Lesson 1: How did this little girl (Addie) get so sick?

Teacher Guide

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been This is the first lesson in the series. Up until this moment, students may never have considered why antibiotics today don't work as well as they used to . In this lesson you will draw upon their experiences with antibiotics and introduce an anchoring event (Addie's case) to which you'll refer throughout the unit.

This Lesson....What we are doing now: Students will analyze a Frontline video about a pan-resistant bacterial infection case in a little girl, named Addie. Students will ask questions regarding why aren't the antibiotics helping Addie get better. You'll guide them to decide to start a fact timeline with what happened to Addie in chronological order and separate out the differences between species of bacteria "kinds" and strains "types" with each kind.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L1: How did this little girl (Addie) get so sick? (1 period) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2 & HS-LS4-4*	A Frontline video clip introduces us to the case of a little girl (Addie) who came into the hospital with a bacterial infection. After several weeks of antibiotic treatment she ends up with life threatening pan-resistant bacteria:. We share our own experiences and related cases with sickness and antibiotics.	**Ask questions** that arise from careful observation of unexpected results, to clarify and seek additional information *about how bacteria caused this little girl (Addie) to become and stay so sick despite receiving antibiotics.*	We have lots of experiences related to bacterial infections and taking antibiotics. For example, some of us have had to take antibiotics from a doctor, some of us have taken other family member's antibiotics. We know family members who had to take antibiotics because they had pneumonia, while others took antibiotics due to a minor infection from a cut. We noticed some important patterns in Addie's case and organized these events into a timeline: • Addie was cut while playing on the playground in 2011. • She came to the hospital sick from an infection caused by one type of bacteria from this cut. • Doctors gave her an antibiotic that worked for awhile, but then stopped working. • She ended up getting another infection from a different type of bacteria while in the hospital. • Doctors then gave her a new antibiotic that worked for awhile, but then it stopped being effective and Addie got sicker. They tried a third antibiotic and Addie started to improve but this antibiotic also stopped being effective and she got worse once again. • They repeated this process trying every antibiotic available to them. We identified some important differences in bacteria that the doctors refer to: • Addie had a type of bacteria in her lungs that was not the type they expected (pan-resistant). • Pan drug-resistant bacteria have "armor" that the antibiotic can't penetrate. • There are different types of bacteria, resistant vs. susceptible (non-resistant). • And there are different kinds of bacteria: Staph (*Staphylococcus*) and *Stenotrophomonas*. We decided it was important to pay attention to the different types and kinds of bacteria and kept track of this information in a summary chart. She seems to have had infections from two different "kinds" of bacteria: (a) *Staphylococcus* and (b) *Stenotrophomonas*. Some of both kinds of bacteria appear to have been killed by antibiotics. However, some of both kinds of bacteria were not killed by those antibiotics. It appears that there are two types of bacteria within each kind of bacteria—those that were resistant to one antibiotic (and lived) and those were not resistant to an antibiotic (and died). *We have a ton of questions! Why is that happening? Can this happen to me? From where can you get bacteria? How can a substance that helps wipe out the bacteria work for a bit, then stop working? How do antibiotics even work?* **After making a record of our questions, we identify some next steps to pursue. Because we are really concerned about whether this can happen to us, we want to know if cases like Addie's are common, or if this is a pretty isolated case.**

Next Lesson....Where we're going Your students will investigate the answer to some of their most personally relevant questions like "Could this happen to me?" and "How common is this sort of problem?"

These materials were developed with funding through a grant from the Gordon and Betty Moore Foundation to Northwestern University and the University of Colorado Boulder.

Getting Ready: Materials Preparation

Materials For Partners

- Provide each group of two students with a Transcript of the video: http://www.pbs.org/wgbh/frontline/film/hunting-the-nightmare-bacteria/transcript/

Preparation of Materials (5 min.)

- Bring up the Frontline video on a projector and check the sound http://www.pbs.org/wgbh/frontline/film/hunting-the-nightmare-bacteria/, through end of Addie's case; 12:10 min:sec).
- Remember that Addie's case is only in the first 13 min. of the video. The rest of the video goes on to introduce other cases, that are not the focus of future lessons in the unit.
- Class Slides

Materials For Each Student

- Lesson 1: Student Activity Sheets (1)

Materials shared between classes.

- Clip magnets to hold papers to board and to move them around
- Roll of tape

Safety

- None

Materials per class

- Blank poster papers (4)
- Blank papers (20)

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Getting Ready: Teacher Preparation

Background Knowledge

From the FRAMEWORK:

LS4.C: Adaptation by natural selection is ongoing. For example it is seen in the emergence of antibiotic-resistant bacteria.

Cause and Effect: Mechanisms and Prediction Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures.

Other information:

MRSA stands for methicillin-resistant staphylococcus aureus. It is a form of bacterial infection that is resistant to numerous antibiotics including methicillin, amoxicillin, penicillin and oxacillin. Methicillin is a type of antibiotic. The scientific name for Staph is *Staphylococcus aureus.*

Alternative Student Conceptions

Students will come into this lesson with lots of prior experiences about taking medicine for a time they were really sick. Many will recall times that the medicine they took or someone in their family took had to be proscribed by a doctor. Some will recall that their doctor wrote a prescription for an antibiotic to take in some cases.

Students may not know what an antibiotic is or what type of sickness it is or isn't prescribed for.

Linking Our Understanding to Scientific Terminology

- Different kinds of bacteria (like *Staph* and *Stenotrophomonas*)
- Different types of bacteria (ie. variations within a kind like resistant or nonresistant)
- Antibiotic
- Pan-resistant bacteria

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Learning Plan: How did this little girl (Addie) get so sick? (45 min)

1. (5 min) Post a prompt for students to independently answer as they are entering class to elicit experiences with sickness and medicine.

Suggested Prompt:

➔ Write down a time when you or a family member got really sick, and you went to the doctor and the doctor wrote you a prescription for a medicine to take for several days. Did the medicine help you get better?

Ask students to share some examples. Possible *student responses*:

I took aspirin for a headache I had for a couple days.
I took advil for a few days for a sprained ankle that I got from a basketball game.
I took cough medicine for an entire week while I was sick.
I took medicine the doctor gave me for a cut that I had on my hand that got infected. I took a lot of pills for a lot of days.
I took an antibiotic for a high fever and rash I got from my little brother.

If students don't bring up examples of taking antibiotics that were prescribed by the doctor, then ask students a few additional questions.

Suggested Prompt:

➔ How many times have you or your family had to go to the doctor and get a prescription to take special kind of medicine called an antibiotic?

Summarize some differences you heard between the type of medicines taken and the different kinds of sicknesses to introduce the role of taking antibiotics to help fight bacterial infections: A

Teacher Supports & Notes

Strategies for this Sharing Initial Ideas Discussion

A The goal of this discussion is to introduce the Frontline documentary. Many kids might not know what antibiotics do, and the video does not explain what they are. We suggest using student responses to the writing prompt to bring up antibiotics, then tell kids that antibiotics kill bacteria before you play the video, rather than asking kids what antibiotics are and correcting their responses early on in the unit. This type of correction early on could position the teacher as the source of all knowledge, which undermines the knowledge building culture the class is working towards.

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Suggested Summary:

- It sounds like we have experiences taking different kinds of medicines for different kinds of sicknesses.
- Many of you brought up that doctors also prescribe different types of medicine like antibiotics for different kinds of sickness.
- We are going to be introduced to a young girl who had a sickness in the video we are about to watch.
- In the video you will hear that the doctors give her different antibiotics. Antibiotics are a type of medicine that is used to kill bacteria.

Tell students that they will need to keep track of important ideas on their activity sheet 1.1 as they learn about her case after they watch the video, which will be about 13 minutes long. Tell students that a transcript of the video will be passed out after watching it, if they want to refer to it for specific details they heard mentioned at that point.

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2. (13 min) Show the first 12:10 minutes of the Frontline video (stop right before the India case). Pass out transcripts of the video toward the end of the video.

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3. (10 min) Have students record the most important events that happened during Addie's story.

Suggested Prompt:

➔ What were some important events that happened to Addie that we discovered from the video?

Have students start to share out a few of the important events that they heard in the video. Tell students that you will be the recorder for class ideas and you need a moment to record each event they share on a piece of paper to post on the board. Post each event after you

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record it on the board. After three events are shared, and you have made three pieces of paper with one event on each, pause the conversation at this point.

Suggested Prompts:

- ➔ Are these events in the correct order?
- ➔ Was the first one we posed the event that happened before the other two, or should they be in a different order in terms of what happened earlier and what happened later?

Add "earlier" to the left side of the board and "later" to the right side of the board. B

Ask for student suggestions on how to reorder the three pieces of paper so they are in chronological order. Add a title to this emerging organization that says "Timeline of important events in Addie's case."

After the class agrees on the order for these three events, have students bring up their notes and transcripts to form a "scientist's circle" around the board for a Building Understandings Discussion. C **Have students continue sharing out and ordering the events by asking for a student volunteer(s) to write down additional important event(s) (one per piece of paper) shared by others in the class. Once they are written down, have students suggest where they need to be put on the timeline. These key student responses need to be included on the timeline:**

Addie was cut while playing on the playground in 2011
She came to the hospital sick from an infection caused by one type of bacteria from this cut.
Doctors give her an antibiotic that would work for awhile, but then stopped working.
She ended up getting another infection from a different type of bacteria while in the hospital.
Doctors give her an antibiotic that would work for awhile, but then stopped working.
Doctors switch the type of antibiotic and encounter similar results.
They repeated this process trying every antibiotic they have available.

Additional Guidance

B This is the start of the timeline of events that happened in Addie's story and will be important for students to be able to reference and build on throughout the unit. Put it in a place that can be left up throughout the unit, or make it on chart paper that can be easily removed and relocated to a different wall. If you have multiple classes doing this unit. Tell students, "let's take a photograph of our timeline. I'll clean up our version tonight and relocate our group timeline so we can all see it." If you need to clean up or merge the classes timeline, you may want to check with each class the next day to see if they are okay with the cleaned up version of the timeline. Also, you may want to send kids the photograph of their classes first draft.

Strategies for this Building Understandings Discussion

C If this is the first time students are sitting in a scientist circle, emphasize that this coming together is an important part of the work we do together the course of this unit. When we come together, we are relying on everyone's contributions to ensure we get all ideas on the table and don't overlook anything that might prove important to our work later.

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As students start raising new questions, have students stop and jot them on their activity sheets.

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4. (8 min) So the doctors finally identified that she had a type of bacteria in her lungs that was not the type they expected. They called this type pan-resistant. They also said that resistant bacteria have some kind of "armor" that prevents the antibiotic from getting into it. Let's keep track of the kinds and types of bacteria that we uncovered in Addie's case.

Suggested Prompts:
➔ What was the name of the kind of bacteria Addie got first?

***Sample student response*:**
The video said she got some kind of staph D

Build a 2x2 chart on poster paper and write "Kind" across the top. Then write Staph under the category "Kind" in box A. After starting that part of the table ask about the kind of bacteria that Addie got from the Ecmo machine.

Suggested Prompts:
➔ Did they say that there was a certain type of staph that Addie got?

***Sample student response*:**
The video said she got MRSA

Tell students what MRSA[E] stands for emphasizing the 3rd point below:
- **MRSA stand for "methicillin resistant *Staphylococcus aureus*"**
- **Methicillin is a type of antibiotic**
- **So what this means is that MRSA is a kind of staph that can't be killed by antibiotics.**

You may want to draw a parallel to the type of work that doctors and scientists do together, where they make time to share their cases with each other (or their research with each other) to make sure they didn't miss anything critical.

If students are want to explicitly tell students that that it is ok to reorder things in the timeline, and that we may have to reorder things a few times, until we all agree on whether our representation of the timeline accurately reflects the order of events in Addie's case. Encourage students to double check their transcripts to see if anything needs to be revised in the order as we move our pieces of paper around.

Additional Guidance

D If students bring this up as an event, point out that this is also an important piece of information that we might want to keep track of, but since we don't know when this occurred, let's put in a different place than the timeline. Put it off to the side for now and use it in the next step.

Do not focus on the bacteria being gram - or gram +. It will confound later explanations and investigations. This alone does not

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Write "type" in box B, and put "Resistant to antibiotics or can't be killed by them" in Box C and "Non-resistant to antibiotic (can be killed by them)" in Box D.

Let's see if we can do a similar categorization that for the other kind of bacteria that Addie got from the Ecmo machine.

Suggested Prompts:

- ➔ What was the kind of bacteria Addie got later from the Ecmo machine?

***Sample student response*:**

The video said she got Stenotrophomonas from the machine

Fill in Box F with the name of this kind. Lasty, fill in the details for boxes G, H, I , and J

Suggested Prompts:

- ➔ Do we know if Addie for sure has resistant Staph?
- ➔ Do we know if Addie for sure has resistant Stenotrophomonas?
- ➔ What about the non-resistant versions of Staph and Stenotrophmonas? Does Addie have those too? E

***Sample student response*:**

Yes, Addie definitely has resistant Staph and Stenotrophomonas, but we never really thought about if she has non-resistant Staph and Stenotrophomonas too. I guess we're really not sure, the video didn't say.

Type (Box B)	Kind (Box E)	
	Staph (Box A)	**Stenotrophomonas (Box F)**
Resistant to antibiotics (**can't** be killed by	Resistant Staph - Yes, Addie has it **(Box**	Resistant Stenotrophomonas - Yes, Addie

explain why a particular kind of bacteria becomes more resistant. All bacteria within a species are either gram - or gram +, so that variation is a difference between species (kind), not variation within a species (type). Variation within species is the essential component of the explanations that students develop in the first ⅔ of the unit.

Rather, just focus on the idea that some bacteria have special armor around them that can make them harder to kill. Planting this idea now will help motivate the trait variations we mess around with when we get to the simulation in Lesson 7.

Additional Guidance

E It's important for students to think about the possibility that Addie also had some non-resistant bacteria in her too. We know that one of the reasons she gets better is because she does have some non-resistant bacteria that gets killed by the antibiotics, which is the reason she gets better for a while, but as the pressure from the antibiotics selects for the resistant kinds, she ends up with only resistant bacteria. From the kids perspective, they haven't figured this out yet, so leave the boxes for non-resistant *Stenotrophomonas* and *Staph* as open questions for now.

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them) (Box C)	**G)**	has it **(Box I)**
Non-resistant to antibiotic (**can** be killed by them) (Box D)	Non-resistant Staph -Addie? We don't know if she has this **(Box H)**	Non-resistant Stenotrophomonas -Addie ? We don't know if she has this **(Box J)**

Save this poster paper and keep one copy of it posted in the room for all classes to refer to in future lessons.

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5. (10 min) Remind students that at the start of the lesson the class brought up examples of other times that someone they knew went to the doctor to get a prescription for antibiotics.

Tell student to take 2 minutes to record some questions you now have about Addie's case, or other cases you've heard of or experienced related to bacteria or antibiotics or other how/why questions related to this stuff.

Post a poster with the title "Initial Questions" on the top and have students quickly share out some of their questions and make a record of them on the poster. Allow space to write at least 6 questions. F

Samples of anticipated *student questions:*

What happened to Addie after this?
How can a substance that helped wipe out the bacteria work for a bit, and then stop working?
Where can you get bacteria from in the first place?
Is the bacteria infection that Addie picked up from the playground the same bacteria that got her so sick?
Has the same thing that happened to Addie, happened to anyone else?
How do antibiotics even work?
Can this happen to me?

