes coding for antibiotic-resistant traits. Some bacteria produce antibiotics naturally in an attempt to kill other bacteria, especially when there is a lot of competition for resources in a certain area. Other organisms, such as fungi, also produce antibiotics in order to fight off infections. When a bacteria population is exposed to antibiotics, the one with the advantageous trait (the antibiotic resistance) will survive and reproduce while the sensitive (those missing the trait) will die. But what are these traits that bacteria have? Before we need to understand how antibiotics work.

Antibiotics in Action

Some antibiotics (for example Beta-lactams, the most known penicillin) interfere with cell wall formation, so when a bacterium tries to replicate, the cell wall is destroyed and the bacterium dies. Other antibiotics (for example Quinolones) interfere with DNA and/or protein synthesis in the bacteria, causing cell death. Antibiotics are a great strategy since they only target bacteria and not human cells. For this reason, antibiotics have been used for almost a century to treat bacterial infections

Unfortunately, some bacteria possess specific traits that allow them to survive the antibiotics. For example, some bacteria can destroy the antibiotics once they enter the cells (using specific enzymes that inactivate the antibiotics). Other bacteria have a different trait and are able to survive it by “spitting out” the antibiotics using special pumps on their membranes called “efflux pumps”.

It is important to remember that in each bacteria population (*E. coli*, *P. aeruginosa*, *N. gonorrhoeae*, etc), there are few “lucky” bacteria that possess these traits and so can survive in the presence of antibiotics. When a patient is sick and treated with antibiotics, the bacteria possessing the resistant trait will survive and take over, creating a population of antibiotic resistant-bacteria.

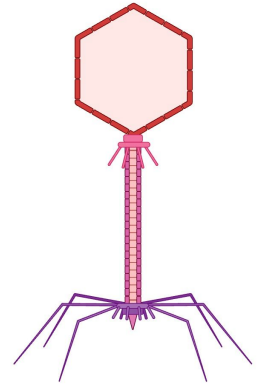
Bacteriophage Text

Have you ever caught a cold? If your answer is yes, it means a virus infected your cells in your throat and made you sick. Did you know that there are some viruses that can only infect bacteria? They are called Bacteriophages (phages for short). Yes, even bacteria can catch a cold! Phage comes from Greek and means “to eat”, and these viruses eat bacteria and kill them. Fortunately, they cannot infect human cells at all.

Billions of these phages are present all around us and protect us from bad bacteria. Scientists have used them even before antibiotics have been invented to treat bacterial infections. Indeed, even today you can buy them in a pharmacy in Russia. But how do phages work? As you can see in the picture, they can attach to a bacteria and send their DNA inside. Once inside, the DNA will use the bacteria to make more copies of the phages. Eventually the bacteria will explode and release all the phages.

The key these phages use to attach to and enter the bacteria is called an efflux pump, which is on the bacteria’s cell wall. When phages infect a bacteria population, only those with a special trait will survive. In this case, bacteria with a non functional efflux pump will survive (since the phages will not be able to attach it), while all the bacteria with a functional efflux pump will die. This means that if phages are used on a patient to get rid of a bacterial infection, only bacteria with non functional efflux pumps will survive.

Scientists are trying to use this cutting edge strategy to treat bacterial infections that are antibiotic resistant. What do you think are their strategies? How can scientists leverage phages to treat antibiotics resistant infections?



Bacteriophage. Created in <https://BioRender.com>

Claim 1: Take antibiotics
Claim 2: Use Bacteriophages

- | | | |
|-------------|-------------|-------------|
| Name: _____ | Name: _____ | Name: _____ |
|-------------|-------------|-------------|

- [illegible]

What do we know about cholera resistance to antibiotics?

You might have discovered by now that bacteria are smart and sneaky! They can learn how to “play the game” and “win it” by becoming resistant to antibiotics. Antibiotics are drugs that work by killing or stopping the bacterial growth. As you have seen in the video in this unit, the more we use antibiotics the more bacteria can become resistant to them. Also, as you might have discovered in our investigation, when we take antibiotics, the “sensitive” bacteria are killed first, while the ones who have the resistant trait survive and they can pass that trait to newborn bacteria, increasing the bacteria resistant population.

Is cholera resistant to antibiotics?

Short answer is yes! Cholera is one of the bacteria that over the years has become resistant to antibiotics. While in the past many antibiotics were able to easily treat cholera, recently scientists have noticed that treatment failed because the cholera bacterium acquired the resistance trait for antibiotics (figure below). Scientists believe that the resistance to antibiotics in cholera has been caused by the overuse and misuse of antibiotics in several sectors (health, agriculture, food).

For example, 12,000 refugees in Zaire, Africa, died in 1994 because of antibiotic resistant cholera (4 times the number of deaths of the 9/11 attack in NYC). Antibiotic resistance is a serious issue that must be addressed if we want to treat and cure people when they get any type of bacterial infection.

How does cholera become resistant to antibiotics?

In 1992 a new strain (type) of cholera showed up in Southeast Asia that was resistant to 4 different types of antibiotics. When scientists studied this new strain they found out that it came from the original cholera bacterium that acquired the resistant trait. How do bacteria acquire resistance traits? There are two major ways.

1. Random Mutations: as you learned in the pocket mice investigation, mutations can be responsible for the creation of new traits and if the trait is advantageous (like antibiotic resistance), then the organism can survive and reproduce to pass that trait. Over generations, the population with the advantageous trait increases.
2. DNA exchange: interestingly enough, cholera prefers this strategy over random mutation. With DNA exchange, different strains of bacteria can exchange parts of DNA (called plasmids) that possess the resistance to antibiotics (figure below). For example, a cholera bacterium that is resistant can share a plasmid with another cholera bacterium that is not resistant and provide it resistance up to 6 different antibiotics. Similar to when you play a video game and you share your “resources” with another player to help him/her survive in the “battle”.

Either because of DNA mutations or exchange of DNA between bacteria, antibiotics resistance is becoming more and more common amongst several bacteria. Scientists are running out of antibiotics to use to treat infections and more people are dying because bacteria are resistant to antibiotics. Do you think antibiotics can be the solution to preventing a future cholera outbreak?

Antibiotic Resistance Mini-Rubric

Claim: Focus on Antibiotic Resistance - We need to stop *V. cholerae* from becoming resistant to antibiotics.

Component	Developing	Proficient
Evidence	Effectively and clearly provides evidence that includes some of the elements below: - At least 2 examples of evidence are provided - Provided evidence is data from an investigation completed in the learning cycle - Evidence supports the claim(s) - If appropriate, evidence that refutes the claim is included and clearly indicated	Effectively and clearly provides evidence that includes all of the elements below: - At least 2 examples of evidence are provided - Provided evidence is data from an investigation completed in the learning cycle - Evidence supports the claim(s) - If appropriate, evidence that refutes the claim is included and clearly indicated
Scientific Reasoning & Logic	Effectively and clearly provides scientific reasoning and logic that includes some of the elements below: - An accurate explanation of the concept of natural selection is used to link the evidence to the claim including: - Variation and mutation in a population allowing for resistance (an advantageous trait) in an environment w/antibiotics - Differential survival and reproduction - Changes in the bacterial population leading to increased resistance to antibiotics - Includes a logic statement that links the evidence to the claim (including words such as because and therefore) - If appropriate, an idea or concept is used to refute or question the claim	Effectively and clearly provides scientific reasoning and logic that includes all of the elements below: - An accurate explanation of the concept of natural selection is used to link the evidence to the claim including: - Variation and mutation in a population allowing for resistance (an advantageous trait) in an environment w/antibiotics - Differential survival and reproduction - Changes in the bacterial population leading to increased resistance to antibiotics - Includes a logic statement that links the evidence to the claim (including words such as because and therefore) - If appropriate, an idea or concept is used to refute or question the claim
Evaluation of claims, evidence, and reasoning	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with some of the following components: - Cause and Effect or Patterns is checked off - An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with all of the following components: - Cause and Effect or Patterns is checked off - An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.
Student Self-Evaluation Circle one	Teacher/Peer Evaluation Circle one	

Evidence	Developing	Proficient	Evidence	Developing	Proficient
Reasoning	Developing	Proficient	Reasoning	Developing	Proficient
Evaluation	Developing	Proficient	Evaluation	Developing	Proficient
Glow			Glow		
Grow			Grow		

The Microbiome 5E

Unit 2 Humans vs. Bacteria

Biology

Student Name:

A New Treatment!

Patients who are hospitalized often or live in nursing homes sometimes get a nasty and recurring infection from a bacteria called *Clostridium difficile* (or *C. diff*). People with *C. diff* infections can suffer severe colonic inflammation, which could lead to symptoms ranging from recurrent diarrhea (which could last from weeks to months) to kidney failure, or even death. *C. difficile* is responsible for about 29,000 deaths annually, and administering antibiotics often does not cure these patients. Due to this, researchers are constantly on the lookout for better ways to treat the infection. Research coming in from the University of Texas Health Science Center at Houston may lead to just that, in the form of a pill.

But what is inside of that pill?

Fecal matter from a healthy donor. This process is called *fecal matter transplant* and it involves extracting healthy bacteria from another individual's fecal matter and then processing and transferring that bacteria to the infected patient directly. Frozen or freeze-dried bacteria from fecal matter can be administered in pill form at a patient's or doctor's convenience, whereas fresh transfers require a donor and recipient to spend hours at the hospital to obtain the fecal sample, refine it, and then deliver it to the infected patient.