Strategies for this Sharing Initial Questions Discussion

F Encourage risk taking with sharing first draft questions we have. If some students raise additional questions later in the lesson or unit that they don't know the answer to, make sure to add those to the initial questions board to validate them and encourage this collective place to share our thinking.

Strategies for this Consensus Building Discussion

G Your kids probably have a lot of good ideas now. If you are looking back at a bunch of blank faces, this is a good time to do a quick turn and talk about possible responses to these prompts. Or, alternatively, ask "what are some big discoveries we made today?"

Another good strategy to use here to make sure we are all on the same general page is to make sure we get a response from everybody. Ask the class to put their thumbs up or thumbs down or thumbs sidewise to answer the question, "Do we all agree on the ideas that student A raised? Do others agree or do you have something else you want to add?"

If students seem to be dancing around

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6. After creating their initial questions chart, have the class think about the question, "What have we figured out so far?" Use the following prompts to guide this Consensus Building Discussion.

committing to a specific idea or main take away, latch on to any productive fragments they raise, "Wow that's an interesting thought and it seems like multiple students have been thinking about this too, what I think I hear you saying is, ".... " did I get that right? Make sure to allow the students to respond on your rephrasing to give feedback or further clarify their thinking.

Suggested Prompts:

- ➔ What did the Timeline of events that happened to Addie help us figure out?
- ➔ What did the Kind vs. Type chart help us figure out?
- ➔ What did writing out our Initial Questions help us see?

***Sample student response*:**

The timeline helped us figure out that the order to what happened to Addie may help us see what the possible causes and effects were of some of the things in her case.
The Kind vs. Type chart helped us sort out what kind of bacteria we think Addie had. We decided that Addie definitely has resistant Staph and Stenotrophomonas, but we're really not sure if she has non-resistant Staph and Stenotrophomonas too.
We have a ton of questions still! We are so curious about what happened to Addie. Some are about Addie, others are about us and the world around us. We are really concerned that this may not be an isolated case.

7. After creating the initial questions poster chart, have the class think about how we can use the questions we generated to plan next steps for future lessons. As students suggest possible next steps to pursue, keep track of the ideas that students come up with on another poster chart "initial ideas for future investigations".

Suggested Prompts:

- ➔ We came up with so many interesting questions! Which question are we most interested in investigating next?
- ➔ It's crazy to think that Addie got some of this from her local playground. Do you think there

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could be resistant bacteria like that at our parks? What about other public places we visit?

➔ Is anyone interested in wondering if this has happened to other kids who were healthy? Is anyone wondering if this could happen to them?

***Sample student responses*:**

We have all sorts of ideas of which question we are interested in investigating next. What happened to her was really weird - she got so sick so fast! I'm a little nervous that this could happen to someone like me, and I want to know if it could.

Has the same thing that happened to Addie, happened to anyone else?
How do antibiotics even work?
Can this happen to me?

We don't know if resistant bacteria could be in our parks or schools or busses. We've never heard of someone getting sick like Addie, so we think that the places we go might be safe. Hmmm, now I'm a little curious.

Yeah, I want to know how often this happens! Do I have to be concerned for myself or my family? Could we look into this next?

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

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Lesson 2: Can this happen to me? How common is this sort of problem?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been In the last lesson, your students were worried about whether or not what happened to Addie could happen to them and how common is this problem. They wanted to know if people are getting infected with resistant bacteria often today, or if Addie was a rare case.

This Lesson....What we are doing now: Students find the answer to their questions by analyzing different graphs and public health bulletins from the CDC and NIH in different groups. They summarize the discoveries from other groups in a class data summary table.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L2: Can this happen to me? How common is this problem? (1 period) *Building toward* *NGSS PEs: HS-LS4-2 & HS-LS4-4*	Data from the CDC show patterns of multidrug resistant infections not being uncommon:  Other public health bulletins provide information about Who's at risk for getting MRSA? and Is there only type of MRSA? Graphs from the CDC show historic trends in the number of antibiotic resistant infections over the past 60 years.	**Evaluate, and communicate information** by comparing and integrating multiple sources of information presented in different formats *in order to find patterns in the information that help answer some of our* questions related to *how common these sorts of infections are now vs. in the past, what kinds of resistant bacteria there are, and what kind of places do people get these sorts of infections from.*	We wanted to know, *are people getting infected with resistant bacteria often today, or was Addie a rare case?* From looking at the CDC summary data together we discovered that today a lot of people get infected with resistant bacteria! Then we were wondering, *has this always been the case?* So we looked at some data in the past. We jigsawed the data analysis into 5 groups and figured out some patterns after each group shared out their summary of the data which helped answer some of the questions we had: *1. Who gets MRSA?* • Anyone can get MRSA. • You can get it from lots of different places. *2. Is there only one type of MRSA?* • There are more than just two types/strains of staph. One type was resistant to two antibiotics, another type was resistant to one antibiotic, and the rest were susceptible to all known antibiotics. *3. What is the History of Resistance to Different Strains of Bacteria? (Page 28 - CDC report timeline)* • Some types of bacteria that were successfully treated in the past are the same types of bacteria that are resistant to various antibiotics today. • Penicillin-resistant *Staphylococcus* existed prior to the drug being widely used in public. *4. How many cases like Addie's were there in the past?* From the graph of data showing where and when resistance was acquired,we figured out: • Cases like Addie's are out there. • The number of cases like Addie's are growing over time (since the 1940s). • There were very few untreatable cases long ago (early decades after the 1940s). We added this information to our timeline. But this led us to wonder: *"What do community resistant and hospital acquired resistance mean?"* ***We thought that maybe findings from one of the other group's research can help us answer this question....*** *5. What is the difference between community-associated and hospital-acquired MRSA = Who Has Staph?*

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L2: (continued)	[Historic data from the CDC](#) shows when the first occurrence of antibiotic resistant infections were noted. [A summary from the NIH provides](#) information on the known types of MRSA and average % of people that have staph on their bodies.		• Community-associated MRSA is the kind acquired on playgrounds, out in the community. • Hospital-acquired MRSA is the kind acquired in hospitals, often as a result of invasive procedures and/or improper hand washing. After coming to this conclusion, we have some new questions and new concerns: • *Did Addie have both community-associated and hospital-acquired MRSA?* • *Why are so many more people getting this now compared to in the past? How did this happen?* • *If these resistant bacteria have always been around, why is resistance increasing?* • *Where are these resistant bacteria coming from?* • *What will keep happening in the future?* • *How am I just hearing about this now?* • *How can we make sure that other people know about this? How can we protect ourselves and people in our communities against getting this scary bacteria?* **Next Steps: People should know about this! We need to get the word out, because we don't want to get this sort of thing (we are freaked out) and we want to figure out ways we can help protect ourselves and others from having this happen.** We can't believe that ⅓ of us have resistant bacteria on our skin right now! This leads us to wonder: • *Where do we pick up this kind of bacteria and where do we get bacteria from in general?* • *If Addie got hers from the playground and the hospital,where else does bacteria live? How could we investigate where bacteria are found in our world?* • *We think bacteria might be everywhere, are they really? Or are they only in dirty places?* **Additional Next Steps: We want to find out where there are bacteria in our world.**

Next Lesson....Where we're going The class will develop a protocol for applying antibiotics to bacteria (e. coli) in Petri dishes and then conduct an investigation to see how this affects the growth of the bacteria over time.

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Getting Ready: Materials Preparation

Materials For Each Group

- Copies of National summary data (CDC, p. 13)
- Copies or access to the following data and articles
  1) What is MRSA? http://www.sfcdcp.org/mrsa.html
  2) A diversity of Antibiotic-resistant *Staphylococcus spp.* in a Public Transportation System: http://www.sciencedirect.com/science/article/pii/S2210909911000968
  3) Timeline chart of MRSA resistance: http://wiki.ggc.usg.edu/images/thumb/9/9b/SdoanMrsaChart.jpg/600px-SdoanMrsaChart.jpg
  4) Methicillin-Resistant Staphylococcus aureus (MRSA): https://www.niaid.nih.gov/topics/antimicrobialresistance/examples/mrsa/Pages/overview.aspx
  5) Antibiotic Resistance Threats in the United States, 2013: http://www.cdc.gov/drugresistance/pdf/ar-threats-2013-508.pdf (Page 28 ONLY)
- Chart or large construction paper - 1 piece per team

Preparation of Materials (15 min.)

- Create a set of materials for each group of students in advance.
- Check technology and websites to confirm that links are still functioning. Other sites can be substituted if needed. (Make sure other sites do not provide an explanation for how/why antibiotic resistance emerges in bacteria)
- Clear a space for students to be able to present their work
- Class Slides

Materials For Each Student

- Data mentioned above

Safety

- None

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Getting Ready: Teacher Preparation

Background Knowledge

From the FRAMEWORK (LS4.C): Adaptation by natural selection is ongoing. For example it is seen in the emergence of antibiotic-resistant bacteria.

Cause and Effect: Mechanisms and Prediction Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures.

Other information:

Hospital-acquired MRSA (HA-MRSA): HA-MRSA is acquired in the hospital setting and is one of many hospital-acquired infections exhibiting increased antimicrobial resistance. HA-MRSA has increased during the past decade due to a number of factors including an increased number of immunocompromised and elderly patients; an increase in the number of invasive procedures, e.g., advanced surgical operations and life support treatments; and failures in infection control measures such as hand washing prior to patient contact and removal of nonessential catheters. Community-associated MRSA (CA-MRSA): CA-MRSA is caused by newly emerging strains unlike those responsible for HA-MRSA and can cause infections in otherwise healthy persons with no links to health care systems. CA-MRSA infections typically occur as skin or soft tissue infections, but can develop into more invasive, life-threatening infections. CA-MRSA is occurring with increasing frequency in the U.S.and around the world and tends to occur in conditions where people are in close physical contact, such as athletes involved in football and wrestling, soldiers kept in close quarters, inmates, childcare workers, and residents of long-term care facilities.

Alternative Student Conceptions

Students may come into this lesson thinking that Addie's situation was a rare case. By the end of the lesson, students should figure out that, in fact, cases like Addie's are more and more prevalent. Also, students may still think that something was wrong with Addie and that's why she got so sick. (e.g. she has a bad immune system or similar abnormality). However, after this lesson students should know that many healthy people have gotten sick and even died from antibiotic resistant bacteria and that everyone is at risk. Something doesn't have to be "wrong" with Addie. By the end of this lesson students should realize that more and more bacteria found in public areas is resistant to at least one type of antibiotic.

Linking Our Understanding to Scientific Terminology

- Staphylococcus aureus
- Methicillin Resistant Staphylococcus Aureus (MRSA)

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Learning Plan: Can this happen to me? How common is this sort of problem? (60 min)

1. (10 min) Begin with a Consensus Building Discussion A to help re-orient students in the story line. Use the following prompts to help students articulate what they figured out in the last lesson.

Suggested Prompts:

- ➔ What questions did we generate in our last class?
- ➔ We agreed that we want to figure some things out in our last lesson. What were they?

Listen for *student responses* that refer to what we figured out last time, such as:

We had a lot of questions, including:

- *Why are bacteria changing like that?*
- *Can what happened to Addie happen to me?*
- *Where can you get bacteria from?*
- *How can a substance that helps wipe out bacteria for a little while just stop working?*
- *How do antibiotics even work?*

The most pressing question we had was, "We want to know if cases like Addie's are common or if hers was an isolated case. We think we should do a little research to find out."

---

2. (10 min) Present students with the CDC National Summary data on page 13 of the report. Give students a moment to read the infographic and turn and talk to a partner about what they notice and wonder. Next, shift to a Sharing Initial Ideas Discussion. B Use the following prompts to guide students to articulate what should be our next steps to focus on in today's lesson .

Suggested Prompts:

- ➔ What conclusions can we draw from this infographic?

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A In this, the second lesson of the unit, it is particularly critical for students to draw connections from one lesson to the next. By putting students in charge of recalling the questions they had and the next steps they determined, students maintain ownership of the work and remember the purpose of the work they set out to do in each lesson.

Strategies for this Initial Ideas Discussion

B This discussion is designed to give students the power to lay out the next steps for the lesson. While this particular discussion is short and to the point, it allows students to be the ones to identify what should be done and why. Considering the challenging nature of the materials, this is especially important in this case.

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Listen for *student responses* such as:

Lots of people get infected with resistant bacteria.

Suggested Prompts:

➔ Has this always been the case that lots of people get infected with this type of bacteria?
➔ How can we find out?
➔ What would we need to know if this was always the case in the past?

Listen for *student responses* that mimic the next step in the story line, such as

We're not sure. We think if we read some historical data about bacteria we might be able to figure it out.

---

3. (30 min) Explain to students that they will use a thinking routine to engage with the materials they read today. This routine is called "Connect, Extend, Question" and is designed to help students connect what they read or observe to prior knowledge, extend their thinking, and generate and collect additional questions.

Model this thinking routine for students, C using page 13 of the CDC document you examined earlier. Begin by drawing students' attention to the last paragraph of text on the page, saying, "This text connects to the question we had about whether or not what happened to Addie could happen to us, too. It turns out that most of the infections of antibiotic-resistant bacteria happen in the general community." To demonstrate the "Extend" part of the routine, note the statistics, saying, "These numbers seem very high, and they are only the minimum number of illnesses and deaths! This is a bigger problem than I originally thought." Finally, pose some questions related to the text, such as: "Has it always been the case that this many people contract antibiotic-resistant bacteria?"

Helping support students in literacy and ELA learning goals

C Thinking routines allow for students to engage in structured exploration of materials. The most important aspect of any thinking routine is that it allows students to make their thinking visible so they can go public with their ideas.

The Connect, Extend, Question routine asks students to engage with the following questions:

- Connect: How are the ideas and information presented connected to what you already know (did it answer any prior questions?)
- Extend: What new ideas did you get that extended or broadened your thinking in new directions?
- Question: What new questions arise after reading the new material?

Differentiation Strategies and Alternate Activities

D The articles provided for students are written at various difficulty levels. In order to meet the needs of your students, be sure to assign students to groups strategically and likewise assign articles that students will be able to access.

It may be helpful to work directly with the

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After modeling, place students into 5 groups, D giving each group one of the documents listed in the Materials section above along with a sheet of chart paper. Instruct students to use the thinking routine you modeled to engage with these materials. As they do, students should record their thinking on the chart paper. Remind students that once they have completed their work in their teams they will be asked to share out their findings with the whole group.

When students are ready to present their findings, use the following prompt to guide their sharing:

Suggested Prompts:

- ➔ What key takeaways helped you answer some of your questions?
- ➔ What did you learn that was new or unexpected?
- ➔ What new questions did you come away with?

As students share, collect ideas in a common place or ask students to take notes. Listen for and write down questions from students such as:

Why are so many more people getting this now compared to in the past?
How did this happen?
If these resistant bacteria have always been around, why is resistance increasing?
Where is this resistant bacteria coming from?
What will keep happening in the future?
How am I just hearing about this now? How can we make sure that other people know about this?
How can we protect ourselves and people in our communities against getting this scary bacteria?

Then, engage students in a Building Understandings Discussion using the following prompts. Invite students from any group to share answers, even if they did not read the associated article.

Suggested Prompts:

- ➔ Who gets MRSA?
- ➔ Is there only one type of MRSA?

group to which you assign the article, "A diversity of Antibiotic-resistant Staphylococcus spp. in a Public Transportation System." Students should only work with the abstract of this study, but it is important to help them make sense of the highly scientific language in that abstract.

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- ➔ What is the history of resistance to different strains of bacteria?
- ➔ How many cases like Addie's were there in the past?
- ➔ What is the difference between community-associated and hospital acquired MRSA and who has Staph?

Listen for *student responses* that share relevant information from student presentations and articles :

Anyone can get MRSA! You can get it from lots of different places.
Scientists found more than just two types/strains of staph on public transportation. One type was resistant to two antibiotics, another type was resistant to one antibiotic, and the rest were susceptible to antibiotics. There are more than two variations in how resistant bacteria is (what drugs it is resistant too); it's not just pan-resistant vs. not resistant.
The species of bacteria that were treated in the past are the same species of bacteria that we can't treat now. Penicillin resistant staphylococcus existed prior to the drug being widely used.
Some kinds of bacteria that were treated in the past are the same kinds of bacteria that we can't treat now.
Cases like Addie's are out there. The number of cases like Addie's are growing over time.
There were very few untreatable cases long ago.
Community-associated MRSA is the kind acquired on playgrounds, out in the community.
Hospital-acquired MRSA is the kind acquired in hospitals, often as a result of invasive procedures and/or improper hand washing.

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6. (10 min) After students have shared, guide them in reflecting on the information they learned from all of the articles today.

Suggested Prompts:

- ➔ What did you find most disturbing about the information you learned today?

Listen for *student responses* such as:

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We can't believe that of us have resistant bacteria on our skin right now! This makes us think about where do we pick up this kind of bacteria and where do we get bacteria from in general? Addie got hers from the playground and the hospital. Where else does bacteria live? How could we investigate where bacteria is found in our world? So we think bacteria is everywhere, but is it really? Or is it only in dirty places?

Then, enter into a Consensus Building Discussion to determine what steps to take in the next (and future) lessons.

Suggested Prompts:

- ➔ Do you think most people know about the information we learned today? Should they? How can we help?

Listen for *student responses* such as:

People should know about this! Because we don't want to get this sort of thing (we are freaked out), and also think about ways we can help protect ourselves and others from having this happen.

Invite students from any group to share answers, even if they did not read the associated article.

Suggested Prompts:

- ➔ Where do we pick up this kind of bacteria and where do we get bacteria from in general?
- ➔ If Addie got hers from the playground and the hospital, where else does bacteria live?
- ➔ Is it only in dirty places?
- ➔ How might we go about investigating where bacteria is found in our own world (in places like our school)?
- ➔ Do you have any ideas for the sorts of experiments we might be able to gather evidence for some of these ideas?

Listen for *student responses* such as:

From dirty places (bathrooms, rotten food)

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In shoes, the soil, on living things, etc
Maybe bacteria also lives in clean places .or places that look clean.
Maye there is some way to detect whether there is bacteria on us or on stuff around us.
Maybe there is some kind of experiment we might be able to do!

Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Building Toward Common Core Standard(s)

- CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

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Lesson 3a: Where is the bacteria around us?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been Students have just found out that there is an increasing number of people in the world with antibiotic resistant bacteria. They have analyzed historic and current data about antibiotic resistant bacteria. Students were concerned to learn that 1/3 of people have resistant bacteria on their skin and are thinking about where we are picking up this bacteria.

This Lesson....What we are doing now: Students will discuss where bacteria might be growing, or not growing around us, even though we can not see it. They brainstorm how they can test whether or not bacteria grow in various places and then form questions to investigate. As a class, you will organize questions into three categories. 1). Where can we pick up bacteria? 2). Does the bacteria get on me from the environment? 3). How can we get the bacteria off us? Then, you will guide groups with similar questions to design and carry out their experiments after they have seen how scientists can put swabs of different places on Petri dishes with agar to see if bacteria grow.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L3a: Where is the bacteria around us? (2 periods) *Building toward* ⬇ *NGSS PEs: HS-LS4-2 & HS-LS4-4*	We see no bacteria in the places we go around the school, but we think they might still be in some of these places, based on prior experience (such as getting food poisoning, having to wash our hands after using the bathroom etc.) . When we take swabs of different places in the school and plate them on Petri dishes, and seal them in ziplock bags we still see no visible bacteria in the Petri dishes.	**Plan and Carry Out Investigations** collaboratively to produce data that will serve as the basis for evidence in a future scientific explanation *(related to predicted and observed patterns in where can we pick up bacteria, how does it get on us, and how can we get it off us?).* Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.	We share ideas about where we might get bacteria from, including both "clean or disinfected" surfaces as places where there shouldn't be any or many bacteria, and "dirty places" where there should be lots. But the more we thought about it, the more we realized we can't see how clean or dirty something is at a microscopic level, so we are curious about where there are bacteria living and growing on things around us. From prior knowledge we brainstorm that they can get into us by various means - breathed in, through cuts, contaminated food we eat, and so on... We are predicting there are bacteria in some places in our room or school, even though we can't see them. We also want to know how we get bacteria on our bodies, and what we can do to get bacteria off us when that happens. We are excited about thinking where bacteria can come from, but we don't know how we can actually tell if we have bacteria growing in those places. This leads us to wonder: *How can we figure out if there are bacteria growing on our drinking fountains, chairs, etc.?* We brainstorm how we can test our ideas and formed some questions we could investigate. We group like ideas together, and we categorize those different ideas into three categories of questions these ideas are related to: 1. *Where can we pick up bacteria?* 2. *Does the bacteria get on us from the environment?* 3. *How can we get the bacteria off us?* **We want to make sure we have investigations that help us figure out where bacteria grow, and where they can get on us, and if we can get off if they get on us. But we still are struggling to design an experiment to investigate our questions.** Our teacher showed us an example of a sterile Petri dish with agar, which scientists can put samples in the dish to see if bacteria will grow from that sample. This led us to wonder: *What do bacteria need to grow and reproduce?* We see the recipe for the agar. Bacteria need food, which is the sugar in the agar. Scientists use lamps to keep them warm to make them grow faster - so there must be something about temperature connected to how fast they grow. We use these tools in a experimental design plan our group's make and setup. We prepare our Petri dish experiments using strict safety protocols. We predict that washing our hands with soap and putting on hand sanitizer will show less bacterial growth on our plates. We think maybe it kills bacteria, *but we really are not sure why or how.* **Next Steps: Next we want to figure out how antibacterial things get rid of bacteria. We also want to gather information about how people we know use antibiotics, so our home-learning assignment before the next lesson is to go home and ask some family members/friends about a time they needed antibiotics:** *(a) Do they know where they may have caught the bacteria? (b) What did they need to take (type and dosage if they can remember) and for how long? (c) Did they stop taking them when they felt better - or finish them all?*

Next Lesson....Where we're going While you are waiting for bacteria to grow on the plates, in the next lesson, teachers will support students in developing mathematical models that begin to explain how antibiotics work to kill bacteria.

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Getting Ready: Materials Preparation

Safety

- Petri dishes should be taped shut and placed inside clear ziplock bags and sealed after swabs are collected.
- Collecting tools need to properly disposed of in a hazardous material container (Stericycle.com will arrange drop off and pickup of such a container as well as OSHA approved disposal),or can be placed in a container of bleach and then disposed.
- Petri dishes also need to be disposed of in a hazardous material container, or exposed to bleach and then exposed.
- https://www.nsta.org/docs/TipsForSafeHandlingOfMicroorganisms20160412.pdf

Preparation of Materials (30 min.), 2 hours (or more before class)

- You will need to prepare the Petri dishes with agar at least **2 hours** prior to class. The agar needs to be mixed with distilled water and heated in order to dissolve, poured in the Petri dishes, and then allowed to cool. Instructions in link: https://www.youtube.com/watch?v=xgh1IZrnqVc
- You can also purchase Petri dishes with agar https://www.amazon.com/EZ-BioResearch-Bacteria-Science-Kit/dp/B004MKHNJK/ref=sr_1_1?ie=UTF8&qid=1469194631&sr=8-1&keywords=Petri+dish+with+agar
- Class Slides

Materials For Each Student

- Lesson 3a Student Activity Sheet (1)

Materials per class

- Sterile Petri dishes (four for each investigation group)
- Clear ziplock bags (1 per Petri dish)
- Inoculating loops, loops made from wire, wooden splints for each Petri dish used, or cotton swabs
- Agar (powder or liquid) and distilled water to make solution to pour in Petri dishes
- MAKE A COPY OF THIS survey (or create your own in google forms)

https://docs.google.com/forms/d/11-SKkQbjUfFTONcl--i0nkVI7fXL5kj48wLtKVo9UYc/edit?ts=57bf3982

Materials shared between classes

- Hazardous material collection bags for all used collecting tools and Petri dishes (enough for all groups traveling in the school for collection)
- Sharpies or masking tape for labeling dishes

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Getting Ready: Teacher Preparation

Background Knowledge for the Teacher

From the FRAMEWORK:

LS4.C: Adaptation by natural selection is ongoing. For example it is seen in the emergence of antibiotic-resistant bacteria.

Other information:

Some of what will grow in the Petri dishes in a few days will be fungus rather than bacteria. Since students are not likely to know how to distinguish them at this point, there isn't a strong motivation from their perspective to tell them this ahead of time, when they haven't seen any growth in their Petri dishes yet.

Alternative Student Conceptions

Students will come into this lesson with prior experiences with bacteria and getting sick by association with others who are sick. They will also have knowledge about employees in the food industry being required to wash their hands after using the bathroom. They may not know why though.

Students may not have seen a Petri dish before, or know about agar.

Linking Our Understanding to Scientific Terminology

- Different kinds of bacteria (like *Staph* and *Stenotrophomonas*)
- Different types of bacteria (ie. variations within a kind like resistant or nonresistant)
- Antibiotic
- Pan-resistant bacteria

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Learning Plan: Where is the bacteria around us? (2 periods of 45 min)

1. (15 min) Post a prompt for students to independently answer as they are entering class to elicit experiences and opinions on places bacteria can be found.

Reiterate to the students about what they learned from Addie's story: "In our previous lesson we figured out that a third of us are carrying around antibiotic resistant bacteria on our skin. And we know that Addie picked up her antibiotic resistant bacteria from the playground and from a machine at the hospital. This got us wondering, where exactly can we pick up bacteria from our things in our everyday world?"

Suggested Prompt for warm up: A

- What do we know about who can get infected by antibiotic resistant bacteria?
- What do we know about where you can get Community-associated MRSA and Hospital-acquired MRSA?
- Where exactly can we pick up bacteria from things in our everyday world?

Possible *student responses*:

We think bacteria is all around us and anybody including healthy people can get infected with resistant bacteria.
We know that people (including Addie) can pick up resistant bacteria from places in their communities like the gym or public transportation - ie. community acquired MRSA.
We know that another common place people pick up resistant bacteria is from going to their hospitals - ie. hospital acquired MRSA
We know we could have some of these bacteria on our skin.

Now that we know antibiotic resistant bacteria is found on our skin, and all around us, where do we think it can be picked up in places we visit on a daily basis? Have a very brief discussion with

Teacher Supports & Notes

Strategies for this Sharing Initial Ideas Discussion

A Students may be asking "If they can't see bacteria, how will they know where it is?" Use this as leverage to motivate this experiment of trying to detect what's there even though we cannot see it. Validate their idea, "Yes, that's a great point, maybe we should think about ways we can tell if bacteria is present even though we can't see it. Or maybe sometimes we can see it?" Students probably have an intuitive idea that bacteria exists even though we cannot see it. If they get stuck trying to come up with places it might be, try to guide them to thinking about why they wash their hands, or what it means to "pass germs around". Encourage students to think about their daily routine and where they think bacteria exists..

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students about the following prompts.

Suggested Prompt:

- ➔ What places around our school (if any) do we think we can pick up bacteria?
- ➔ What do we want to investigate about these places? Why?

Possible *student responses*:

We want to know where it is in our school.
We want to know if there are places that have more bacteria than others?
We want to know if it looks dirty does that mean there is more bacteria?
We want to know if where there is more people, is there more bacteria?

Have students write down the answers to the following prompts in their Student Activity Guide 3a.1

Suggested Prompts:

- ➔ Write down two places in the school where you think there might be a lot of bacteria, and write down two places in the school where you think there will be very little bacteria. Explain why you chose these places.
- ➔ We know Addie was exposed to bacteria on the playground, but how do you think it got into her body?

Possible *student responses*:

The drinking fountain will have a lot, because everyone's mouth is close to it.
The bathroom door will have a lot because people don't wash hands after the bathroom, even though you can't see them.
The countertops in kitchen will have few bacteria because they are cleaned every day.
Our phones will have a lot of bacteria because we touch them and carry them everywhere.
The whiteboard won't have a lot because only markers touch it, and not many people.
The trash can will have a lot of bacteria because there is a lot of food in bacteria.
Bacteria could have gotten into her body from breathing it in or maybe from off of her skin

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somehow

After students share examples of places in the school with and without bacteria, ask students to look for patterns in their examples. B

Suggested Prompt:

➔ What are some patterns you see between the kind of places you have chosen and the amounts of bacteria you predict we will find living there?

Possible *student responses*:

Places people are around will have more bacteria.
The more people around a place, the more frequently they touch that place, the more bacteria.
Places with food will have more bacteria.
Places that are cleaned with soap or disinfectants will always have less.
Places with no people and no food will have less bacteria.

Summarize what the students have predicted about bacteria in their school, this can be done on chart paper or on the board. This should be posted so we have a record to refer back to when we have gathered some data.

Suggested Summary:

- It sounds like we think that people have an effect on the amount of bacteria found in a place.
- Seems like people can pick up bacteria around them in lots of different ways.
- Places with food keep the bacteria alive and will tend to have more of them.
- Bacteria can be found places even though we can't see them.
- Places that are exposed to soap, or disinfectant can get rid of bacteria, (how much?)
- From prior knowledge we know we can get bacteria in our bodies through cuts, by eating rotten food, breathing them in, touching, etc.

Additional Guidance

B Our goal here it to get students to start thinking about the patterns in their predictions, however we also want them to start to think about why they think these patterns exist. Students should start to recognize the cause/effect relationships between human contact and where they think bacteria is abundant.

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2. (5 min) Sharing Initial Ideas Discussion: Lead students in a discussion to decide on the direction for this lesson.

Suggested Prompts:

- ➔ We have ideas of where the bacteria might be, but how will we know where they actually are if we can't see them?
- ➔ How do scientists know these bacteria are around if they can't see them either?
- ➔ If we had special goggles to view all the bacteria by us right now, what do you think you would see?
- ➔ How might we be able to capture them to bring them back to the classroom to study?
- ➔ If we could bring bacteria samples safely back to our classroom, then what would you be most curious about investigating? What questions would you want to explore by taking samples of things from our environment around us?
- ➔ Where are we curious to explore to figure out if bacteria is growing around us right now?

Possible *student responses*:

We might have to trap them in order to see them.
We might be able to see them if they grow enough, and get big.
We might be able to see different kinds of bacteria if they are colored.
Now I'm wondering if we had some way to make all the bacteria around us visible. I really want to see what's growing around me right now. Would I see a bunch of different colors? Would there be gross stuff on my desk? Would there be more stuff on my neighbor's desk compared to mine? I think we should investigate what's growing in our class next.

3. (10 min) Sharing Initial Ideas Discussion: Now that we have a direction for this lesson, encourage students to continue thinking about how do we test for something we can't see.