One of the participants in the Texas Health Science Center study is already sold on the new method of treatment. He excitedly told a reporter that his cure is "a miracle!" He added that prior to the new treatment, he had been considering retiring from his teaching job because the infection had made him so ill he wasn't always able to do his best work. "I love teaching, and I can't tell you what it was like to be healthy again, to be able to do my job and not retire before I was ready," he said.

Comparing Microbiomes Investigation

Introduction

We hear a lot about bacteria that are pathogenic (make us sick). However, our outsides (including our skin, eyes, mouth and ears), and inside our digestive system is literally covered in bacteria! The vast majority of the approximately 39 trillion bacteria living in and on the human body are harmless, and many of them are actually beneficial to our health! All of the bacteria, and other microorganisms we host, are collectively called the microbiome. Everyone has a slightly different microbiome, and your microbiome can change throughout your life, or even from month to month. One important component of the microbiome is that our symbiotic bacteria often make specific molecules, called metabolites, that often assist the human host in nutrient and energy acquisition, proper immune function, and protection against pathogens.

In this exploration, we will compare the microbiome in different populations of people:

- Urban Europeans from Italy
- Rural Africans from Burkina Faso and Malawi
- Hunter-gathers from Tanzania (the Hadza)

Experimental Question

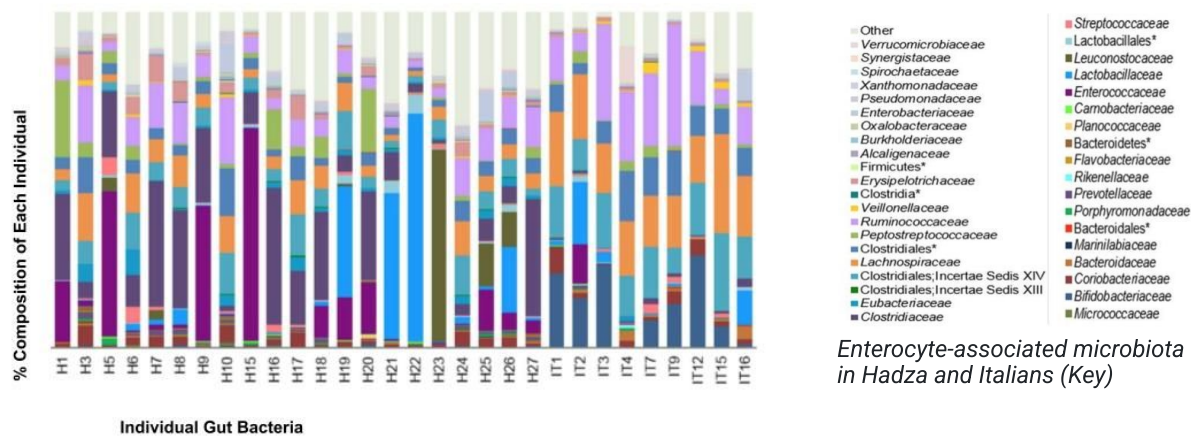
Procedure

1. In order to compare the microbiomes of these three populations, you will analyze three different data sets, noting your inferences on each in the See-Think-Wonder organizer.

The three data sets are:

- Figure 1. Composition of the Microbiome in Urban Italians and the Hadza (hunter-gathers)
 - Figure 2. Comparison of Microbiome Diversity in Different Populations of People
 - Table 1. A comparison of lifestyles and diets
2. Choose 1 lifestyle or diet variable from Table 1. A Comparison of Lifestyles and Diets and graph each against the data found in Figure 2. Comparison of Microbiome Diversity

Figure 1. Composition of Gut Bacteria in Urban Italians and Hunter-gathers (Hadza)



Enterocyte-associated microbiota in Hadza and Italians

Figure 2. Microbiome diversity in different populations of people

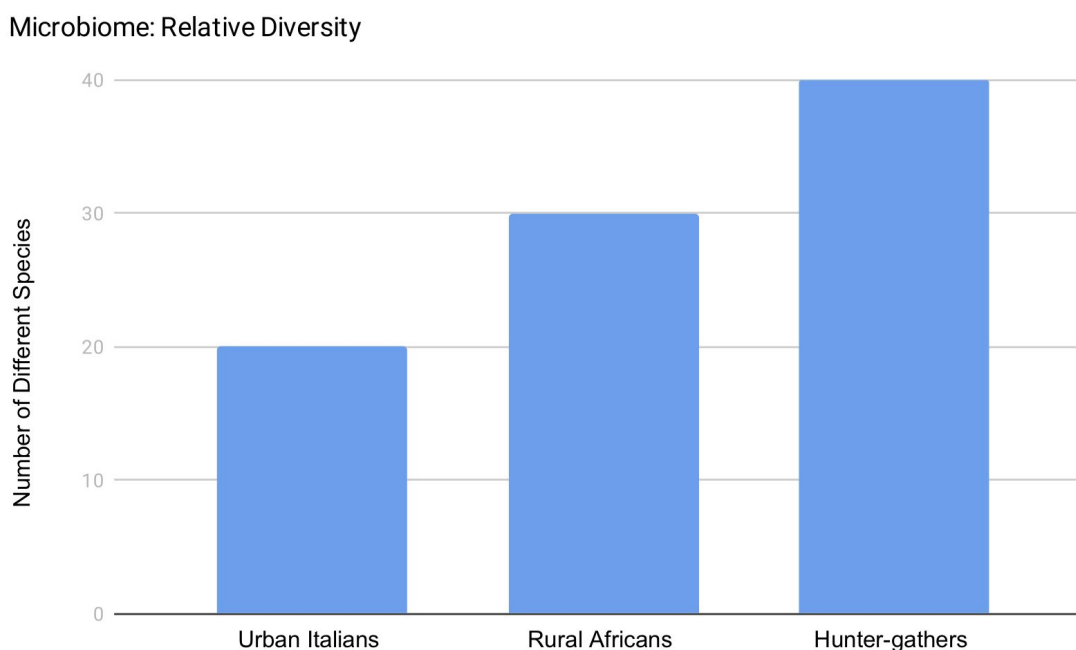


Table 1. Lifestyle Comparison

The information below provides the average description of some variables of each population's lifestyle and diet. These variables may have an impact on each population's microbiome composition.

Population	Average Diet	Average Lifestyle Description
Urban Italians	A diverse diet of many types of plant foods including vegetables, fruit, and whole grains (about 60% of the diet). Moderate amounts of meats and dairy products make up about 25% of their diet. Moderate to low amounts of processed food such as baked goods, and sweets (about 15% of the diet).	Urban environment with cars and public transportation. The work day (offices, schools, factories) is typical of all cities. Hygienic and fully modern environment including water and garbage treatment. Abundant access to medical care including antibiotics. The antibiotic prescription rate for Italians is 26 DDD*.
Rural Africans (Burkina Faso and Malawi)	Large percentage of calories come from whole grains and tubers, such as cassava (manioc). Approximately 75% of the diet is from plants. Some meat, and limited dairy products (about 20% of the diet). Very low to no processed foods such as bread and sweets that make up about 5% of their diet.	Rural environment with limited access to cars or public transportation. The workday primarily involves agricultural work, with frequent contact with animals and soil. Little access to running water and no organized garbage or waste treatment facilities. Limited access to medical care or antibiotics. The antibiotic prescription rate for rural Africans is 7 DDD*
Hunter-gathers (Hadza)	Seasonal diet, but averages 70% unprocessed and diverse plant foods such as wild tubers, green foliage, and berries. 29% of the diet is from wild animals such as birds and small deer. No processed food or sweets beyond occasional foraged honey (approximately 1% of the diet)	Wilderness areas with no access to cars or transportation. The work day involves walking long distances to gather food and to hunt small game (animals). No access to running water, waste facilities, medical care, or antibiotics. The antibiotic prescription rate for the Hadza is less than 1 DDD*

*DDD is the defined daily dose per 1000 people.

See-Think-Wonder

Note your inferences from the data sources above in the graphic organizer, using the prompts to guide your thinking.

See	Think	Wonder
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• Which group has the greatest microbiome diversity? • What are the most common bacteria in the guts of each group? (Italians vs Hadza) • Describe the differences in diet between the three groups. • Which group has more contact with different types of bacteria in their environment?	• Why do you think there are differences in the microbiome between the groups? • How do you think diet and lifestyle impact the microbiome? • How do you think exposure to antibiotics has shaped the microbiome? • What impact on health do you think having more or less diversity in the microbiome may have?	• Based on your understanding of the diet and lifestyle of the average American, what do you predict about their microbiome in comparison to the Hadza? Or the average Italian?
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Finding Relationships- Which lifestyle variables may impact microbiome diversity?

Review Table. 1 Lifestyle Comparison and Figure 2. Microbiome diversity in different populations of people. Choose one variable that you predict will have an impact on the diversity of a population's microbiome.

Variable:

Generate a scatter plot that represents the relationship between the microbiome diversity in a population and the identified variable.

Scatter Plot

Title your scatter plot and use the space below to create a scatter plot, including a line of best fit to represent the relationship.

Calculate - Calculate the correlation coefficient in order to identify if the variable you choose is correlated positively or negatively with microbiome diversity.

Correlation coefficient

Share your results with the class. As a class, identify which variables demonstrated a positive or negative correlation.

Three Level Guide to Interpretation - Figure 1. Composition of Gut Bacteria in Urban Italians and Hunter-gathers (Hadza)

1. Reading the Lines - Annotate the figure.

Read the title. Re-write the title in your own words.

Find the bacteria called Bacteroidales. Circle the square that represents that bacteria on the figure.

What color represents Bacteroidales in the figure?

Find individual H3, and place a star next to it on the figure. What does the 'H' stand for?