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Suggested Prompts:

- ➔ Were the bacteria that Addie got infected with on the playground alive?
- ➔ What do we think bacteria need to stay alive?
- ➔ If we want to investigate the bacteria, we probably have to keep it alive. How are we going to keep them alive when we bring back samples to our classroom (that may or may not have bacteria in/on them) ? [D]
- ➔ What type of environment do we think helps bacteria stay alive the best?
- ➔ How do we think bacteria reproduce?
- ➔ What do all living things need to stay alive and reproduce?

Possible *student ideas*

Bacteria need water, because all living things need water to survive
All living things need food to survive. So, bacteria need food, not sure what they eat though?
Bacteria may need other bacteria to reproduce ..or maybe not, maybe they are asexual. Not sure .
Bacteria live better in warm temperatures, than cold (refrigeration). Other living things need certain temperatures in order to survive.
Maybe if there was a way we could give the bacteria all the things they need to survive and put them in some kind of a cage, that we could look into, without letting them get out (because that might be dangerous based on what we learned about Addie) we could see them growing. I think I've seen something like that in pictures before.

We need to provide students with some information about bacteria before they can move ahead with planning their investigation. Show students a Petri dish with agar that has not been used.

Suggested Framing and Prompts:

"We know all living things need water, and nutrients. We have learned that bacteria are living. Therefore we can assume that the bacteria we collect will need water and a source of nutrients. So we will have to provide nutrients and water to the bacteria we investigate, and we need to think about

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helping our bacteria survive as we design our investigation.

We also know from Addie, and from experience that some bacteria, even if we can't see them, can make us sick. We want to be able to safely control the bacteria, and keep it away from making us sick. We have small containers that scientists use called Petri dishes that will feed the bacteria, and safely contain them and seal them up as we watch them grow. Looking at this Petri dish talk with your group about how you think it works to help us with our investigations."

- ➔ What do we think is in the jelly substance inside the container?
- ➔ How do we think the Petri dish could help us with our investigation?

Possible *student ideas*

We think it has a lid to keep it closed to keep bacteria from escaping.
We think there must be food and water in the jelly like substance.
We are wondering if they can still get out of the container?
We are wondering if we will be able to see them? How will we know they are there?

Based on your students prior knowledge working with Petri dishes, share with students the following points if they do not come up during discussion:

- A Petri dish is used by scientists to see if samples put in the dish have bacteria in them.
- Scientists can put a small sample in the dish, and then wait to see the kinds and types of bacteria that grow from that given sample.
- The dish has a gel like substance on the bottom called agar that is used to feed the bacteria.
- The agar has gelatin, sugar and nutrients in it.
- Scientists use a sterile inoculating loop to place the sample on the agar: we will use a sterile cotton-swab to collect our bacteria.
- In order to to be extra safe that they can't get out of the container, we will tape the edge of the top of the Petri dish to the bottom of it, to close it up, after we put a sample on it, and then we

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will slide the closed dish into a Ziplock bag and close it up and label the bag.

- Then we can leave it in our classroom and see if anything grows in our dishes that we swabbed after a couple days.

Demonstrate the last two bullet points. C

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4. (15 min) Now that we have some ideas about how we can test for bacteria around us even though we can't see it, we want students to start thinking about where should we collect our samples. In small groups, discuss the following questions:

Suggested Prompts:

- ➔ How often do you think the drinking fountains get cleaned?
- ➔ What other ways do you think people try to stop bacteria from growing?
- ➔ Has anyone kept a piece of beef jerky or dried fruit in their bag for a long time before? Did it go bad right away? Why do you think this happened?
- ➔ Individual question: We are interested in investigating where we can find bacteria in our school and on our own bodies. What investigation questions do you want to ask about bacteria in our school, or on ourselves? Write a question you want to know on a post-it note.

Possible *student responses*:

I don't know how often the drinking fountains are cleaned - maybe once a week? This makes me think about if cleaning helps get rid of bacteria, are there days when more bacteria are on the drinking fountain than others? Like should I only use drinking fountains on Mondays? How well does cleaning remove bacteria?
People probably get rid of bacteria by cleaning, washing hands, hand sanitizer, maybe put stuff in refrigerator like in the cafeteria.
I've kept dried cranberries in my bag for weeks. Does that mean that drying helps get rid of bacteria? Maybe it works because if bacteria need water - drying out makes it hard for them to

Additional Guidance

C Have one Petri dish that has already been poured, and cooled at your desk for the demonstration (you can reuse it for each class since it won't be sterile after the demonstration). Be sure to remind students that they want only their sample of bacteria they collect to be inside the dish. Based on your students prior experience working with Petri dishes, show them how to collect in pairs and have the lid of the dish only barely open so as to not let any other bacteria get onto the agar. Show students how to streak the plate by placing the tip of the collecting tool on top of the agar, without digging into the agar itself. They will make a zig zag pattern on the dish, and then close the lid. Then barely open the lid again after turning the dish 90 degrees, and make the zig zag pattern again on the agar. The tool can then be properly thrown away, or placed in a shallow bath of bleach. Students should label the dishes on the bottom (the side the agar is on, since they will need to be stored upside down after they are sealed). Have students label the dishes with the date, places of collection, and group names. Then **seal the dish completely**, so that is cannot be opened back up. Dishes can be stacked in an incubator or warm place.

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grow.
If there is more visible dirt, then will there be more bacteria?
How do we protect ourselves from getting sick?
How can we get bacteria off of us?
Does hand-sanitizer get rid of bacteria?
Does hand-sanitizer better than soap?
When we touch dirty things does the bacteria get on us? How much?
Does our phone have a lot of bacteria? What about if we compared our phone to school computers?
Can bacteria get in your body if you eat them? Does food have bacteria on it?

Have small groups share out answers to the discussion questions.

Consensus Discussion: Now that we have come up with some questions we want to know about bacteria, let's compare our question to other people's questions. We can take our question and walk around the room and find other people with questions that are similar to our own. We can make a group with other people that have questions similar to our own. Within our group we can create a broad question that links all of our individual questions together. D

Suggested Prompt for each group:

- ➔ Moving around the room with our question and comparing it to other people's questions, can we find others that are similar to our own?
- ➔ Talking with our new group of similar questions, what do our questions have in common?
- ➔ Write one broad, single question that links all our group's questions together?

Possible *student responses*:

If chemicals kill bacteria, why are they still on us?
If bacteria is all around us, what is the best way to get rid of it?
Are there places that bacteria is more likely to grow than others??
Is bacteria all over, or only in certain places?
Does temperature affect the bacteria and how they grow?

Strategies for this Consensus Building Discussion

D This is a good opportunity to check for student understanding of experimental design. Students should be mindful of the following:

- Will the investigation produce usable data to provide evidence?
- Is the question testable?
- Does the investigation's design ensure that the variables are controlled?
- Does the investigation design ensure the safety of those involved?

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If you touch a place with bacteria do they always get on you? Only certain kinds? And then can I spread them to other places?

This leads us to three main questions we are wondering about bacteria.

- **Where can we pick up bacteria?**
- **How does bacteria get on me from the environment?**
- **How can we get the bacteria off of us?**

DAY 2

5. (5 min) Warm Up: Have students independently answer the following question:

Suggested Prompt:

Last class we discussed how bacteria are in the environment around us, and that bacteria need certain requirements to stay alive, and to grow. Our main three questions that we were wondering about were: **Where can we pick up bacteria? How does bacteria get on me from the environment? How can we get the bacteria off of us?**

➔ Pick at least one of the three main questions and refine your investigation questions to align with that main question. For example: I'm picking main questions number 1 and 2: "Where can we pick up bacteria? And "How does bacteria get on me from the environment?" So I want to see how much bacteria is found on the light switch? And if I touch the light switch and then swab my finger, will I see the same bacteria transfer to my finger?

6. (15 min) Planning our investigations. E **Divide students into investigation groups based on class size and available materials. Have students refine their investigation questions and develop a collaborative investigation plan, and possible ways to obtain data as evidence for our**

Strategies for planning and carrying out investigations.

E Remind students to consider a control for their investigation, and to consider the variables that may affect their results. Encourage students to think about a real question they may have about the bacteria in the school. Once they get into groups they can be more specific about their claims, and how they plan to test them. If you have time, you could also have each group peer review another groups Student Investigation Sheet. Remind them that scientist review and share ideas regularly.

Be sure to have already set up classroom norms for mutually respectful behavior expectations that create a safe environment for students to be able to share ideas with each other.

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claim.

Summary of Investigation prompt:

- ➔ Share your investigation question from the warm up with your small group. Decide on 1-3 questions to investigate as a group that fit under one or more main questions we generated. Make sure to approve your question(s) with your teacher before moving on to deciding how to test your investigation.
- ➔ Recall our discussion yesterday about using Petri dishes. Plan in your groups, how can we carry out our investigation and obtain data.
- ➔ What materials might we need to help us with answering questions about bacteria at our school?

Remind students about following points as they plan how to test their questions: F

- A Petri dish is used by scientists to see if samples put in the dish have bacteria in them.
- Scientists can put a small sample in the dish, and then wait to see the kinds and types of bacteria that grow from that given sample.
- The dish has a gel like substance on the bottom called agar that is used to feed the bacteria.
- The agar has gelatin, sugar and nutrients in it.
- Scientists use a sterile inoculating loop to place the sample on the agar: we will use a cotton-swab to collect our bacteria.
- When the plate is warm the bacteria will grow faster (84-100 degrees, but above 100 degrees most bacteria will die)
- We will create our own heat source. (lamp, incubator, or just a warm place in room)
- We store the Petri dishes upside down so they won't have moisture from condensation on our sample
- Be sure to label your plates/bags before you begin collecting data with the date, place and a name.
- As you collect samples, each person should wear disposable gloves.

Formative Assessment Opportunities

F As students are working you can use this opportunity for a formative pre assessment. Some key look fors include:

- Are students making connections between the amount of human traffic and the amount of bacteria?
- Bacteria can be killed
- Bacteria lives on many things including people
- Bacteria can make other organisms sick

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- Collecting a sample is done as at least a two person job. One person lifts the lid, the other with use the loop to place sample on the agar. (see teacher guidance notes in right margin)
- Students should seal the petri dishes after they have collected their sample. Parafilm can be used, or classroom tape.
- Students should also seal each petri dish in a clear ziplock plastic bag after taping them shut.
- Students should dispose of gloves and swabs in a hazardous material collection bag.

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7. (20 min) Instruct students to collect samples based on their investigation question and plate their bacteria samples according to their protocols they developed. G

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8. (5 min.) Next steps and homework: Ask students to make predictions about what they expect to find in their Student Activity Guide 3a.1.

Suggested prompt:

➔ What would we predict to find when we follow up on our experiments?

After students make predictions, assign their homework.

Suggested framing:

➔ Some of us made predictions about what we would expect to find on plates with some kind of antiseptic on them. We think those things like hand sanitizer kill bacteria, just like antibiotics are supposed to. Last class we read a bunch of stuff about the CDC and people using antibiotics. What about people in our community? Do they follow what the CDC says? What about our own family? For homework: Pass out a survey to your family and people you interact with about their use of antibiotics. Tomorrow we will see what our community has to say.

Additional Guidance

G While your students are writing and completing the Student Investigation Sheet use this time to either hand out materials to each group, or have them set up on a table for each group to obtain when they are ready. They may need a bag or container to place their collecting tools in while they are out gathering samples. The Petri dishes should not be placed in sunlight, or on a heater. The best temperature is between 75 and 85 degrees. A lamp, or a warm place like on top of a refrigerator can be used if there is no incubator available. The warmth will help the bacteria grow faster.

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Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Building Toward Common Core Standard(s)

In the 1st part of the student activity sheets (parts A-D)

- CCSS.ELA-LITERACY.WHST.9-10.2 Write informative/explanatory texts, including the narration of …..scientific procedures/ experiments.

In the 2nd part of the student activity sheets (part E)

- CCSS.ELA-LITERACY.WHST.9-10.1.A Introduce precise claim(s), ….. and create an organization that establishes clear relationships among the claim(s),....reasons, and evidence.
- CCSS.ELA-LITERACY.WHST.9-10.1.B Develop claim(s) ...supplying data and evidence... in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns.
- CCSS.ELA-LITERACY.WHST.9-10.1.C Use words, phrases, and clauses to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence…..

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Lesson 4: How do (did) antibiotics and antiseptics work?

High School Unit: Why Don't Antibiotics Work Like They Used To?

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Previous Lesson....Where we've been In the previous lesson, students generated questions about bacteria and bacterial growth in "clean" and "dirty" locations. They prepared Petri dishes that they will continue to observe in Lesson 3b. Finally, students prepared interview questions for friends and family about their antibiotic use, whether they completed the dosage, etc.

This Lesson...What we are doing now: Students discover that many people do not follow the recommendations of the CDC to finish all of their prescribed antibiotics by reviewing survey data from the previous lesson. Students will determine that this is a problem that needs to be addressed publicly, creating a Mission Board to organize ideas for a public information campaign. Students investigate how antibiotics work by creating a mathematical model. They ask questions about why people don't complete their antibiotic prescriptions, despite the effectiveness of the antibiotics over time. Finally, students relate what they learn about antibiotics back to Addie's case by creating a model of how the antibiotics did or did not work in Addie's system.

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L4: How do (did) antibiotics and antiseptics work? (3-4 periods) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2 & HS-LS4-4*	Results from our home-learning survey reveal patterns (ie. most people were prescribed an antibiotic for 10 days, sometimes for 4; some people stopped taking it, some finished the whole bottle of medicine) CDC provides Recommendations for antibiotic use and preventing antibiotic resistance (e.g. Need to take antibiotics for 10 days or full course) A video of bacteria under a microscope shows them exploding or popping when antibiotics interact with them. Bottles of hand sanitizer and antibiotic soap state that that they kill 99.999% of bacteria.	**Analyze Data** to compare and contrast data sets to examine inconsistencies *(between patterns in our survey results and CDC recommendations)* to *help define problems related to designing a more effective public health message (infographic) that includes understanding how/why antibiotics work (or stop working).* **Use Mathematical Thinking** Use and develop mathematical representations *(tables and graphs)* of phenomena *(changes in population size over time)* to support claims *for why it takes multiple doses of antibiotic to wipe out a large bacterial population.*	Our conversations and surveys with relatives gives us hints that people are doing different things in terms of taking their antibiotics. **We want to know what doctors' recommendations say.** After reading the CDC recommendations, we see a discrepancy with what the CDC recommends doing and what our friends and family are actually doing from our survey results. We realize the list from the CDC is about "what to do", but not "why you should do it". The CDC thinks not following their recommendations is part of what is causing antibiotic resistant bacteria to grow in frequency. This raised a question: *Why are people not following these recommendations?* We think that maybe one reason people don't do the "what" is because they don't understand the "why/how", and we feel that we are in the same boat. **We think that if we figure out the why/how, maybe we can craft more compelling and effective public message in the form of an infographic that people will follow, vs. what the CDC does right now. We could actually hand these out in our school health clinic! As a class we create a "Mission Board" that states we want to share a public message about how to stop antibiotic resistance. We add some initial criteria to our "Mission Board" that our message needs to have information about the "why/how," not just the "what" like the CDC.** From the video, we learned that one way antibiotics work is by "exploding" bacteria. This led us to wonder, *how that works and if that is how all bacteria are destroyed by antibiotics?* We read an article that helps provide information about different mechanisms that can destroy bacteria (dissolving their cell membranes, blocking the construction of their cell walls, interfering with their DNA copying or DNA repair, blocking the production of proteins) and we also find out some unintended consequences of taking antibiotics (killing off good bacteria in your stomach) If this is how antibiotics work then, *Why don't all bacteria die after the first day of antibiotics? Why do you have to take dose after dose?* We see labels on antiseptics that claim kill 99% of bacteria or 99.999% of bacteria. We used this idea to mathematically model an example of 90% of the bacteria being killed by each antibiotic dose starting with an infection of 1,000,000 bacteria, and found some interesting patterns.  From our mathematical modeling we discovered that: • A single dose probably won't completely kill off a large bacterial population. • Repeated doses could increase the odds that we kill off all the bacteria from an infection