4. Find individual IT1, and place an 'x' next to it on the figure. What does 'IT' stand for?

5. Circle the title of the y-axis. Re-write the title in your own words.

2. Reading between the lines - Use the graph to respond to the following prompts.

Find individual H10. Approximately how many different types of bacteria did this individual have in their gut?
Note: It may be difficult to see the difference between every color; just do your best to estimate.

Find individual IT9. Approximately how many different types of bacteria did this individual have in their gut?

Name one type of bacteria found only in the Hadza.

Name one type of bacteria found only in the Italians.

Name one type of bacteria found in both the Hadza and the Italians.

3. Reading beyond the lines- Use the graph, and your knowledge of biology, to respond to the following prompts.

The bacteria named as 'other' are bacteria that are unknown or have not been given a name yet. Which group, the Italians or the Hadza have more bacteria in their gut classified as 'other'?

Why do you think this group has more unknown bacteria?

In general, which group, the Hadza or the Italians have a greater diversity (number of different types) of bacteria in their gut?

Why do you think this group has a more diverse gut microbiome?

Why do you think that groups of people that live very far away from each other (like the Hadza and the Italians), would have some bacteria in common?

Investigation Summary

1. What trends do you notice across all three data sources?

2. What are some of the limitations of the data presented in this investigation?

3. In order to have more confidence in the correlation between lifestyle variables and microbiome diversity, what further data would you need to collect and what further analysis would you do?

4. Based on the data you collected and analyzed so far, how can you explain the phenomenon that some bacterial infections can be treated using bacteria from a donor (fecal transplants)?

5. What else do we need to figure out in order to explain the outcome of fecal transplants?

Comparing Microbiomes Investigation Rubric

Student Rubric - Comparing Microbiomes Investigation

How did you do in the investigation?

Student Self-Score Circle one			
I know how this investigation connects to our current unit.	No - I need help.	Almost	Yes
I was able to contribute to the See-Think-Wonder and respond to the Investigation Summary questions.	No - I need help.	Almost	Yes
I used my time well in this investigation.	No	Mostly	Yes
I plan to come in for extra help to complete parts of the investigation or ask questions.	No		Yes

What other resources could you have used to get more out of this investigation?

- More time
- More resources
- More information
- More help from my partners
- More help from my teacher
- Other:

Partner Rubric - Comparing Microbiomes Investigation

How did your partners do in the investigation?

Directions: Think back to how your partners participated in the lab. For each of the four categories, write your partner's or partners' names in the appropriate box.

	Unsatisfactory	Pretty Good	Excellent
Contributions	Did not participate.	Did the minimum of what was required.	Provided useful ideas when participating in discussion
Working with Others	Rarely listened to others. Disrupted or discouraged others' attempts to participate.	Usually listened to, shared with, and supported the efforts of others.	Listened to, shared with, and supported the efforts of others.

Time Management

Procrastinated, did not use school time or schedule provided to get work completed.

Mostly used time well and completed investigation on time.

Used time well to ensure things get done on time.

The Microbiome as an Ecosystem

Humans have bacteria and other microorganisms living on and in their bodies. The collection of these microorganisms are called the microbiome. The human microbiome is often compared with an ecosystem. What do you think the microbiome and an ecosystem have in common?

Directions:

1. Using your prior knowledge of ecosystems, predict what an ecosystem and the human microbiome may have in common and what might be unique about each. Note your ideas in the graphic organizer below.
2. Read the text, using the following annotations:
 - a. Identify information that confirms your initial ideas
 - b. Identify information that contradicts your initial ideas
 - c. Identify information that adds on to your initial ideas
3. Respond to the final prompt.

Predict

How can you compare an ecosystem to the human microbiome?

Unique to an ecosystem	Commonalities	Unique to the microbiome

Read and Annotate

Forests and the human microbiome are both examples of ecosystems. They have many characteristics in common, and some differences. When either system is disrupted, there may be on-going consequences. Surfacing what we know about ecosystems may be helpful in understanding more about the microbial community that lives in and on humans, and how it helps maintain our health.

An *ecosystem* is a biological community of interacting organisms and their physical environment. Generally, a more diverse ecosystem, one with many different types of organisms, is more resilient than one with less diversity. A diverse ecosystem includes a wide variety of *ecological niches*, or the specific role that an organism plays in an ecosystem.

Competition for resources often plays a strong role in determining an ecological niche. For example, in a forest ecosystem, one type of herbivore may specialize in eating trees, and another type of herbivore may specialize in eating shrubs, while a different herbivore eats mainly grasses. This system reduces competition, and allows for many organisms to co-exist. Therefore, a forest ecosystem may have many different types of herbivores because there are many ecological niches to fill. If a disease wipes out one type of herbivore, the ecosystem may be able to quickly bounce back because there are other herbivores remaining to maintain stability. In other words, the vegetation in the forest won't become overgrown because just one type of herbivore is removed, as species can contract and expand their niche based on competition.

Additionally, because of the competition between many different species in a diverse ecosystem, no one species can overpopulate and dominate the resources. A less diverse ecosystem is less *resilient*, because there is less competition that may allow one or two species to dominate. When this happens, it may contribute to loss of further diversity and even local extinctions of organisms. Extinction causes further disruption because organisms that once played a key role in the ecosystem are gone forever.

The *human microbiome* refers to all of the microscopic organisms (including bacteria, fungi, viruses, and protists) that live in and on the human body. However, the bacteria among us play the largest role in cooperating with their human host. Over the course of time, humans and bacteria have co-evolved. Many of the bacteria that live in our gut, live nowhere else on Earth. Living in our gut, skin, and all over our bodies has been advantageous for these bacteria, because they are able to use human bodies as a place to live and to obtain the resources they need to survive. It is also advantageous for humans, because our symbiotic bacteria help us digest our food, make vitamins for us, assist our immune system in fighting off pathogenic bacteria, and make compounds that even impact our mood and general health! The bacteria form distinct interacting communities on different parts of our bodies and play different functions, or roles, based on their location.

Diversity and competition are also important in the human microbiome. For example, healthy people have a more diverse microbiome than those suffering from *C. difficile* infections. Scientists have noticed that people with *C. difficile* infections often have low bacterial diversity in their gut, which allows *C. difficile* to dominate and take over the digestive system. In healthy people, competition between different types of bacteria keeps the entire population stable, without allowing any one type to overpopulate. Competition over space and resources restricts pathogenic bacteria from gaining a foothold. Fecal transplants may help those suffering from *C. difficile* infections, because doctors are re-introducing a healthy, more resilient microbiome from a healthy donor. Fecal transplants are very successful in treating *C. difficile* infections.

Table 1. Success rate of fecal transplants in treating *C. difficile* infections across multiple hospital studies

Study #	Number of patients	Success rate
1	146	96%
2	10	90%
3	80	89%
4	26	92%

Many scientists are concerned that, as a population, we are losing a healthy microbiome and that may contribute to more *C. difficile* infections, and even diseases such as diabetes and obesity. Diet plays an important role in maintaining a healthy gut (digestive tract) microbiome. Fiber, from plant foods, nourish gut bacteria, while a diet heavy in processed foods, sugar, and fats starves gut bacteria resulting in a decreased level of diversity.

Modern lifestyles have decreased our interaction with bacteria in our environment. People rarely interact with soil or animals outside the home, and because of hygienic practices we rarely 'pick up' beneficial bacteria from other people. Additionally, the overuse of antibiotics has most likely led to a decrease in diversity, and even the extinction of certain types of bacteria in modern populations. These symbiotic bacterial extinction events may be localized occurring in only some populations, or more worrisome, these helpful bacteria may be eventually lost to the human population as a whole.

Respond to the prompt

Based on your understanding of evolution, ecosystem dynamics, and extinction, and using evidence from the text and investigation, explain why fecal transplants are used to treat infections such as *C. difficile*.

Summary Task

Summary Task

We recently completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

2. One thing we can improve the next time we have a discussion:

3. One person who helped me learn today:

4. What did you learn from this person?

5. One idea that I contributed to my group or my class:

Explain what you know about the following questions, based on what we discussed today.

1. Many species of bacteria coexist with their human hosts. Using what you have learned about natural selection, explain how this may have occurred over time.

2. Using evidence from the investigation, explain why some species of symbiotic bacteria may have gone extinct in industrialized countries such as the United States.

3. Describe the evidence you would want to investigate to evaluate the claim: A diverse microbial community/microbiome causes better health outcomes.

4. How is correlation different from causation? Describe one example that we have discussed in class.

Hadza Microbiome Text

Introduction:

Would you accept a fecal transplant for science?? Jeff Leach, a scientist who studies the microbiome of the Hadza, decided to run an experiment on himself. While he was living among the Hadza in Tanzania, he transplanted fecal matter from a Hadza donor to himself even though he was not sick. From studying the Hadza, he knew they had a very diverse microbiome, so he wondered if he would benefit from their microbial diversity, and what would happen to his microbiome over time after a transplant. Do you think this was a good idea?

Directions:

Using all of the resources you have on the microbiome, evaluate the following claim:

The Hadza, hunter-gathers in Tanzania, have an ideal microbiome. The average American should receive a fecal transplant from a donor Hadza, in order to improve their microbiome and health.

1. Identify evidence and scientific reasoning from the Engage, Explore, and Explain portions of this learning sequence.

Supportive Evidence	Scientific Reasoning	Contrary Evidence	Scientific Reasoning

2. Identify evidence and scientific reasoning from the text below to add to your ideas.

Should we all have a fecal transplant from a Hadza donor to improve our microbiome??

Researchers have found that the Hadza generally have much less chronic disease, such as obesity and cardiovascular disease, than Americans. Hadza do have a much higher infant mortality rate than Americans, but when Hadza survive to adulthood, they generally live almost as long as Americans, and tend to be healthy until their death in old age.

Table 1. Components of health and longevity in Americans and Hadza

	Model Age of Death	Average BMI for Males	Prevalence of Type 2 Diabetes	Prevalence of Cardiovascular Disease in Adults	Prevalence of High Blood Pressure in Adults
Americans	85 years	29	≈ 10%	> 60%	≈ 50%
Hadza	72 years	21	≈ 1%	< 30%	≈ 5%

Is a diverse microbiome the secret to Hadza's health? Perhaps. For example, studies in mice have shown that gut bacteria play an important role in determining obesity. When a lean mouse is inoculated with the gut bacteria of an obese mouse, the lean mouse can become obese as well. However, a correlation (or relationship) between a diverse microbiome in humans and better health outcomes does not necessarily prove causation (that a diverse microbiome causes better health). There may be many factors that explain the differences in health outcomes between these two groups of people. For example, the Hadza have an extremely different diet than the average American, consuming a large amount of unprocessed plant food.

Additionally, Hadza people have very high activity levels. The average Hadza walks between 5 and 10 miles a day! Their diet and exercise habits may be the cause, or a partial reason behind their lack of chronic disease. Interestingly, most gut bacteria consume plant fiber that they obtain through people's diet. The average hunter-gatherer eats up to 150 grams of fiber a day, while the average American eats only 20 grams. Even if a diverse microbial population is a contributing factor to Hadza's health, as soon as someone eats the typical American diet that is missing fiber, the beneficial bacteria may all die off quickly.

Humans and their microbiome have evolved together over time through the process of natural selection. Some scientists have argued that the temporary loss and even the extinction of some of our symbiotic bacteria have made us less fit, because those bacteria once played a role in our health. Symbiotic bacteria do provide nutrition, produce important metabolites, and help regulate our immune system. However, we do not have enough data yet to determine which species of bacteria are essential for health or how to classify an unhealthy versus a healthy microbiome. Although, scientists do consistently find that diversity overall is a positive factor.

There are some risks involved in fecal transplants. The donor, although healthy, may transmit pathogenic bacteria or viruses in their feces that they have developed immunity for, but the recipient has not. For example, the Federal Drug Administration (FDA) issued a warning in June of 2019 about using fecal transplants. Two patients became very sick and one died from an antibiotic resistant infection from a donor. The FDA suggests that donors must go through extensive screening before their fecal matter is transferred to another person.

Evidence Gradient Graphic Organizer

Preliminary claim/argument:

Gradient Level	Evidence	Rationale/Scientific Reasoning
Color 101 It's On Fire!		
Color 102 Ready to Burn		
Color 103 Beginning to Sweat		

Source: Evidence Gradient as a tool comes from the Argument Toolkit (<http://www.argumentationtoolkit.org/>) and is reproduced here under Fair Use.

Summary

1. What makes evidence strong? What factors might impact the criteria for strong evidence?

2. Based on the evidence and scientific reasoning from the text and learning sequence, evaluate the claim.

How can the microbiome stop cholera infections?

In the beginning of this unit, you learned that cholera is a bacterium that infects your intestine and can cause deadly diarrhea. You also have figured out that your body, especially your intestine, is populated with tons of good bacteria (called the microbiome), the superheroes that keep you safe and also provide nutrients. How do cholera and the microbiome interact with each other?

Friends or foes?

Once cholera enters your body, it will travel to the intestine and make it its “home”. Since cholera is not the only bacteria in the intestine, it has to compete and take space from other bacteria that live there. How would you react if out of the blue someone moved into your bedroom? I am sure you would try to claim your space and push the intruder away. This is what the microbiome does to cholera.

The status of the microbiome in the intestine is associated with increased or decreased susceptibility to cholera infections (and other types of infections). Scientists have discovered that when the microbiome is destroyed by the use of antibiotics, cholera has higher chances to colonize and cause a severe infection. This is because there is more space and less competition for cholera. On the other hand, a diverse and more rich microbiome can protect you from cholera infections, or make a cholera infection less severe. For example, if you have enough good bacteria in your intestine, they can produce molecules that can disrupt the communication between cholera bacteria and stop them from replicating.

A specific bacterium called *Lactobacillus* (you might know it from the probiotics commercials on TV), can stop cholera from creating colonies in the intestinal tract. Your diet also plays a big role in fighting the enemy. A recent study showed that a plant based diet low in proteins helps increase the type of good bacteria in your intestine and also stimulate the bacteria in producing proteins that help increase the immune response. Moreover, it is not only the bacteria, but also the fungi, parasites, and bacteriophages in our microbiome that can fight against cholera or other intruders. For example, bacteriophages in our intestine can attack and kill cholera. Since scientists noticed that bacteriophages have been effective with cholera, they used and added them to the drinking water in India to prevent cholera outbreaks. Unfortunately, cholera can evolve and become resistant to bacteriophages as it does to antibiotics.

Can we leverage our microbiome to fight cholera? Do you think the Hadza are more resistant to cholera infections? For sure, a highly diverse and healthy microbiome makes it really hard for cholera to take over and cause deadly diarrhea.

The Microbiome Mini-Rubric

Claim: Focus on the microbiome - We can leverage a healthy microbiome in order to reduce the chances of infection from *V. cholerae*

Component	Developing	Proficient
Evidence	Effectively and clearly provides evidence that includes some of the elements below: • At least 2 examples of evidence are provided • Provided evidence is data from an investigation completed in the learning cycle • Evidence supports the claim(s) • If appropriate, evidence that refutes the claim is included and clearly indicated	Effectively and clearly provides evidence that includes all of the elements below: • At least 2 examples of evidence are provided • Provided evidence is data from an investigation completed in the learning cycle • Evidence supports the claim(s) • If appropriate, evidence that refutes the claim is included and clearly indicated
Scientific Reasoning & Logic	Effectively and clearly provides scientific reasoning and logic that includes some of the elements below: • An accurate explanation of the concept of natural selection is used to link the evidence to the claim • An accurate explanation the ecological concepts of niche, competition, biodiversity, or extinction is used to link the evidence to the claim • Includes a logic statement that links the evidence to the claim (including words such as because and therefore) • If appropriate, an idea or concept is used to refute or question the claim	Effectively and clearly provides scientific reasoning and logic that includes all of the elements below: • An accurate explanation of the concept of natural selection is used to link the evidence to the claim • An accurate explanation the ecological concepts of niche, competition, biodiversity, or extinction is used to link the evidence to the claim • Includes a logic statement that links the evidence to the claim (including words such as because and therefore) • If appropriate, an idea or concept is used to refute or question the claim
Evaluation of claims, evidence, and reasoning	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with some of the following components: • Cause and Effect or Patterns is checked off • An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with all of the following components: • Cause and Effect or Patterns is checked off • An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.
Student Self-Evaluation Circle one	Teacher/Peer Evaluation Circle one	

Evidence	Developing	Proficient	Evidence	Developing	Proficient
Reasoning	Developing	Proficient	Reasoning	Developing	Proficient
Evaluation	Developing	Proficient	Evaluation	Developing	Proficient
Glow			Glow		
Grow			Grow		

Cooperation & Survival 5E

Unit 2 Humans vs. Bacteria

Biology

Student Name:

Biofilm See-Think-Wonder

As you watch the video, use the graphic organizer below to note down your ideas and questions.

See	Think	Wonder

Cooperation vs Cheating Investigation

When organisms live close together, they have to choose how to interact. Are they friends? Are they foes? Should they help their neighbors? All across the kingdoms of life, from bacteria to plants to humans, we face these same questions.

Procedure Part 1

Your task is to create the most nutritious meal possible. At the front of the room are food items to buy, each with a nutrition score. You have been given \$10. You may spend them however you like on the options available. You may not buy part of an item. In calculating your nutrition score, you can count up to two servings of the same item; beyond that, you cannot earn more points. For example, if you buy a whole pizza, you will get 6 nutrition points (3 points per serving, two servings), even if the other 6 servings remain on your plate.

After assembling your meal, answer the following questions:

1. How much of your money did you spend?

2. What food(s) did you have in the end?

3. Calculate your nutrition score. Remember, only two servings of the same food item can count.

4. Describe your strategy for getting the most nutritious meal with your limited budget

Class data:

Strategy	Number of Students Using that Strategy	Average Nutrition Score Achieved through that Strategy

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1. Based on the meals everyone created, which strategy or strategies are most successful? Why?

2. Are there any weaknesses of those strategies? If so, what are they, and why are they weaknesses?

Long Term Strategies

Introduction

In Part 1, did you work in a group? Have you ever worked in a group before? Did everyone contribute equally? What are the benefits and potential costs of working in a group?

Bacteria also collaborate in groups, with some individuals doing the majority of the 'work' while others may sit back and 'cheat' a little by exploiting the work of others. In this investigation, we will explore the conditions under which organisms may cooperate or cheat, and the impacts of these different strategies. First, you will interact with a simulation about collaboration and cheating, and then analyze data collected on a population of bacteria in cystic fibrosis patients.

Experimental Question

Procedure Part 2

1. Open up, [The Evolution of Trust Simulation](#) and click "...let's play a game." Note that you can turn the music off by clicking the sound button on the lower left hand side of the screen.
2. On the next screen, choose to cheat or cooperate in the each scenario, then answer the questions:

According to the first set of interactions, are you more successful when you always cheat, always cooperate, or sometimes cheat and sometimes cooperate? Explain why.

Do you think that strategy would be effective long term? Why or why not?