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L4: (continued)	Old medicine bottles that say take full dose or something like that. A written (and visual) summary of how antibiotics work provides brief summaries of how they interfere with or destroy the functioning of cell structures (e.g. cell walls) unique to bacteria cells, but common between good and bad bacteria (those that help with digestion vs. those that make you sick).	**Developing and using a model** Develop a model of a simple system *(to represent how the structures and function of the circulatory system could explain how antibiotic particles are spread to other parts of the body where bacteria might be located).*	We see agreement between the CDC recommendations (to take all your antibiotics doses to completion) and our mathematical model predicting that many doses are needed to completely wipe out an infection, but we see a mismatch between this and what some of the people we surveyed are doing (taking only a few doses until they feel better). *We wonder if this could be a problem? Do some people stop taking antibiotics because it makes them feel queasy (upset stomach), so they stop after they symptoms of the infection become hard to detect, but the bacteria might still be there (in small numbers)?* We add these thoughts under a "Mission Board" as questions to consider when sharing what we figure out with the public *This also led us to wonder whether or not it's a big deal if people don't finish all of their prescribed dosage? Does it even matter? Why doesn't a single dose of antibiotic kill 100% of the bacteria?* We try to apply everything we've figured out so far in this lesson and agree to try make an initial model to explain, *why didn't the antibiotics kill the bacteria in Addie?* After sharing out our initial models (gallery walk), we come to consensus on some things we want to include in consensus model to explain what might be going on with Addie. 1) Antibiotics travel through our bloodstream to all parts of the body (through digestion/transfusion and circulation). They aren't always equally distributed throughout the body. 2) If the antibiotic doesn't interact with a bacterium, it can't kill it. There isn't a 100% guarantee that every particle of antibiotic would touch/interact with every bacterium as it moves through our bloodstream. 3) Some antibiotic particles might get used up as they kill bacteria. 4) Antibiotic particles don't remain in our blood stream forever. The body breaks them down and excretes them at a certain rate (about 50% removed a day). 5) Some bacteria might actually be different from the others - even though one antibiotic particle interacts with these bacteria, it doesn't kill them. Maybe it takes more than one antibiotic particle to destroy it. Or maybe some don't get killed by any # of antibiotic particles that interact with it. **Next steps: We tried out our models to apply what we've figured out, and we've learned some things about how bacteria inside a body can be destroyed, but we don't really know if there's a way to stop bacteria growing that's outside our body. Our experiments are going to maybe help us figure out if bacteria grows well in the outside world, and if we can stop it. Checking in on our Petri dishes can help us answer this.** 

Next Lesson….Where we're going The class will develop a protocol for applying antibiotics to bacteria (E. coli) in Petri dishes and conduct an investigation to see how this affects the growth of the bacteria over time.

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Getting Ready: Materials Preparation

Materials For Each Group

- Chart paper will be needed for whole group activities.
- When students break out into small groups temporarily, they will need a section of the article: What is an Antibiotic to read, make sense of, and report out to the class.
- Groups will need blank large format construction paper or chart paper on which to sketch their initial models.

Preparation of Materials (15 min.)

- Designate a space in the room for a Mission Board where students will capture and organize ideas for their public information campaign about antibiotic use and resistant bacteria.
- Make copies of Student Activity Sheet 4.1 for each student
- Prepare the video of exploding bacteria and test the sound.
- Collect bottles of weed killer, insect killing spray, hand sanitizer, antibacterial soap, antiseptic sprays, and old antibiotic bottles that indicate that you should complete the full dose. These bottles must also state that the product is "99.9% effective" or that it kills "99.9% of bacteria."
- Class Slides

Materials For Each Student

- 1 copy of Lesson 4 Student Activity Sheets
- 1 copy Lesson 4 Student Article #1 (adapted from CDC)
- 1 copy of this article (article 2): https://docs.google.com/document/d/1U_TiH3tudbLWO5-J9iVFRmYda6aGOOjeZQBtH5dZLUU/edit#

Safety

- Take care to dispose of any old antibiotics within the bottles.
- Monitor students' use of aerosol products and other chemicals.

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Getting Ready: Teacher Preparation

Background Knowledge for the Teacher

LS4.C from the FRAMEWORK: "Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions."

Our investigation of bacteria that are resistant to antibiotics is the entry point for students into the concept of adaptation by natural selection. Eventually, Those bacteria that are resistant to antibiotics are killed, while those that are resistant can reproduce and further the species This is one important mechanism of adaptation that students will figure out by the end of lesson 7. When antibiotic prescriptions are not completed in full by patients, bacteria populations have an increased likelihood of this form of adaption to future exposure to this same antibiotic. This is one way that antibiotic resistance emerges. Other mechanisms (related to mutation) will be included in lessons 20 and beyond in this unit.

From Common Core State Standards for Math:
CCSS.MATH.CONTENT.HSF.LE.A.1 Construct linear and exponential functions, including arithmetic and geometric sequences, given a graph, a description of a relationship, or two input-output pairs.
CCSS.MATH.CONTENT.HSF.LE.A.1.C Recognize situations in which a quantity grows or decays by a constant percent rate per unit interval relative to another.
In our mathematical model students will construct a table of two input-output pair, and construct a graph from these values, based on a description of a relationship (how often bacteria reproduce). They should recognize the shape of the graph as non-linear. They will not need to construct a function or equation to model this relationship.

Linking Our Understanding to Scientific Terminology

- Antibacterial
- Centers for Disease Control and Prevention (CDC)
- Antiseptic
- Exponential relationship

Alternative Student Conceptions

It is likely that students will believe that antibiotics can be successful, even if the entire prescribed dose is not taken. As students engage in the readings and modeling in this lesson, they will learn that antibiotics and other products such as antibacterial or antiseptic products take multiple applications in order to destroy all of the bacteria in a system.

The purpose of the Mission Board isn't just to restate the CDC recommendations in an easy to read format. The purpose of the Mission Board is to construct a message that gets to the heart of WHY the CDC recommendations are important to stop the spread of resistant bacteria. This message requires students to understand how evolution works and how resistant bacteria, which have been selected for within a person, get released back out to the community, contributing to why antibiotics don't work like they used to in the 1950's. Students will not get to this full explanation until after the Juncos bend of the unit. The goal then of the "Mission" is for students to fully understand the problem, and then share that message in a user friendly way which should demonstrate their mastery of how evolution works.

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Learning Plan: How do (did) antibiotics and antiseptics work? (4 periods of 45 min)

1. (15 min) As students enter the classroom, hand out Student Activity Sheet 4.1, asking students to complete the first question. Once students have had sufficient time to record their answers, ask students to share what they learned from their friends and family about their antibiotic use.

Suggested Prompts:

- ➔ Did your family or friends have any ideas about where they might have picked up the bacteria that caused them to be prescribed antibiotics?
- ➔ What type of antibiotics did they need to take and for how long? Did they remember their dosage?
- ➔ Did they take all of the prescribed medicine, or did they stop taking it when they felt better?
- ➔ Did anyone report that they stopped taking their antibiotics early for any other reasons?

Listen for *student responses*[A] that report key information from their interviews such as:

My mom is a teacher and she said that when she started a job at a new school she got sick. She said it was because there were "new germs" that her body wasn't used to yet. My sister said somebody sneezed on her on the bus and she caught their germs.

Penicillin, amoxicillin, sulfa, z-pak, etc. Dosages vary

Some of the people we interviewed took all of the medicine because that's what they were told to do by their doctor. But some others stopped taking it when they felt better. Some people said it's because they didn't want to take too many antibiotics. Others said it was because they felt sick to their stomach or got diarrhea from taking the antibiotics.

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2 (10 min) Pose the following questions to help Build Consensus around the patterns in the data that was shared, questions that this raises, and what additional information we need in order to

Teacher Supports & Notes

Additional Guidance

A As students share the information they gathered from their interviews, be sure to keep track of opposing experiences. You may want to write on the board or some chart paper, categorizing information according to type. For instance, "Where we get bacteria," "Type and Dosage of Antibiotics," and "Taking Prescriptions" could be category headers.

By keeping track of information visually, you are supporting students' ability to recognize patterns or contradictions in the data from the interviews.

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investigate these questions

Suggested Prompts:

- ➔ What patterns or contradictions do you notice across all of the responses we heard? What else do you notice that you think might be significant?
- ➔ What are you wondering about antibiotic prescriptions?
- ➔ Whom or what might help us confirm whether or not we need to take all of the prescribed antibiotics every time?
- ➔ What additional information would be helpful in answering our questions?

Listen for *student responses* that draw out patterns or contradictions in the data:

We are noticing that people don't always finish their prescriptions. We also noticed that people choose not to complete a prescribed dosage for different reasons. We know that people have different ideas about where they can pick up germs.

We are wondering whether or not it's a big deal if people don't finish all of their prescribed dosage. Does it even matter? We're wondering what doctors say about finishing antibiotics. We're wondering if people are correct about the places and ways you can pick up germs.

We think we should hear from or do research about what a doctor or scientist says about antibiotics and whether or not you have to finish your whole prescription. B

3a. (20 min) Once students have indicated that they need to consider current research from experts in the field, pass out the article 1 saying, "I came across an article from the CDC, or Centers for Disease Control and Prevention, that I think might be helpful in answering our questions about recommendations for antibiotic use."

Turn students attention back to Student Activity Sheet 4.1. Review the directions and introduce the symbols students should use to annotate their work. As students read and annotate, circulate and observe students' annotations. Ask probing questions where appropriate to ensure students are engaging deeply with the text. C

Additional Guidance

B If students do not offer up the idea to consider current research on whether or not prescribed antibiotics should be taken in full, consider posing the following more explicit questions, "What do your doctors say about taking antibiotics?" Do they all say take the same number of days or to finish the whole bottle? Why or why not? What could we do to figure out what we are supposed to be doing?

It is best if students can offer up the idea to look at research so that they can maintain ownership of the flow of the lesson from one step to the next. It is critical that students feel that they are in control of the flow of the lesson so that they remain deeply engaged in the content.

Supporting Students in
CCSS.ELA-LITERACY.RST.9-10.9

C The CCSS asks that when reading Scientific texts, students are able to, "Compare and contrast findings presented in a text to those from other sources (including their own experiments), noting when the findings support or contradict previous explanations or accounts." While you circulate during this portion of the lesson, stop and ask students about their annotations, particularly as it relates

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When most students have finished reading and annotating, come together as a large group for a Sharing Initial Ideas Discussion.

Suggested Prompts:

- ➔ What questions did you have about the article?
- ➔ What did you think was interesting or important about the article?
- ➔ What connections did you identify between what the CDC recommends and what people you surveyed are (or are not doing)?
- ➔ Why do think there some discrepancies between what the CDC recommends and what people are actually doing (or are not doing)? Do you think people not aware of the recommendations? Or do they ignore them? Or do they not understand them?

Listen for *student responses* that answer these questions: D

We had a lot of questions about the information in this article. We're wondering why people would not complete their prescribed antibiotic dosages when the CDC clearly states that you should definitely do this! We also wonder if people just don't know about this and that's why they're making this mistake.

We now know that our friends and family have been guilty of not taking all their antibiotics and therefore potentially creating more pan-resistant bacteria. We can't risk letting this continue, otherwise it could be dangerous to all of us.

We aren't sure why people aren't following those recommendations.

3b. (10 mins) Dig more deeply into the question of why some people aren't following these recommendations by posing the following question and options in the form of a poll, using a paper/pencil version or a free online tool such as Poll Everywhere: *If you were someone reading the list of CDC recommendations, what do you think the most likely reason would be that a person would not follow those recommendations? A. People don't trust what their doctors say. B. The recommendations tell you what to do, but they don't explain WHY doing these things actually prevents antibiotic resistance. C. There is conflicting advice out there so people don't know what to do. Or D. Prescription drugs can be*

to this standard. Support students in making connections and noticing contradictions to what was shared earlier in the class period.

Strategies for this Initial Ideas Discussion

D In this particular discussion, we want to draw out students' concerns that their friends and family are actually contributing to a dangerous problem. Latch onto this concept of a dilemma as soon as it comes up in an effort to cultivate urgency. This will facilitate the next step in the lesson where we create a Mission Board to solve the problem of people not being informed about the dangers of not taking all of their antibiotics.

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expensive, so people want to save money by saving extra antibiotics for other family members.

Ask students to turn and talk with a partner to discuss their answers. Then, ask for students to share out with the whole group.

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4. (20 min)Once students have shared out their responses to the poll, use the following prompts to generate ideas about how to inform the public about the importance of finishing their antibiotic prescriptions:

Suggested Prompts:

- ➔ It looks like most of you selected (insert most common answer(s) here). If that's the case, what can we do to change or impact that mentality or belief?
- ➔ What message should we be spreading to the public, and who needs to hear it?
- ➔ How can we help get that message out there?

Listen for *student responses* that answer these questions:

We need to change people's mindsets about antibiotic use. People need the facts about why it's important to finish their antibiotics so that they can make an informed decision.

Anybody who is prescribed antibiotics should be hearing about this. We want them to know that not finishing antibiotics is actually doing more damage than good. In fact, it could be making antibiotics less effective because it's creating more resistance in bacteria.

We think the message from the CDC is really important, and it's one that more people need to know about. We think that if people knew why it was important to take all of your antibiotics, they would be more likely to do so.

We want to come up with a way to spread this message to others. E

Check in with students to gauge their interest in the idea of creating a "Mission Board" to keep track of what we want to share with the public. Then, ask students to consider what else we might need to figure out about how antibiotics work in order to build our Mission Board using the

Additional Guidance

E If students don't propose the idea of creating a Mission Board to keep track of and organize ideas for communicating a message to the public about the importance of finishing prescribed antibiotics. Say to students, "It seems that many of you feel passionately that we should find a way to take action and spread the message about the importance of finishing prescribed antibiotics. What if we created a Mission Board to help us keep track of the message we want to spread and our ideas for how we can spread that message?

Also, think about ways students could actually distribute a message or info graphic in your school or community that's concrete. For example, maybe your school's nurse station would be willing to distribute an infographic. Or maybe your school could air a youtube video one day during announcements or health class about the public message regarding why antibiotic usage makes a difference in spreading resistant bacteria.

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following prompts:

Suggested Prompts:

➔ What else would we want people to know about antibiotics?

➔ What are the gaps in what we know about what antibiotics are and how they work?

Listen for *student responses* that help lead to the next steps in the storyline: F

We want people to know how antibiotics kill bacteria. We also think they should be aware of the effectiveness of antibiotics based on whether or not you take all of them when they are prescribed. We actually aren't sure about how antibiotics kill bacteria, exactly. We want to learn about what actually happens to bacteria when someone takes antibiotics. We also want to figure out why it is that you need to take all of your antibiotics. What's going on in the body when people don't complete their prescriptions?

---

5. (20 min) Once students have identified that they need more information about how antibiotics interact with bacteria, show the video of bacteria exploding when they interact with antibiotics. You may want to play the video multiple times, drawing students' attention to the left pane, the right pane, and the elapsed time in the top right corner. Debrief with students about their experience using the following prompts:

Suggested Prompts:

➔ What did you notice is happening to the bacteria on the left side when they interact with the antibiotics?

➔ What did you notice about the bacteria without antibiotics on the right side?

➔ What are you still wondering?

Listen for *student responses* that help lead to the next steps in the storyline:

We noticed that the bacteria are actually exploding! The ones on the left just blow up. The bacteria on the right side without any antibiotics are growing at a pretty fast rate. They seem to be multiplying.

We're wondering if all antibiotics work this way. We remember from the Addie video that there

Additional Guidance

F This discussion helps us transition students away from the Mission Board in step 3 in an organic way. We want students to generate questions about how antibiotics actually work so that we can motivate the need to watch the video of Bacteria exploding when they interact with antibiotics and so that we can motivate creating a mathematical model of how antibiotics work with repeated doses.

If students don't ask these questions, consider asking, "Does anybody know what happens inside the body when we take or don't take antibiotics?"

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were different kinds of bacteria and antibiotics, so we wonder if they all blow up bacteria or if there are other ways. G

Tell students that you have another article (article 2) that will help answer their questions about different types of bacteria. Organize students into Jigsaw groups. Put students in groups of 3, assigning each student a number (1-3). Instruct students to read their assigned paragraph, working to make sense of how their particular antibiotic interacts with bacteria. Ask students to be prepared to summarize what they learned with their jigsaw group.

Once students have read and understood their individual paragraphs, ask students to join back together to share their summaries of the other types of antibiotics. When all students have shared, turn students' attention back to Student Activity Sheet 4.1 Jigsaw Summary. Ask students to complete this section independently. Circulate and assist as needed.

---

6. (20 min) Transition students back to the whole group to begin a Building Understandings Discussion. Use the following prompts to get students thinking about why antibiotics require multiple doses to be effective.

Suggested Prompts:

- ➔ Earlier in our discussion it was mentioned that we wanted to figure out why we need to take all of the prescribed doses of an antibiotic before they effective. Aren't chemicals like that supposed to kill all of whatever they target at once?
- ➔ Do we know about any other chemicals that are used to kill things? In what situations have we used chemicals that are supposed to eliminate problem-causing bacteria or other organisms?

Listen for *student responses* that help lead to the next steps in the storyline:

We can think of a few situations where you might want to use a chemical to kill things. For instance, we use weed killer in our lawns or gardens to kill weeds, but sometimes it kills grass. Some of us remember this working right away, but others remember it taking multiple doses. Some of us have used bug killing spray to kill bugs. We think this is also something that takes

Differentiation Strategies and Alternate Activities

G In this case, if students don't offer the idea that other types of antibiotics might affect bacteria in different ways, you can present the idea to students in a different way. Try asking, "Do all bacteria react the same way to antibiotics?" If there is even a hint of disagreement amongst students, or if they simply offer that they aren't sure, you have an authentic opportunity to introduce the information in the next article.

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multiple doses in some cases to really take care of the problem.
We can also think of a time when we used spray on our countertop, disinfecting wipes, or hand sanitizer to kill germs. We assumed those worked the first time, but now we're not so sure!

Bring out a bottle of hand sanitizer for students to consider. Place the label under a document camera or pass it around the classroom, asking:

- ➔ If the label says that this kills 99.9% of germs, does that mean it will kill all of the germs in one use/application?

Listen for *student responses* that contradict, such as:
Actually, 99.9% isn't 100%. It's close, but it's not entirely effective every time.

Continue to provoke students' thinking with the following prompts:

Suggested Prompts:
- ➔ So if a label says 99.9% and there were 1000 bacteria, how many bacteria would be destroyed and how many would be leftover?
- ➔ Does that one leftover bacteria matter?
- ➔ What about if there were 10,000 bacteria? One million?

Listen for *student responses* that contradict, such as:
If there were 1000 bacteria, there would be just one bacteria left over. We're pretty sure that's not very significant. But when the number of bacteria increases, so does the number of bacteria leftover from that .01% of ineffectiveness. This larger number might actually matter when it comes to health and safety.

Suggest to students that you create a mathematical model to help you make sense of why we might need multiple applications of a product like hand sanitizer for it to be completely effective. Do so by working with a more approachable figure, such as 90% effective.

On the board or on chart paper, co-construct a mathematical model to represent what would

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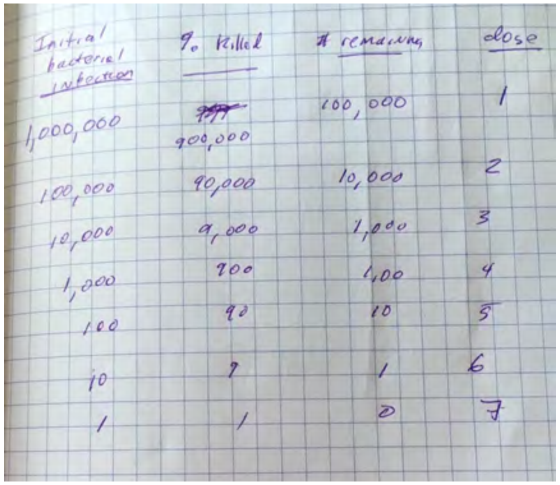
happen if you had 1,000,000 germs (bacteria) and you used a product (hand sanitizer) that was 90% effective. The resulting product should look something like the table below:



Initial bacterial infection	% killed	# remaining	dose
1,000,000	900,000	100,000	1
100,000	90,000	10,000	2
10,000	9,000	1,000	3
1,000	900	100	4
100	90	10	5
10	9	1	6
1	1	0	7

Ask students to turn back to Student Activity Sheet 4.1 and guide students through the construction a graph of "# of bacteria in the population vs. dose" for this data.

Suggested Prompts:

- ➔ What should the title of the graph be?
- ➔ What should we label the x-axis? Y-axis?
- ➔ What should the intervals be on the x-axis?
- ➔ What should the intervals be on the y-axis? H

Have students work independently (or with a partner) to write an explanation that tells how this mathematical model helps us understand why someone might need to take multiple doses of antibiotics in order for them to be fully effective. Circulate and assist as students write, probing deeply to get students to write complete and thorough explanations.

Join students back together to continue the Building Understandings Discussion you started earlier in this step.

Suggested Prompts:

- ➔ Did the model help us understand anything more about antibiotics and taking all of the doses?
- ➔ If there's agreement between our mathematical model and the recommendations from the CDC, what reasons might people have for not completing their full prescriptions of antibiotics?

Listen for *student responses*, such as:

The mathematical model confirmed what the CDC was saying in the article we read previously. If

Supporting Students in Using Mathematical Thinking

H Students may need some guidance in how to set up the y-axis intervals. They may assume that since the # of bacteria is decreasing by a factor of 10 with each dose, that they should decrease each major interval by a factor of 10.

Help students recognize that they should equal intervals for the y-axis and x-axis, even when the data appears to jump by unequal values. An equal interval for these axes will help students see what sort of mathematical relationships might fit the data (e.g. linear, exponential, quadratic).

Students will need to use this labeling approach to their graphs in future lessons (where the pattern data will once again be a non-linear relationship)

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you only take a few of the prescribed doses, you might not actually kill all of the bacteria in your system. You really can't know how many bacteria are in your system when you get sick, so it makes sense to take all of the doses just in case you have lingering bacteria in your system. We know that if bacteria remain in the system, they will just multiply like they did in the video. The only way to ensure this doesn't happen is to take the antibiotics in full.
We remember from the interviews we conducted that sometimes people feel good after only a few doses of antibiotics, then they stop taking the rest of the antibiotics. Some people also reported that antibiotics do crazy things to their stomachs, so they don't like to take them any longer than they feel they have to.

---

5. (45 min) Transition students back to the whole group to begin a Consensus Building Discussion. I **Gather students around the Driving Question Board, drawing their attention to the questions they generated at the beginning of the unit. Help students consider which of the questions they may have answered so far, using the following prompts:**

Suggested Prompts:
- Have we answered any of the questions on our Driving Question Board?
- What evidence do we have to support our answers to these questions?

Student responses will vary, depending on the specific questions students posed earlier in the unit. Once students have gone through the DQB and answered as many individual questions as possible, ask:

Suggested Prompts:
- How do the answers to some of these questions help us to answer our Driving Question: Why didn't the antibiotics kill all the bacteria in Addie?
- What would it look like if we were to draw an initial model J of what might be happening in Addie's body?

Encourage students to revisit all of the articles and materials they used throughout this lesson to

Strategies for this Consensus Building Discussion

I In this Consensus Building Discussion, it is crucial to encourage students to revisit the questions they generated previously in the unit, to consider the activities that produced evidence that might help answer their questions, and to combine these two to state clearly what we've "figured out" so far in the unit.

Before a question is considered answered, the class needs to come to consensus. The student or students who feel they have an answer to the question must provide evidence for their answer that is satisfactory to the whole group. If argument arises, encourage students to use the talk moves to engage in polite and productive discussion. It is best to give students as much control of the discussion as possible, with the instructor serving as a facilitator only.

Additional Guidance: Drafting an Initial Model

J The modeling process can be daunting for students if they are unsure of the goal of the activity. State clearly for students that there are many ways to model something, including drawing a labeled sketch that can be explained. The model serves as a visual aid here to help

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help them answer these questions. Students should work in teams to try to develop an initial model that helps explain what might be happening in Addie's system that would make it so that the antibiotics couldn't eliminate all of the bacteria. To support students in this work, consider using the following prompts to help students determine what to include in their models:

Suggested Prompts:

- What did we learn from the "What is an antibiotic?" article that we want to incorporate into our models?
- Do we want to include anything from our mathematical model into this model?
- If you take antibiotics orally (pills) then what happens to it after it is digested? What happens to food after it is digested? Where does it travel to in our bodies next and how does it get there?
- What parts of the body does the blood circulate to?
- Is blood flow to all tissues of the body the same? Are there some parts of the body that it harder to get blood flow into than others?

When students have drafted an initial model, display them around the room and conduct a gallery walk, where students will observe one another's models and collect ideas for a Consensus Model. Students should use Student Activity Sheet 4.1 to collect their ideas on the Gallery Walk.

Once students have completed the gallery walk and collected ideas for a Consensus Model, use the following prompts to ask for volunteers to share their ideas. As the ideas are shared, keep track of them on chart paper in list form or in the form of a draft Consensus Model.

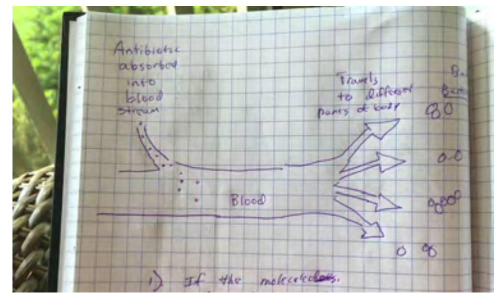
Suggested Prompts:

- What elements did you feel we should include in our class Consensus Model?
- Why do you feel these elements are important?

Listen for *student responses*, that may include such elements as:

explain how the antibiotics could have missed eliminating all of the bacteria in Addie's system.

It may help to let students know that there isn't one correct model - rather, students should sketch out whatever makes the most sense to them at this point. As the lesson progresses, students will have the opportunity to share and critique one another's models, eventually combining ideas into a consensus model that represents the thinking of the entire class.



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Antibiotics travel through our bloodstream to all parts of the body (through digestion/transfusion and circulation). They aren't always equally distributed throughout the body.

If the antibiotic doesn't interact with a bacterium, it can't kill it. There isn't a 100% guarantee that every particle of antibiotic would touch/interact with every bacterium as it moves through our bloodstream.

Some antibiotic particles might get used up as they kill bacteria.

Antibiotic particles don't remain in our blood stream forever. The body breaks them down and excretes them at a certain rate (about 50% removed a day).

Some bacteria might actually be different from the others - even though one antibiotic particle interacts with these bacteria, it doesn't kill them. Maybe it takes more than one antibiotic particle to destroy it. Or maybe some don't get killed by any # of antibiotic particles that interact with it.

---

5. (10 min) Return to a Consensus Building Discussion to conclude the lesson and think forward to the next steps in the storyline. K

Suggested Prompts:

- ➔ We've applied some of our initial thinking about how antibiotics work inside the body in our models. What do we know about the bacteria that are growing outside of our bodies?
- ➔ What should we be sure to do in the next class to help us figure out what happens to the bacteria that grow outside of our bodies?

Listen for *student responses*, such as:

We're still not completely sure about bacterial growth outside of our bodies. We started an experiment to help us figure this out in the last lesson. In our next class, we want to check on the petri dishes we started to see what we can figure out about bacterial growth from that investigation. We predicted that washing our hands with antibacterial soap would prevent bacteria from growing in our dishes, but after our work with the mathematical model, we're not

Additional Guidance

K To conclude the lesson, ensure that students offer suggestions that will connect this lesson to the next row in the storyline. Students should offer suggestions for what to pursue in the next lesson so that the ownership remains in their hands moving forward.

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sure if that's still correct.

Have the complete final 3 questions on Student Activity Sheet 4.1 so that they may reflect on and keep track of any new questions or discoveries from this lesson, either in class (as time permits) or as an out of class at home-learning assignment due at the start of next class.

Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Building Toward Common Core Standard(s)

- CCSS.MATH.CONTENT.HSF.LE.A.: Distinguish between situations that can be modeled with linear functions and with exponential functions.

- CCSS.MATH.CONTENT.HSF.LE.A.1.C: Recognize situations in which a quantity grows or decays by a constant percent rate per unit interval relative to another.

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Lesson 3b: How do our Petri dish samples (swabs) compare?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been In the last lesson, students figured out how antibiotics interact with bacteria. In the lesson before that (lesson 3a) students designed the investigation that they are collecting data from today.

This Lesson....What we are doing now: Students will observe their own group's Petri dishes as well as other group's and construct a scientific explanation to answer some of the questions they raised in lesson 3a. They will observe bacteria growing & reproducing from under a microscope and construct tables and graphs to predict how the size of a bacteria population would change over many hours (with unlimited resources and in combination with antibiotic doses).