Imagine that you had to encounter the same person every day for this coin interaction. Would you be more successful if you both cheated every day or if you both cooperated?

If you began cheating, how do you think the other player would respond? How would that affect your success overall?

Using this information and the first part of the activity, explain why cooperation is a valuable evolutionary strategy, even if cheating might be more successful at times.

Natural variation results in individuals that respond differently to the same scenario. Even though we know that everyone is the most successful if everyone cooperates all the time, that may not happen.

3. Click "...more than once?" to move to the next screen

4. If you have time, play the first game, making any decisions that you want. Note your general observations below.

What strategy or strategies seemed successful against your varied opponents, and why?

5. If you played the first game, follow the arrows to move on to the tournament game. If you are skipping the first game, click on the fourth circle at the bottom to navigate directly to "one tournament." In this part, different characters (strategies) are pitted against each other.

6. Hover over the character names to see their strategies, and choose the strategy that you think will win the tournament. Note your choice, the winner, and observations in the table below (Data Table 1, Tournament)

7. Click on multiple tournaments, then use the data table (Data Table 2, Multiple Tournaments) to record the numbers of each type of player after each round. Then answer the question beneath it.

8. If you have time, replay the tournaments with all five characters.

9. Navigate to the next section, the evolution of distrust. You can either get there by clicking through the steps on the last screen, or click directly on the sixth circle at the bottom. We said before that everyone always cooperating results in the best outcomes for everyone, but that natural variation can add other behavior types. In this scenario, we see a group of cooperators where two variations have emerged: one copycat, and one cheater. Play the game with 10 rounds per match, 7 rounds per match, 5 rounds per match, and 2 rounds per match, and record your responses and observations (Data Table 3, The Evolution of Distrust).
10. If you have time and your teacher says to, you can play the rest of the game.

Data Tables

Data Table 1. Tournament Round
Predicted winner:

Winner of the Tournament	Observations
Who won in the short term?	
Who won at the end of the tournament?	

Data Table 2. Multiple Tournaments

Which strategy do you predict will win?

Round	Cooperate	Cheat	Copycat
0			
1			
2			
3			
4			
5			
6			
7			

Summarize: How did the proportions of each player type change throughout the game?

Why was the winning strategy so successful?

Data Table 3. Evolution of Distrust

Winner of the Tournament	How did the proportion of players of each type change over the course of the game?
1. Who won with 10 rounds per match, and what were their scores?	
2. Who won with 7 rounds per match, and what were their scores?	
3. Who won with 5 rounds per match, and what were their scores?	
4. Who won with 3 rounds per match, and what were their scores?	

Summarize:
Under what conditions is cooperation the best strategy, and why?

Under what conditions is copycatting the best strategy, and why?

Under what conditions is cheating the best strategy, and why?

Even if cheating is the best strategy under some conditions, it has shortcomings. How could a population of cheaters taking over a group make the whole group less successful?

Procedure Part 3

Cystic fibrosis (CF) is a genetic disease, in which a thick mucus builds up in the lungs of patients. Pathogenic bacteria often thrive in this mucus, causing frequent infections. Bacteria living in lungs of CF patients need to acquire iron from their environment (the human host). Cooperative bacteria living in these patients can generate biofilms. Here the bacteria produce molecules that help acquire iron, which can be shared amongst the bacteria living in the biofilm. Mutations may arise in a population of cooperating bacteria that turn the individual into a non-cooperator or 'cheat' that does not produce the beneficial molecule, even though they can still acquire iron from the other cooperative bacteria in their environment.

The data below represents samples of this bacteria population from a CF patient over time. The samples are sequential (sample 1 was taken first, followed by sample 2, and so forth). Analyze the data, and note your observations in the See-Think-Wonder graphic organizer.

Sample	Number of Cooperative Bacteria (in millions)	Number of Non-cooperative Bacteria (in millions)
1	100	5
2	90	8
3	85	15
4	75	25
5	62	40
6	50	45
7	25	30
8	5	25

Use the space below to complete your analysis.

See-Think-Wonder

See	Think	Wonder

Cooperation vs Cheating Investigation

When organisms live close together, they have to choose how to interact. Are they friends? Are they foes? Should they help their neighbors? All across the kingdoms of life, from bacteria to plants to humans, we face these same questions.

Procedure Part 1

Your task is to create the most nutritious meal possible. At the front of the room are food items to buy, each with a nutrition score. You have been given \$10. You may spend them however you like on the options available. You may not buy part of an item. In calculating your nutrition score, you can count up to two servings of the same item; beyond that, you cannot earn more points. For example, if you buy a whole pizza, you will get 6 nutrition points (3 points per serving, two servings), even if the other 6 servings remain on your plate.

After assembling your meal, answer the following questions:

1. How much of your money did you spend?

2. What food(s) did you have in the end?

3. Calculate your nutrition score. Remember, only two servings of the same food item can count.

4. Describe your strategy for getting the most nutritious meal with your limited budget

Class data:

Strategy	Number of Students Using that Strategy	Average Nutrition Score Achieved through that Strategy

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1. Based on the meals everyone created, which strategy or strategies are most successful? Why?

2. Are there any weaknesses of those strategies? If so, what are they, and why are they weaknesses?

Long Term Strategies

Introduction

In Part 1, did you work in a group? Have you ever worked in a group before? Did everyone contribute equally? What are the benefits and potential costs of working in a group?

Bacteria also collaborate in groups, with some individuals doing the majority of the 'work' while others may sit back and 'cheat' a little by exploiting the work of others. In this investigation, we will explore the conditions under which organisms may cooperate or cheat, and the impacts of these different strategies. First, you will interact with a simulation about collaboration and cheating, and then analyze data collected on a population of bacteria in cystic fibrosis patients.

Experimental Question

Procedure Part 2

1. Open up, [The Evolution of Trust Simulation](#) and click "...let's play a game." Note that you can turn the music off by clicking the sound button on the lower left hand side of the screen.
2. On the next screen, choose to cheat or cooperate in the each scenario, then answer the questions:

According to the first set of interactions, are you more successful when you always cheat, always cooperate, or sometimes cheat and sometimes cooperate? Explain why.

Do you think that strategy would be effective long term? Why or why not?

Imagine that you had to encounter the same person every day for this coin interaction. Would you be more successful if you both cheated every day or if you both cooperated?

If you began cheating, how do you think the other player would respond? How would that affect your success overall?

Using this information and the first part of the activity, explain why cooperation is a valuable evolutionary strategy, even if cheating might be more successful at times.

Natural variation results in individuals that respond differently to the same scenario. Even though we know that everyone is the most successful if everyone cooperates all the time, that may not happen.

3. Click "...more than once?" to move to the next screen

4. If you have time, play the first game, making any decisions that you want. Note your general observations below.

What strategy or strategies seemed successful against your varied opponents, and why?

5. If you played the first game, follow the arrows to move on to the tournament game. If you are skipping the first game, click on the fourth circle at the bottom to navigate directly to "one tournament." In this part, different characters (strategies) are pitted against each other.

6. Hover over the character names to see their strategies, and choose the strategy that you think will win the tournament. Note your choice, the winner, and observations in the table below (Data Table 1, Tournament)

7. Click on multiple tournaments, and use the simulation to record your responses and observations (Data Table 2, Multiple Tournaments), and answer the question beneath it.

8. If you have time, replay the tournaments with all five characters.

9. Navigate to the next section, the evolution of distrust. You can either get there by clicking through the steps on the last screen, or click directly on the sixth circle at the bottom. We said before that everyone always cooperating results in the best outcomes for everyone, but that natural variation can add other behavior types. In this scenario, we see a group of cooperators where two variations have emerged: one copycat, and one cheater. Play the game with 10 rounds per match, 7 rounds per match, 5 rounds per match, and 2 rounds per match, and record your responses and observations (Data Table 3, The Evolution of Distrust).
10. If you have time and your teacher says to, you can play the rest of the game.

Data Tables

Data Table 1. Tournament Round

Predicted winner:

Winner of the Tournament	Observations
Who won in the short term?	
Who won at the end of the tournament?	

Data Table 2. Multiple Tournaments

Which strategy do you predict will win?

Winner of the Tournament	Observations

Summarize: how does a world of copycats evolve from a mixed population? Why is this such a successful strategy?

Data Table 3. Evolution of Distrust

Winner of the Tournament	Observations
1. Who won with 10 rounds per match, and what were their scores?	
2. Who won with 7 rounds per match, and what were their scores?	
3. Who won with 5 rounds per match, and what were their scores?	
4. Who won with 3 rounds per match, and what were their scores?	

Summarize:
Under what conditions is cooperation the best strategy, and why?

Under what conditions is copycatting the best strategy, and why?

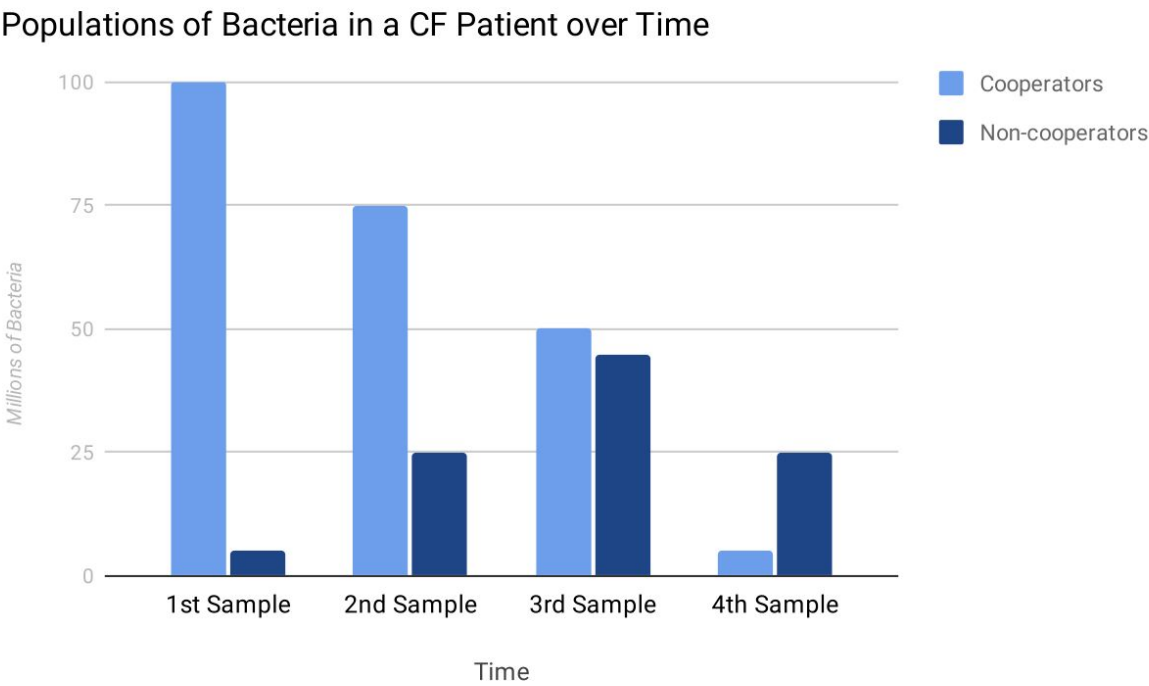
Under what conditions is cheating the best strategy, and why?

Even if cheating is the best strategy under some conditions, it has shortcomings. How could a population of cheaters taking over a group make the whole group less successful?

Procedure Part 3

Cystic fibrosis (CF) is a genetic disease, in which a thick mucus builds up in the lungs of patients. Pathogenic bacteria often thrive in this mucus, causing frequent infections. Bacteria living in lungs of CF patients need to acquire iron from their environment (the human host). Cooperative bacteria living in these patients can generate biofilms. Here the bacteria produce molecules that help acquire iron, which can be shared amongst the bacteria living in the biofilm. Mutations may arise in a population of cooperating bacteria that turn the individual into a non-cooperator or ‘cheat’ that does not produce the beneficial molecule, even though they can still acquire iron from the other cooperative bacteria in their environment.

The data below represents samples of this bacteria population from a CF patient over time. Analyze the data from the graph, and note your observations in the See-Think-Wonder graphic organizer.



See-Think-Wonder

See	Think	Wonder
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Investigation Summary

1. What patterns did you notice in the proportions of individuals with specific traits within the data you collected? How are these patterns helping you make sense of how and why bacteria may have cooperative behaviors?

2. Explain how different conditions change the probability that cooperative behavior is beneficial to the individual, as observed in the investigation.

3. Under what circumstances is cooperative behavior beneficial for a population, as observed in the investigation? Not beneficial?

4. In a population of bacteria, why do you think non-cooperators (cheaters) could appear in a population of cooperators? Where did we see a similar example in the simulation?

5. How are cooperative behaviors in humans similar to cooperative behaviors in bacteria? How are they different?

6. What else do we need to know to better understand the phenomenon of bacteria cooperating to generate biofilms?

Cooperation vs. Cheating Investigation Rubric

Student Rubric - Cooperation vs. Cheating Investigation

How did you do in the investigation?

Student Self-Score Circle one			
I know how this investigation connects to our current unit.	No - I need help.	Almost	Yes
I was able to contribute to the See-Think-Wonder and respond to the Investigation Summary questions.	No - I need help.	Almost	Yes
I used my time well in this investigation.	No	Mostly	Yes
I plan to come in for extra help to complete parts of the investigation or ask questions.	No		Yes

What other resources could you have used to get more out of this investigation?

- More time
- More resources
- More information
- More help from my partners
- More help from my teacher
- Other:

Partner Rubric - Cooperation vs. Cheating Investigation

How did your partners do in the investigation?

Directions: Think back to how your partners participated in the lab. For each of the four categories, write your partner's or partners' names in the appropriate box.

	Unsatisfactory	Pretty Good	Excellent
Contributions	Did not participate.	Did the minimum of what was required.	Provided useful ideas when participating in discussion
Working with Others	Rarely listened to others. Disrupted or discouraged others' attempts to participate.	Usually listened to, shared with, and supported the efforts of others.	Listened to, shared with, and supported the efforts of others.

Time Management

Procrastinated, did not use school time or schedule provided to get work completed.

Mostly used time well and completed investigation on time.

Used time well to ensure things get done on time.

Evolution of Cooperation Notetaker

Guiding Prompt:

How did cooperation between bacteria evolve?

Directions:

1. Use your assigned video or text to complete the graphic organizer about your behavior
2. Share your ideas with your partners
3. Listen to the ideas of your partners and write down your notes in the space provided
4. Discuss how and why cooperative behavior may evolve over time in a population and write your ideas in the space provided below.

My cooperative behavior:

What I found interesting or surprising about this behavior:

Why is this behavior beneficial for a population or individual?

Some questions I still have about this behavior are:

Partner 1 cooperative behavior:

Notes on what I heard partner 1 say about the behavior:

Partner 2 cooperative behavior

Notes on what I heard my partner say about the behavior:

Group Ideas:

How do cooperative behaviors evolve over time through natural selection? Remember to discuss the following concepts in your response; variation, adaptation, competition, differential survival & reproduction, cause and effect

Cooperative Behavior of Bacteria in CF Patients Text

Cooperating and Cheating in Bacteria

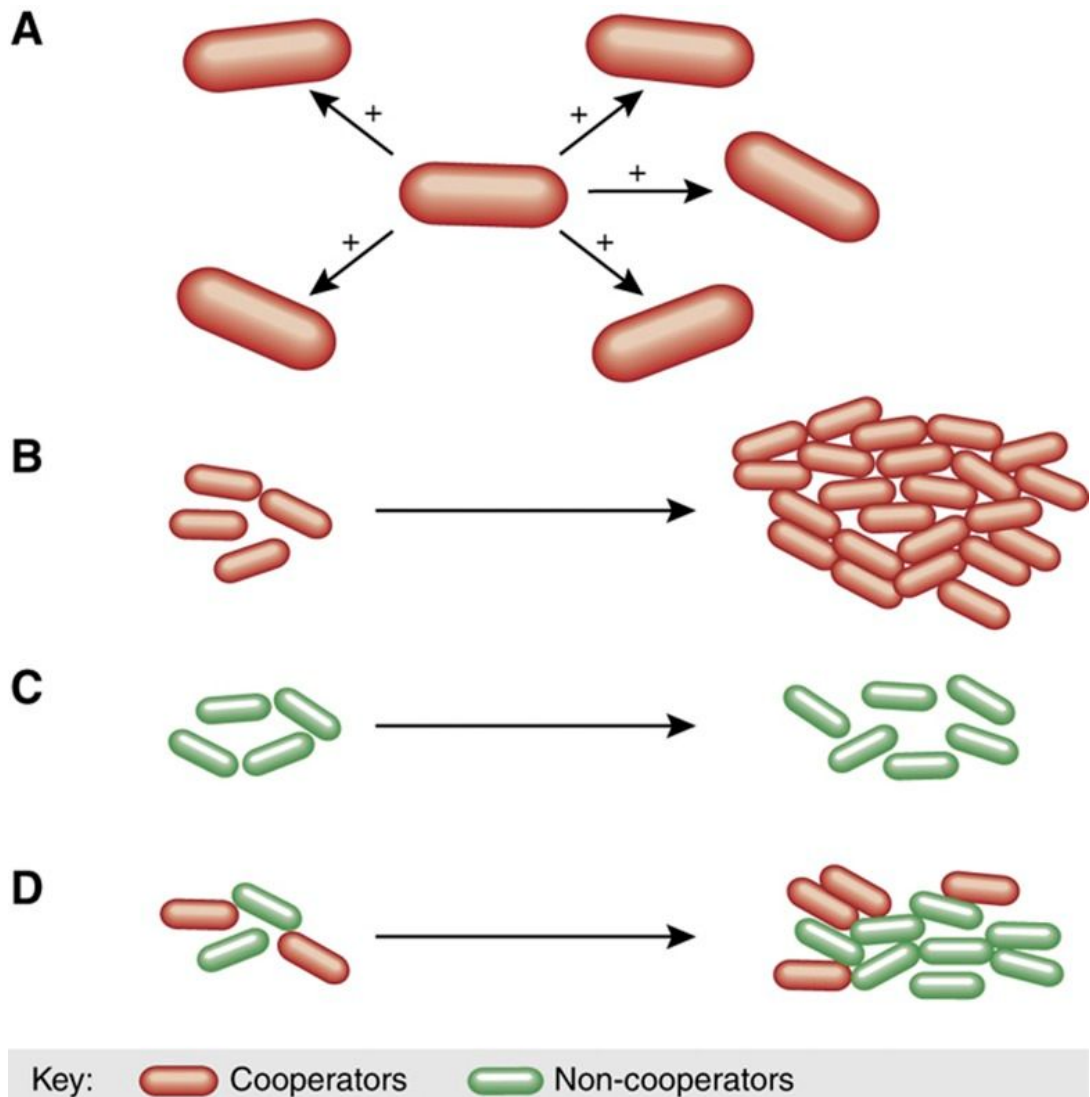
By: Dr. Sandra Breum Andersen

Cooperation is defined as working together to the same end. We can think of many examples of when people do this, to achieve something greater than one could have done alone. Perhaps more surprising is that seemingly simple microbes can do this as well, of course without making a conscious effort to do so. The examples here focus on cooperation within a species, but there may also be cooperation between species.