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L3b: How do our Petri dish samples (swabs) compare? (2 periods) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2 & HS-LS4-4*	The amount of bacteria growing in different environments is not the same (ie. the bacteria from the drinking fountain is different than the floor) and the type and amount of bacteria within an environment is not the same (e.g. more pink bacteria compared to yellow in the drinking fountain, more bacteria grew in the sample before the antiseptic was placed compared to after).  A time lapse video of bacteria growing and reproducing in agar shows cells growing and splitting in half.	**Analyze and Interpret data** Compare and contrast data sets (self-generated *from our experiments*) *across design groups* to examine consistency of observations *in order to identify patterns in the data that* can be used as evidence *to help answer our questions that our class developed related to where can we pick up bacteria from, how can it get on us, and how can we get the bacteria off of us?* **Construct Explanations** Construct an explanation based on valid and reliable evidence obtained from students' own investigations, *referencing different patterns observed in*	Some of us revise our predictions about the results of our Petri dish investigations based on what we had figured out in the previous lesson, because we now know more about antibiotics, alcohol and other chemicals that kill bacteria work. **We decide that in order to answer all of the questions we had (both as a group and as a class) we need time to make observations of our own dishes and some time to observe other people's dishes.** After observing our Petri dishes we find some interesting patterns: • There are bacteria everywhere, particularly in places that we don't clean very often. • There was a lot of bacteria from places where people or animals touch often. • The growth on our plates is not the same. (e.g. our hands have a lot of different types of bacteria on them!) • If we washed our hands or used hand sanitizer, there was less bacterial growth, but not all of it went away. Then we think back to some of the questions that led us to this investigation originally, and organized our discoveries under them: • *Where can we pick up bacteria?* ○ We can get bacteria from the surfaces of lots objects in the world around us, even things that look clean. places. • *How can bacteria get on us from things in the environment?* ○ Bacteria can be moved around by contact between two objects (one that the bacteria was on to a new object that comes in contact with it) ○ Directly touching stuff that has bacteria on it can get it on your skin; touching stuff can transfer bacteria that is on your skin to it. • *How can we get the bacteria off us?* ○ Surfaces that are cleaned tend to have less bacterial growth than those that are not cleaned as often. ○ A single cleaning from a hand sanitizer doesn't kill all the bacteria on our skin. Comparing these patterns of growth raises a new question: *How is it possible that when we first swabbed the Petri dishes, we saw no bacteria on them, but now, a few days later, they we see bacteria colonies on them?* We argued that we think this has something to do with the food in the dish that is contributing to increase in size of the colony, because we know that food provides building blocks for all living things. We also agreed that we think the colony is growing. But that raised some new questions: • *Were there more individual bacteria or just larger bacteria?* • *How many bacteria are in one of these spots on our dish anyway?*

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L3b: (continued)	Same phenomena as above	*our Petri dishes* along with an application of related scientific reasoning *about what living things (bacteria) need from their environment to live, targeted at answering our classes questions.* **Develop and use a model** (mathematical and computational) to generate data to support explanations for *how the bacteria spots appeared so quickly in the Petri dishes,* and to predict phenomena *(what should happen to the size of a bacteria population in the human body given multiple doses of antibiotics?).*	**We decide we would be able to answer these questions if we could see the bacteria up close. We thought looking at them through a microscope would help us get a better sense of what kind of growth was happening, how big they are, and how many bacteria there are in these spots.** From the time-lapse video of bacterial growth on a Petri dish we notice the following patterns: • A bacteria colony is actually made of many individual bacteria. • An individual bacterium is made of one cell. • When the colony grows, it is due to one old bacterium growing in size and then splitting in half producing two bacteria, so the two new bacteria are the same size as the original old bacterium (reproduction: 1 bacterium becomes 2 total bacteria - not 3 total bacteria). We recall from middle school a general model of reproduction of single celled organisms like bacteria: (a) they don't need to find a mate (b) they need food to do this (provides building blocks for the old cell to make new (extra duplicate) cell parts) We construct a mathematical representation, using information from the time-lapse video (bacteria doubles every 20 min.). Our table predicts that a single bacterium grows and reproduces into 1 million new individuals within 7 hours. When we plot the numbers on a graph we get an exponential growth curve. This led us to conclude that anytime we leave a bacterium behind, unkilled, it could reproduce exponentially (given unlimited resources), or it can survive a while waiting for a food source (living on its stored food). We thought that maybe this is what happens to bacteria in us (or Addie), when they aren't killed. They have everything they need for a bacteria population boom. Maybe this is part of why the CDC recommends you need to take all of your antibiotics. We combine the effects of antibiotics along with bacteria reproduction to make new mathematical predictions of what would happen to the size of bacteria population starting with an initial infection of 1,000,000 bacteria, the antibiotics were given every 4 hours and were 99.99% effective, and any surviving bacteria continue to double every 20 minutes. **From the patterns in the graphs we make, we see that these are pretty complex changes predicted in the size of the population over time that we want to validate with some real world data.** *We are wondering if there is someway we could test the interaction between bacteria reproducing and giving a dose of antibiotics in the same environment?* **Next Steps (Next time): We recalled that we could grow bacteria in Petri dishes relatively quickly. Maybe we could add a single drop (small dose) of antibiotic to the dish and let it spread out and interact with growing bacteria and see what happens to bacteria growth if we apply multiple doses over time.**

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T

Next Lesson....Where we're going The class will develop a protocol for applying antibiotics to bacteria (E. coli) in Petri dishes and conduct an investigation to see how this affects the growth of the bacteria over time.

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Getting Ready: Materials Preparation

Materials For Each Group

- Extra graph paper
- Bacteria investigations (keep sealed in ziplock bags)

Preparation of Materials (5 min.)

- Check to make sure this video is available for showing you classes (Time lapse video of bacteria growing in agar): https://www.youtube.com/watch?v=gEwzDydciWc
- Class Slides

Materials For Each Student

- Calculator
- Lesson 3b- Student Activity Sheets(1)
- Students should also have their Lesson 3a - Student Activity Sheets to refer to (which have been completed for sections A-C, but have space for recording observations and writing in sections D and E).

Safety

- Keep bacteria sealed in Petri dishes and sealed in ziplock bags during the entire investigation.
- Dispose of bags (unopened) in appropriate biohazard pickup box and use a certified biohazard pickup service to collect all waste from this investigation (e.g. www.stericycle.com)

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Getting Ready: Teacher Preparation

Background Knowledge for the Teacher

LS1.B from the FRAMEWORK:

- **Organisms reproduce, either sexually or asexually.**

From the preamble in LS1 from the FRAMEWORK:

- **Organisms can be made of a single cell.**

Additional Information

Binary fission ("division in half") is a kind of asexual reproduction. It is the most common form of reproduction in prokaryotes and occurs in some single-celled eukaryotes. After replicating its genetic material, the cell divides into two nearly equal sized daughter cells. The genetic material is also equally split.

Some spots on Petri dishes that have appeared may be fungi rather than bacteria. Unless students already know how to tell the difference between these organisms (e.g. fuzzy spots tend to be fungi rather than bacteria), there is no need to describe that distinction now.

Alternative Student Conceptions

Some students may come into this lesson thinking that bacteria can spontaneously appear in media like the Petri dish, rather than grow or reproduce from existing bacteria. There is no need to address this conception until the end of investigation 1, once the class has evidence that this isn't the case for bacteria.

When you summarize the discoveries from investigation 1 help students connect ideas that they learned from middle school, that all new cells come from old cells or connect to ideas they learned in highschool related to mitosis and how new cells form (using food as building blocks to make duplicate cell parts).

Students may see similarities between how bacteria reproduce (binary fission) and how new somatic cells are formed from old somatic cells in multicellular organisms (mitosis). Encourage students to describe what is similar in both processes.

Linking Our Understanding to Scientific Terminology

- Exponential relationship
- Binary fission

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Learning Plan: What is this thing made of? (45 min)

1. (10 min) Start with a brief Consensus Building Discussion to have students articulate the big ideas we figured out from our last lesson related to how antibiotics work.

Suggested Prompts:

- ➔ What are the big ideas we figured last time about how antibiotics work?

Listen for *student responses* that refer to what we figured out last time, such as: .

When antibiotics interact with bacteria, they pop them (the cell ruptures or explodes)
We figured out that a single application of antibiotic doesn't kill all the bacteria.

Then read the prompt in the prediction question section of the student activity sheets:

- ➔ Based on what you figured out so far about antibiotics work, have you changed you changed your predictions from lesson 3a, about what you would expect to find in any of the petri dishes today? Explain.

Encourage a few students to share out whether their predictions have changed or not and why.

Then ask students to suggest what our next steps should be in light of the broader set of questions the class came up with, such as: a)Where can we pick up bacteria b) How does it get transferred to us? c) How effective are different cleaning methods for get the bacteria off of us?

Suggested Prompts:

- ➔ What do we need to do next in order to check if our all of our predictions are correct
- ➔ How do we want to use our time (15 min.) to get all the observations we want to be able to get. A

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A Help students recognize that looking at their own results may help them answer their own research questions, but that alone won't help the class as a whole answer the broader set of questions they had

Use this idea to motivate needing two rounds of observations of the Petri dishes. One round focussed on each group's own dishes, and another round to check other group's dishes out.

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Listen for *student responses* such as:

We need to check in on our petri dishes and record any observations about what we notice in them.
We also need be able to compare our observations to other groups observations. We should use some of the time for doing both.

Help students come to consensus on an efficient use of 15 min., which may include some amount of time to observe their own petri dishes, and then also have time to visit other group's petri dishes. B **Remind students that they can record observations of their own dishes in section D of lesson 3a. Have students uthe next page of their activity sheets to record other group's observations**

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2. (15 min) Have students use the part of the time (whatever the class decided) for going to their Petri dishes and the remainder of the time for rotating C **to one or more other group's Petri dishes (whatever the class decided).**

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3. (10 min) Have students work with partners to summarize the patterns they noticed in the data by answering the questions in the making sense sections of their activity sheets.

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4. (10 min) Remind students that three of the questions that motivated us to want to do these petri dish experiments were: (i) Where can we pick up bacteria? (ii) How does it get transferred to us?
(iii) How effective are different cleaning methods for get the bacteria off of us?

Tell students that their experiments have provided us evidence that we can use to make and

Differentiation Strategies

B Different classes may want to use the time differently. For example, in one class, they may decide they want 5 min. For observing their own Petri dishes, and then use the remaining time to rotate and visit as many of the other group's dishes as possible (e.g. 1 min. Per rotation).

Another class may decide they want to use half the time for their own Petri dishes, and then the remainder of the time to go to 2 other groups.

Two opportunities to write scientific explanations based on the results from within a group and/or on the results across groups are built into investigation 1 (see the next Formative Assessment Opportunities box: D)

Additional Guidance

C Passing out one paper with a large number on it (1, 2, 3, 4, etc.) to each group as they are observing their own dishes, to help groups to see where the next station is located can be helpful to orchestrating classroom flow. Also having groups call our their numbers at the end of observing their own Petri dishes, right before the

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support claims that could answer our original questions we had. For this part of the conclusions, ask students to go beyond just stating a claim and citing evidence. Ask them to construct a scientific explanation, where they also provide the reasoning for why the evidence supports their claim and any possible mechanisms that they think might be at work that would account for the results they got.

Assign different groups of students a different question to write a scientific explanation for. D

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5. (5 min) Next, shift to a Brainstorming Discussion. Use the following prompts to guide students to articulate responses to the last question in their student activity sheets.

Suggested Prompts:

➔ How is it possible that when we first swabbed the Petri dishes, we saw no bacteria on them, but now, a few days later, they we see bacteria colonies on them?
➔ How did the spot of bacteria get so big in that time?

Listen for *student responses* that mimic the next step in the story line, such as

The bacteria are growing.
Food (in the agar) helps the bacteria colony grow bigger.
The food in the dish contributes to the increase in size of the colony, because we know that food provides building blocks for all living things.

Suggested Prompts:

➔ Some people are mentioning that the bacteria colony got bigger. What do you mean by that?
➔ Do you mean that the bacteria in the colony got bigger or the number of bacteria in the colony increased? Was there more individual bacteria or just larger bacteria?

window of time for rotating between stations can help smooth transitions and efficient use of time in this part of the investigation.

Formative Assessment Opportunities

D The advantage of having groups construct of this scientific explanation for one of these questions are (a) it can provide a model for students to reference when they write a 2nd scientific explanation for their original research question and (b) it is easier to listen in and give timely initial feedback to groups than to individuals as they are writing. Alternately you could have students write this explanation individually and collect it to assess before the next class.

It is most useful for students if they get feedback on the first explanation before writing the second one.

There is space to write the 2nd scientific explanation in section E of lesson 3a. Assigning this explanation as an individual assessment will give students additional practice. This explanation may be more time efficient to have students complete outside of class.

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Listen for *student responses* that mimic the next step in the story line, such as

Maybe the bacteria that are there are just getting bigger
Maybe the bacteria that are there are reproducing.
Maybe both are happening.

Summarize these different ideas and post them in form of a question on a piece of poster paper E, and point out that we are arguing that there might be different mechanisms for what might be going on in the colony as it is getting bigger. Instruct students to turn and talk to your partner to brainstorm some possible ways we might go about investigating this, to figure out if the number of bacteria are increasing or they are just increasing in size?

Next day of instruction:

6. (5 min) Start by having student do a "bell ringer question" modeled on the first two questions their activity sheets at the start of Investigation 2. E

---

7. (5 min) Instruct students follow the procedure for Investigation 2. Show the time lapse video of bacteria growing two times: https://www.youtube.com/watch?v=gEwzDydciWc

---

8. (15 min) Have students use calculators to work with partners to complete the Making Sense section of Investigation 2. Do a quick check in as a whole (e.g. 1 min. later) on the answer for question 7, before having students complete the rest of the questions with their partners. F G

Additional guidance

E Refer to this question at the start of investigation 2. The timing of this lesson, breaks it into two chunks of instruction. Having the question posted that the class ended with from investigation 1, ready to refer to at the start of investigation 2, helps students build coherency between lessons and across the unit.

Supporting Students in Using Mathematical and Computational Thinking

F Help students recognize that (a) even though the data is an exponential pattern, the intervals on their graph should be set up to be constant intervals (100,000 for major intervals on the y-axis) and (b) that they should use as much of that graph space a possible, because visualizing graph as large as possible makes it easier to see patterns of change between points.

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9. (10 min) Lead a Building Understanding Discussion, to help the class articulate and consolidate the important patterns and mechanisms that help answer and explain the initial question that motivated investigation 2.1.

Suggested Prompts:

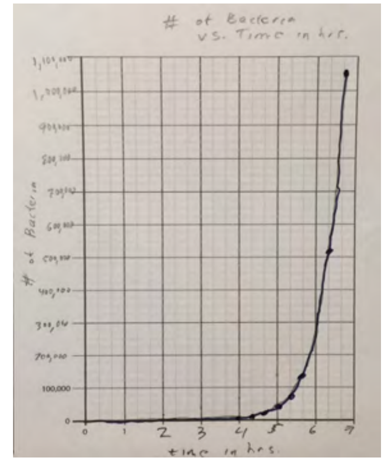
- ➔ What did we discover in this investigation that helps answer our original question, "Why did some of the petri dishes appear to have no bacteria present and then days later they had visible bacteria?"
- ➔ What are the spots we saw on our Petri dishes made of?
- ➔ Is an individual bacteria made of one or many cells?
- ➔ How would we summarize the process by which bacteria reproduce?
- ➔ How is the related to what we know about how other single celled organisms reproduce?
- ➔ How is food related to what happens in this process?
- ➔ Why would cells need to make new (extra duplicate) cell parts before they reproduce?
- ➔ What was the pattern of growth in the size of population?

Listen for *student responses like these* and capture a public record of these discoveries. H

A bacteria colony is actually made of many individual bacteria.
An individual bacteria is made of one cell.
When the colony grows, it is due to one old bacterium growing in size and then splitting in half producing two bacteria, so the two new bacteria are the same size as the original old bacterium (reproduction: 1 bacterium becomes 2 total bacteria - not 3 total bacteria). This process is called binary fission I
Bacteria reproduce like most single celled organisms: (a) they don't need to find a mate and (b) they need food to do this (provides building blocks for the old cell to make new [extra duplicate] cell parts) I
A bacteria population can grow in size exponentially over time.

Formative Assessment Opportunity

G A completed graph is shown here:



Strategies for this Building Understandings Discussion

H Make a public record of these discoveries. A poster paper can be used for this. Try to reuse student language/wording for each point made. Where a discovery seems vague, ask, "It seems like there is an important idea here. Who can restate this important idea?", or "Can someone put these ideas together and summarize what we are thinking?"

If time permits, you may want students to make notes of these as well. Space for this is provided in student activity sheets.