One way that bacteria can cooperate is by excreting something into the environment that can benefit not only themselves, but also their neighboring cells that are often genetically related to them (Fig.1A). This could be an enzyme that breaks down antibiotics, a protective slimy layer to encapsulate the bacteria in a so-called biofilm (like you may find under the plug in the sink, or on teeth that haven't been brushed recently), toxins that kill off competitors, or compounds that assist in acquiring nutrients.

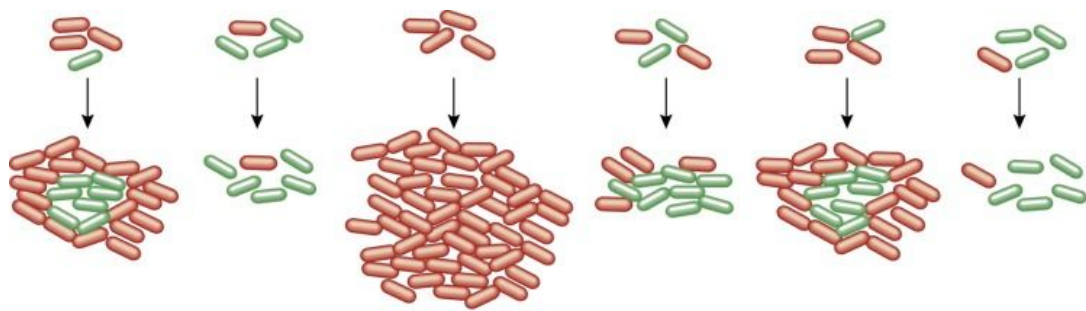
An example is the production of siderophores, which are compounds that help bacteria take up metals. Iron is required for bacterial growth, but limited in many environments. In the human body, iron is bound to a protein called transferrin to starve potential invading pathogens. Some bacteria can circumvent this by producing siderophores that have a higher affinity for iron than transferrin, effectively stealing the iron from the host carrier. The bacteria excrete siderophores, which bind to iron, and the iron-loaded siderophore can be taken up, by the producer or a neighbor.

A population of cooperating bacteria will do better than one of non-cooperators (Fig.1B+C). However, as we know from our own experiences with cooperation, this ideal outcome does not always reflect reality. A non-cooperating "cheat" will do well surrounded by cooperators, exploiting their costly behaviors. This way, a cheat may drive cooperators extinct even if this is to the detriment of the fitness of the entire population in the long run.



Cooperative social interactions that provide a population-level benefit often come at a cost to individual's cells. (A) A cooperative interaction provides a fitness benefit to recipients. (B) A population of cooperators has a higher productivity than (C) a population of non-cooperators. (D) Non-cooperators can exploit cooperators in mixed populations by benefiting from cooperation without contributing.

How does cooperation persist over time if cheats can invade? Cooperation is most frequently directed towards close genetic relatives, who are more likely to also be cooperative. This can be through spatial structure: if a bacterium is growing on a grain of dirt, or on a catheter, its neighbor is most likely a clone. Further, there may be population-level benefits to cooperation (Fig. 2).



Key: ● Cooperators ● Non-cooperators

Multilevel selection is essential for the evolution of cooperation among microbes. Cooperative strategies can have an evolutionary advantage in the global population, even though the same strategy is disadvantageous in local sub-populations. This happens because groups with a higher proportion of cooperators are more productive and therefore contribute more to the global gene pool.

From the beginning, it has been posed that microbial social behaviors are not just a quirk of interest to a particular scientific community, but also of great relevance to human health and disease. This is clear when we consider that the social behaviors affect bacterial traits such as antibiotic resistance, ability to colonize, and build biofilms. Often, the changes in bacteria we observe during infection are assumed to be adaptations to the host, i.e. changes that will increase a pathogen's fitness. A clear example is antibiotic resistance arising when a patient is receiving treatment. However, not all changes driven by social interactions will increase pathogen fitness in the long run – e.g. the loss of cooperation by cheat invasion. To manage our beneficial and harmful microbes it is crucial to understand the factors that drive evolution. We are now finally at a point where we are starting to show the role of social interactions in our microbial associates.

I have studied the evolution of iron acquisition in bacteria that infect cystic fibrosis (CF) patients. CF is a genetic disease that cause the build-up of thick mucus that bacteria can colonize. It is such infection that CF patients eventually die from. The bacterium *Pseudomonas aeruginosa* is found ubiquitously in the environment, and is a major CF pathogen due to its resilience to antibiotic treatment. At colonization, the bacteria produce siderophores to acquire iron, but frequently lose the ability to do so over the course of infection. This has been assumed to be because other mechanisms to acquire iron are more efficient in the deteriorating lung. With a large collection of bacterial isolates from Danish patients, we showed that it is actually the invasion of cheaters that cause the breakdown of cooperation.

The production of siderophores is frequently upregulated in the initial phase of infection, as this is a highly efficient way of acquiring iron. If this happens, non-producing cheats are highly likely to be sampled shortly after. That is, the more some cooperate, the easier it is for the cheats to invade. The cheats are relatives to the cooperators but have lost the production of siderophores from genetic mutations. They can, however, still take up the siderophores with iron produced by others, i.e. cheat. They lose this ability when there are no more cooperators to cheat on, likely because the siderophore receptor is also the entryway for lethal phages and toxins. So what happens with iron uptake when there is no one to cheat on? Iron uptake is "privatized" by upregulating a system that can take up iron from heme. This only happens when cooperation has been lost. With this we have shown that social interactions matter in clinical bacteria and should be taken into account when designing new treatment strategies.

C-E-R Graphic Organizer

1. Prewriting:

What is your question?

Support for your explanation

Claim based on the evidence (What is the answer to your question based on your evidence?)	Evidence (Observations/data that answers your question)	Scientific Reasoning (Why you think this happened based on background research)

2. Peer Review

Have a peer read your work and provide comments on what you plan to write.

3. Drafting

Write your explanation in paragraph form.

Scientific Explanation = Claim + Evidence + Science Reasoning

My claim is (fill in with above claim) because (evidence and science reasoning).

Leveraging Cooperative Behaviors Brainstorm

Directions:

1. Look back at your notes from the cooperative behavior.
2. For your originally assigned behavior, brainstorm how scientists could use what we know about that behavior to prevent infectious diseases, such as cholera.
3. After discussing your ideas with your group, using Think-Talk-Open Exchange, write down new ideas you have about using cooperative behaviors to prevent bacterial infections.

My Cooperative Behavior:

How could scientists use what we know about this behavior to prevent infectious diseases such as cholera?

After discussing possibilities from each type of behavior with my group mates, I now think

Summary Task

Summary Task

We recently completed a class consensus discussion. How did it go?

1. One thing that went well in the discussion:

One thing we can improve the next time we have a discussion:

One person who helped me learn today:

What did you learn from this person?

One idea that I contributed to my group or my class:

1. Explain what you know about the following questions, based on what we discussed today.

Explain how a cooperative behavior can evolve through natural selection.

2. How does a change in the environment, for example the introduction of cheaters in a cooperative environment, cause a change in a population? What evidence would you need to identify the causality?

3. How can scientists leverage cooperative behaviors in bacteria to prevent infections such as cholera? Give a specific example.

C-E-R Rubric

Component	Not Evident	Level 1: Beginning	Level 2: Developing	Level 3: Advancing	Level 4: Proficient
Claim	Does not make a claim	Claim does not answer the question (i.e., describe the relationship between the 2 variables)	Claim does answer the question but it is inaccurate.	Claim answers the question, and is accurate, but is incomplete	Claim answers the question, is accurate, and is complete. Completely describes the trend in the relationship between the IV and DV where appropriate.
Evidence	Does not provide evidence	Only provides inappropriate evidence (evidence does not support the claim)	Provides appropriate, but insufficient evidence to support the claim. May include some inappropriate evidence	Provides appropriate and sufficient evidence to support the claim. May include some inappropriate evidence.	Provides appropriate and sufficient evidence to support the claim
Reasoning: Science Concepts	Does not include reasoning	Restates evidence and does not include explanation of science concepts	Includes explanation of science concepts but all are inappropriate concepts that do not link evidence to claim	Includes explanation of some science concepts that link evidence to the claim, but are insufficient (one or more concepts that should have been included are not included) or some are inappropriate	Includes explanation of science concepts that link evidence to the claim (concepts are appropriate), and they are sufficient (no omission of key science concepts) and are clearly stated and accurate.

**Reasoning:
Logic**

Does not include
reasoning

Restates evidence
or claim and does
not include a logic
statement that
links the evidence
to the claim

Attempts to
include a logic
statement that
links the evidence
to the claim but
does not
adequately link the
evidence to the
claim.

Includes a logic
statement that
attempts to link
the evidence
with the claim
but needs to be
more clearly
stated to
demonstrate
logical
reasoning

Includes a logic
statement that
links the evidence
to the claim
(including words
such as *because*
and *therefore*) that
clearly
demonstrates
logical reasoning

Bubble net Feeding in Whales Text

Bubble-net feeding is a unique and complex cooperative feeding behavior engaged in by groups of humpback whales. Humpback whales are often solitary creatures that feed by themselves. In this method, they work together as a group. The group size can range from a minimum of two or three whales participating and up to sixty at one time. Whales can also perform a similar method of surface feeding called lunge feeding but this is done by individuals on their own.

Bubble-net feeding is a cooperative feeding method used by groups of humpback whales. This behavior is not instinctual, it is learned. Not every population of humpbacks know how to bubble net feed according to some studies. To be successful, they must learn the method. Humpback whales use vocalizations to communicate to one another and effectively and efficiently execute the bubble net so they all can feed. As the group circles a school of small fish such as salmon, krill, or herring they use a team effort to disorient and corral the fish into a net of bubbles.

One whale will typically begin to exhale out of their blowhole beneath the surface at the school of fish to begin the process. More whales will also start to blow bubbles while continuing to circle their prey. They corral the fish into a tight circle while creating a net of bubbles to surround the fish and keep them from escaping. The size of the bubble net created can range from three to thirty meters in diameter. One whale will sound a feeding call, at which point all whales simultaneously swim upwards with mouths open to feed on the trapped fish.

This method of feeding, which is uncommon and unique to humpback whales, has sparked plenty of interest. There has been some speculation behind the net of bubbles and how fish are trapped within. One study suggests that it is the acoustics from the exhalations from the whales that traps the fish. It is thought that within the circle it is silent but outside the sounds have such high intensity that it is nearly impossible for fish to escape. The energy from these calls have measured up to 4000 Hz.

There are also a multitude of theories behind why humpback whales use bubble netting as a feeding method. The earliest documentation of this feeding behavior was recorded in 1929 from the Norwegian Sea. They speculated that it was playful behavior between the whales and a form of socializing. Change in environmental factors over the years has also been discussed as a possibility behind why this feeding method was started. The most popular theory behind bubble net feeding is one of survival. After being hunted to near extinction it is believed that humpback whales developed this method of feeding so many whales as possible can feed in a short amount of time.

Read Generate Sort Solve Organizer

Prompt: Why do these whales cooperate in this way? How can we understand the cause or causes behind the evolution of this cooperative behavior? How could evidence about the proportion of cooperative whales over time help demonstrate that this behavior is beneficial to the survival and reproduction of the whales?

Generate Ideas:

Name:	Name:
Name:	Name:

Sort - Discuss each solution or idea and ⭐ the ideas that seem the most useful

Solve - Individually write your response to the prompt incorporating the most useful ideas from the sorting process!

How can we disrupt bacterial cooperation in cholera infections?

During the Second World War, Alan Turing was an English computer scientist that created a machine able to crack and decipher secret messaging between the Nazis. Thanks to Alan's work, the Allies were able to defeat the Nazis and win the war.

Cholera bacteria, like the Nazis, are able to communicate and help each other survive by creating colonies (biofilms) that protect them from harsh conditions and external attacks. We might need another brilliant mind like Alan Turing to help us decipher the bacterial communication and defeat them for good!

How can we interrupt cholera communication?

How do bacteria communicate with each other? Since bacteria have not invented their version of the iPhone yet, they use molecules to send messages to each other. *Quorum sensing* is the scientific name for bacterial communication. Bacteria can use this communication system to chat about the density of their population and adjust their replication, biofilm formation, and virulence level. The quorum sensing is a signaling system based on molecules that are produced and received from other bacteria. When there are a lot of cholera bacteria in a specific location in the body, the amount of molecules produced also increases (goes up) and this signals to other cholera bacteria to stop reproducing. When the number of cholera bacteria is low, the amount of molecules decreases (goes down) and this sends a signal to increase cholera replication (similar to what you learned about feedback mechanisms with blood glucose level).

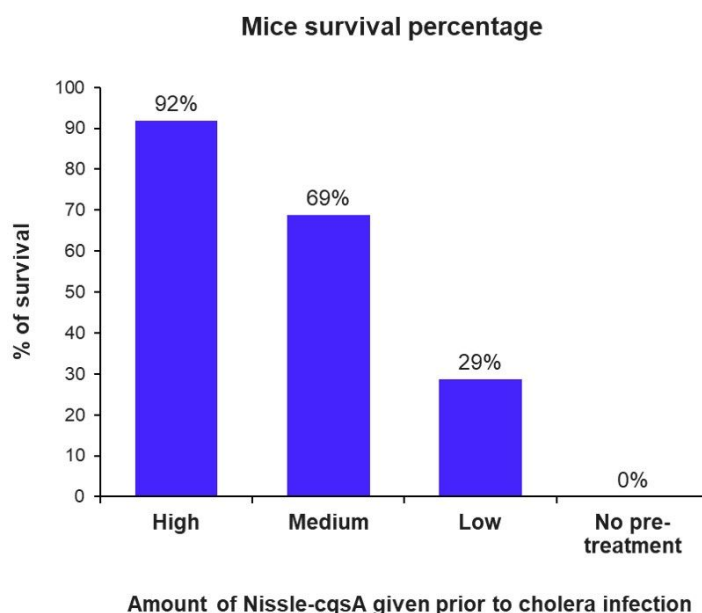
Scientists have discovered that, if this communication is intercepted, it can be disrupted. For example, Cholera quorum sensing can be disrupted by other healthy bacteria. Our microbiome can produce molecules that mimic (imitate) cholerae molecules and alter biofilms production and reduce the production of cholera toxin.

Scientists have also created a genetically modified strain of healthy bacteria (called Nissle-cqsA) that can send fake messages (molecules) to cholera to stop its replication. Mice pre-treated with the highest concentration (amount) of Nissle-cqsA and then infected with cholera had a 92% survival rate, while all those that were not pre-treated and then infected with cholera died (see the graph below). Think about this like a scam message. If the mice receive Nissle-cqsA bacteria before, when cholera arrives after, Nissle-cqsA sends a message to tell cholera to stop reproducing, saving the mice from cholera infection. The more the fake messages, the lower is the number of cholera replicating and the higher chances of survival.

However, since quorum sensing is also used by other bacteria (good ones included), some scientists are skeptical since the disruption of quorum sensing could also affect the communication of healthy bacteria and have a negative impact on the human microbiome.

A Special Case of Cheating

Another really interesting strategy that bacteria use to thrive is cheating. In this unit you figured out what happens when bacteria do not cooperate (when they cheat). The non cooperator (cheaters) will take resources from the bacteria that cooperate and this can reduce the overall number of bacteria in a population. If in a population there are more non-



cooperators than cooperators, then the colony will not have enough resources for all bacteria and many might die. In this case, having too many cheaters is not a good thing.

However, bacteria have also learned how to make cheating an advantageous trait. Scientists call this social cheating, something specifically linked to the disruption of quorum sensing. What would be the advantage of cheating by not responding to quorum sensing? Since quorum sensing regulates the biofilm production, scientists believe that social cheaters can better adapt in an environment that is different from their natural environment. For instance, while cholera bacteria's natural environment is the aquatic habitat, when these bacteria infect humans, they have to adapt to the stomach's harsh acidic environment and then move into the intestine. Scientists have discovered that social cheaters show increased production of biofilms helping them survive in harsh environments (high pH, high salt, high temperature, and food scarcity). This is an example of how one size fits all does not work in the evolutionary process. Cheating can be a bad or a good thing. Indeed, as you discovered in the pocket mice investigation, traits are beneficial only based on the environment and the conditions the organism lives in.

Cooperation & Survival Mini-Rubric

Claim: Focus on disrupting bacterial cooperation - We can prevent infections/outbreaks by disrupting bacterial cooperation

Component	Developing	Proficient
Evidence	Effectively and clearly provides evidence that includes some of the elements below: • At least 2 examples of evidence are provided • Provided evidence is data from an investigation completed in the learning cycle • Evidence supports the claim(s) • If appropriate, evidence that refutes the claim is included and clearly indicated	Effectively and clearly provides evidence that includes all of the elements below: • At least 2 examples of evidence are provided • Provided evidence is data from an investigation completed in the learning cycle • Evidence supports the claim(s) • If appropriate, evidence that refutes the claim is included and clearly indicated
Scientific Reasoning & Logic	Effectively and clearly provides scientific reasoning and logic that includes some of the elements below: • An accurate explanation of the concept of the evolution of group behavior through natural selection is used to link the evidence to the claim including: • Variations in behavior • Behaviors as traits that may be advantageous in certain environments • Differential survival & reproduction for individuals and their genetic relatives in the group • Changes in behavior on the population level based on the environment • Includes a logic statement that links the evidence to the claim (including words such as because and therefore) • If appropriate, an idea or concept is used to refute or question the claim	Effectively and clearly provides scientific reasoning and logic that includes all of the elements below: • An accurate explanation of the concept of the evolution of group behavior through natural selection is used to link the evidence to the claim including: • Variations in behavior • Behaviors as traits that may be advantageous in certain environments • Differential survival & reproduction for individuals and their genetic relatives in the group • Changes in behavior on the population level based on the environment • Includes a logic statement that links the evidence to the claim (including words such as because and therefore) • If appropriate, an idea or concept is used to refute or question the claim
Evaluation of claims, evidence, and reasoning	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with some of the following components: • Cause and Effect or Patterns is checked off • An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.	A lens is used to understand and/or evaluate the scientific concept and how it relates to the evidence and/or claim with all of the following components: • Cause and Effect or Patterns is checked off • An explanation of how cause and effect and/or patterns is used to defend the strength of the claim, evidence, or how the scientific concept links the claim and the evidence.

Student Self-Evaluation Circle one			Teacher/Peer Evaluation Circle one		
Evidence	Developing	Proficient	Evidence	Developing	Proficient
Reasoning	Developing	Proficient	Reasoning	Developing	Proficient
Evaluation	Developing	Proficient	Evaluation	Developing	Proficient
Glow			Glow		
Grow			Grow		