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Ask student to brainstorm some ideas for how these discoveries are related to Addie's case

Suggested Prompts:

➔ "How is what we discovered helpful for explaining what might have happened in Addie?

Listen for *student responses* like these:

If bacteria are reproducing this fast in an infection, maybe that is one reason they are hard to kill.
Maybe the bacteria are reproducing faster in some people (like Addie) than others.

---

4. (10 min) Introduce the motivation for putting together what we figured out from this lesson with stuff we figured out from earlier lessons. Point students to previous graphs they made about how bacteria populations change when given multiple doses of antibiotics (or antiseptics), but we never put both sets of mathematical relationship together, which is what we would need to do in order to predict what would happen to a population of bacteria in a person who is taking antibiotics.

Summarize the assumptions behind the predictions we are going to make using mathematical thinking to predict what would happen to the population every hour if:

- **we started with an initial infection of 1,000,000 bacteria**
- **took our first dose of antibiotic immediately (at hour zero)**
- **the antibiotics was 99.99% effective**
- **Any surviving bacteria continue to double every 20 minutes.**
- **we took we take another dose every 4 hours for 24 hours.**

As a whole class, interactively calculate and fill out the first 5 rows of the table together.

Suggested Prompts:

Strategies for this Building Understandings Discussion

Here you will introduce a way to reference this process. You will refer to it as binary fission ("division in half").

Students may or may not ask about whether the bacteria cells duplicates its genetic material before splitting in half. You can emphasize this idea in the next bullet point.

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➔ We know that we start with 1,000, 000 bacteria initially. And it is right at that point that an antibiotic is given. So we can fill in these two values:

Time (in hrs.)	# of bacteria before dose	Antibiotic dose given?	# of bacteria after the dose reaches them
0	1,000,000	----yes --->	

Fill in the row for time 0, as show above.

➔ "How do I calculate how many bacteria are left if 99.9% of 1,000,000 are wiped out from the first antibiotic dose".

Listen for *student responses* like these:

You can turn 99.99 into a decimal equivalent (.999) and multiply it by 1,000,000 and that will tell you how many died (999,000). Then you take that away from 1,000,000.
You can set up equivalent ratios or fractions (% out of 100 = portion of population out of total 99.99 out of 100 = x out of 1,000,000) and solve x (here again you get that 999,000) died.
In both cases we are left with 100 bacteria that survived

Fill out the last cell in the row for time of 0 hrs.

Time (in hrs.)	# of bacteria before dose	Antibiotic dose given?	# of bacteria after the dose reaches them
0	1,000,000	----yes --->	100

Suggested Prompts:

➔ OK, that helped me complete the first row. But if I have 100 bacteria once the dose reaches them, then how do I figure out how many bacteria there are 1 hour later?

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Listen for *student responses* like these:

You can double the 100, to get 200 for 20 min. And do it again for 40 min, and one more time for 60 min. That gets you 800.
Even though there is 3 sets of 20 min. In 60 minutes, that doesn't mean you can multiply 100 by 6, you have to multiply 100 x 2^3

Fill in the row for time of 1 hrs.

Time (in hrs.)	# of bacteria before dose	Antibiotic dose given?	# of bacteria after the dose reaches them
0	1,000,000	----yes --->	100
1	800	no	

Suggested Prompts:

➔ Then how do I go from 800 bacteria at the end of 1 hour to figure out how many there are at the end of 2 hours? Remember that no more antibiotics are taken until hour 4.

Listen for *student responses* like these:

You can double the 800, to get 1600 for 20 min. And do it again for 40 min, and one more time for 60 min. That gets you 6400.
You can multiply 800 x 2^3

Fill in the # of bacteria for through hour 4.

Time (in hrs.)	# of bacteria before dose
0	1,000,000
1	800

Formative Assessment Opportunity

J A completed table is shown here:

Time (in hrs.)	# of bacteria before dose	Antibiotic dose given?	# of bacteria after dose
0	1,000,000	----yes --->	100
1	80	no	
2	6,400	no	
3	51,200	no	
4	409,600	---yes --->	41.0
5	328	no	
6	2621	no	
7	20,972	no	
8	167,772	---yes --->	16.8
9	134	no	
10	1074	no	
11	8590	no	
12	68,719	---yes --->	6.9
13	55	no	
14	440	no	
15	3518	no	
16	28,147	---yes --->	2.8
17	23	no	
18	180	no	
19	1441	no	
20	11,529	---yes --->	1.2
21	9	no	
22	74	no	
23	590	no	
24	4722	---yes --->	0.5 (zero or 1)

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2	6,400
3	51,200
4	409,600

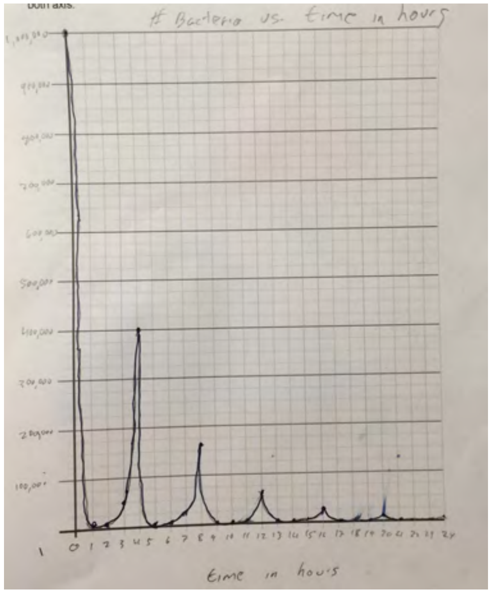
Repeat the above questions, asking students how to calculate the number of bacteria remaining after another dose of antibiotic (99.99%) effective given at hour 4. Fill in all of row 4 and 5 together and ask students if they have any questions about how to use this sort of mathematical and computational thinking to continue the table.

Time (in hrs.)	# of bacteria before dose	Antibiotic dose given?	# of bacteria after the dose reaches them
4	409,600	---yes --->	41.0
5	328	no	

Assign students the remainder of this section as independent practice or as an assessment. J K **Tell students we will follow-up with their responses to last questions in this section at the start of the next lesson (sharing ways that they think of ways we could test whether our predicted changes in these tables and graphs are actually happening in a real bacteria population).**

Formative Assessment Opportunity

K A completed graph is shown here:



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Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Building Toward Common Core Standard(s)

In the 2nd part of the student activity sheets of lesson 3a and lesson 3a (part E)

- CCSS.ELA-LITERACY.WHST.9-10.1.A Introduce precise claim(s), ….. and create an organization that establishes clear relationships among the claim(s),....reasons, and evidence.
- CCSS.ELA-LITERACY.WHST.9-10.1.B Develop claim(s) ...supplying data and evidence... in a discipline-appropriate form and in a manner that anticipates the audience's knowledge level and concerns.
- CCSS.ELA-LITERACY.WHST.9-10.1.C Use words, phrases, and clauses to link the major sections of the text, create cohesion, and clarify the relationships between claim(s) and reasons, between reasons and evidence…..

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Lesson 5a: How do antibiotics affect bacteria when they are put together?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been In the previous lesson students discovered that many people do not follow the recommendations when prescribed antibiotics. Students made a 'Mission Board' and determine it must include the how/why antibiotics work to encourage proper use. They used a mathematical model to explain how antibiotics work to destroy bacteria in the body and relate this information back to Addie's case.

This Lesson....What we are doing now: Students will plan and carry out an investigation in order to explain the relationship between bacteria and antibiotics. Students will make predictions about the behavior of bacteria when exposed to different strengths of antibiotics. Students will use this information from this investigation to help explain why antibiotics are not working for Addie.

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L5a: How do antibiotics affect bacteria when they are put together? (2 periods) *Building toward* ⬇ *NGSS PEs: HS-LS4-2 & HS-LS4-4*	Sample protocol of a science fair project outlines the protocol used in an experiment where bacteria are plated in a Petri dish and at the same time, antibiotics are administered. A demonstration (or Video) of a drop of food coloring placed in a Petri dish with agar shows it gradually spread out and develop lighter coloring near the edge of the drop after 5 minutes.	**Plan and Carry Out Investigations** collaboratively to produce data to serve as the basis for evidence as part of building explanations for phenomena *related to* predicted and observed *patterns from how do antibiotics affect bacteria in our Petri dishes when they are put together?*	**We are interested in seeing how much bacteria die and how much grow back when the bacteria and antibiotics are put together in the same environment. We also want to see what happens at different concentrations of antibiotic doses.** *Will less strength of dose really make that much of a difference?* **We want to try this in our Petri dishes.** We draw some diagrams showing our predictions on what we will see on the Petri dish some days from now (where we will find dead vs. living bacteria) based on watching how a drop of food coloring diffuses throughout a Petri dish with agar, and where we plan to plate the bacteria. Our predictions raise some new questions: • *We think that where the antibiotic hits the bacteria, the bacteria should die, but will the bacteria die in other places on the plate?* • *Will the bacteria stay dead or come back?* We agree on the need for following a really strict/safe protocol in our class for this sort of investigation, because the results of these experiments could potentially end up harmful to humans. We agree that without controlled variables and validating safe procedures, just like when we work with acids/flames, etc., we run a risk to ourselves and others. We read through a recommended safety and procedure protocol and then we execute our experimental plan. (This plan does not yet involve a replating protocol. Change to the procedure will be motivated in lesson 5b). **Next steps: We are excited to check on our future results, but know that it will take a couple days to see the effects (just like it did in lesson 3a to 3b). We think we have figured out some pieces to help answer some the questions on our Driving Question Board, "Why did antibiotics stop working for Addie?" So we want to take stock of the questions we answered and what we figured out so far in the next class and regroup.**

T

Next Lesson....Where we're going In the next lesson, students will dig deeper into why antibiotics didn't work for Addie's illness. We still have many unanswered questions about how bacteria becomes antibiotic resistant, but are starting to form some ideas about why we think this happens. Students will continue building a model to explain how bacteria work, why they don't die right away, and how they can become antibiotic resistant. Students will do this by taking a closer look at how bacteria and antibiotics react when they are plated together.

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Getting Ready: Materials Preparation

Materials For Each Group

- Agar Petri dishes (3)
- Cotton Swabs (1)
- Filter paper (1)
- Hole puncher (1)
- Tweezers (1)
- Pair of disposable gloves (1)
- Masking Tape (1)
- Sharpie (1)
- Bottle of disinfectant (1)
- Paper Towels

Materials For Each Student

- Lesson 5a: Student Activity Sheet (1)
- Lesson 5a: Student Investigation Safety & Guidelines (1)
- pair of gloves (1)
- Safety goggles (1)

Preparation of Materials (90 min.)

- Food coloring 'antibiotic' model video: https://www.youtube.com/watch?v=eebPrMpKG7c

- Agar Petri Dishes - to be prepared and stored ahead of time
  If you would like pre-prepared agar dishes that come with sterile cotton swabs, follow this link: https://www.amazon.com/EZ-BioResearch-Bacteria-Science-Kit/dp/B0165PQST0/ref=sr_1_2?ie=UTF8&qid=1471628112&sr=8-2&keywords=agar+dishes
- E Coli Bacterium Culture -
  - 10mg E Coli mixed with 40ml water

  For ordering information follow this link http://www.bio-rad.com/: E. coli strain HB101 K-12 (Catalog #166-0408EDU) = 1 vial contains 30 mg. This will allow you to prepare 3 vials of 40 ml for students to use. This should be enough to start the swabs for 3 classes. You may wish to order 2 of these cultures in you have 4--6 classes.
- Ampicillin mixtures
  - 1mg ampicillin mixed with 10ml water
  - 3mg ampicillin mixed with 10ml water
  - 5mg ampicillin mixed with 10ml water

More information about preparing mixtures can be found at this link: http://www.bio-rad.com/webroot/web/pdf/lse/literature/1665022.pdf

- Class Slides

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Safety

- Lab safety is everyone's responsibility and we must take precautions especially when working with live bacteria samples. We need to make sure that when we work with these samples that we keep them contained and that we are not exposing them to ourselves or the environment. You need to remember that we are looking for answers as to how bacteria become antibiotic resistant so we do not want to introduce one of these bacteria into the environment by accident.
- Don't even think about having food or drink in the lab space
- Clear your lab space and wipe it with disinfectant
- Put on gloves and safety goggles
- Leave everything at your desk, you don't want to risk getting our sample on your pens, pencils, etc..
- If you should have an accident please get your teacher right away
- When you are finished you will need to put your tweezer in the disinfectant and dispose of your swabs and any other paper product you may have used in the BIOHAZARD bag
- Spray your table with disinfectant and wipe it down when completed.
- Remove your goggles and put them in the cabinet to be disinfected
- properly take off your gloves properly and dispose of them in the BIOHAZARD bag.

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Getting Ready: Teacher Preparation

Background Knowledge

LS4.C from the FRAMEWORK:
"Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions."

- Our investigation of bacteria that are resistant to antibiotics is the entry point for students into the concept of adaptation by natural selection. Eventually (in later lessons) students will figure out that those bacteria that are resistant to antibiotics are killed, while those that are resistant can reproduce and further the species. When antibiotics are overprescribed the environmental conditions change, and bacteria adapt to the new environment by becoming pan-resistant.

Alternative Student Conceptions

It is likely that students will come into this lesson believing that some bacteria within a culture is already antibiotic resistant depending on the strength of the antibiotic used. It is understandable that they will think that even if a bacteria is antibiotic resistant it could still be destroyed if a stronger dose of antibiotics are used.

Linking Our Understanding to Scientific Terminology

- Inhibition Zone
- Concentration
- Solution
- E.Coli (or other bacteria)
- Ampicillin (or other antibiotic)
- Generation

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Lesson 5a: How do antibiotics affect bacteria when they are put together? (45 min)

1. (10 min) As students enter the class, have this question posted on the board along with the discoveries from the Building Understanding Discussion around the first question of the conclusions from lesson, 3b.

Post this question, from the Next Steps section of their activity sheets from the previous lesson: A

Suggested Prompt:

- ➔ Your tables and graphs predict some pretty complex changes in the population size of bacteria over time. *But would we see these sorts of population changes happening a real bacteria population over multiple doses of antibiotics?* How might we design a new investigation using the petri dishes again to investigate this question?

After you have given students a (2-3) minutes to write A**, engage them in a discussion about their thoughts.**

Suggested Prompts: B

- ➔ What were some of the ideas we came up with in the previous lesson to figure out what happens to the bacteria that grow outside of our bodies? Why is looking at bacteria by itself not enough?
- ➔ What were some of the ideas we came up with in order to investigate how bacteria becomes antibiotic resistant?
- ➔ We had some thoughts about why Addie's treatment wasn't working, what did we think?
- ➔ Which idea do you think we should investigate next and why?
- ➔ Why would we want to look at bacteria and antibiotics together? What would we look for?
- ➔ Why would this be different than just looking at the samples we already have?

Listen for *student responses*, such as:

Teacher Supports & Notes

Additional guidance

A If students already completed the Next Steps section of the previous lesson as home-learning, have them share their ideas with an elbow partner, instead of rewriting them down again here.

Additional guidance

B If students are struggling with discussion pieces have them look at the packet from the previous day and make sure to post the consensus list of ideas from the day before. .

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We predicted that washing our hands with antibacterial soap would prevent bacteria from growing but it didn't kill everything, so the bacteria just kept growing

We thought the antibiotics they were using for Addie's treatment were not strong enough to kill the bacteria. We thought they should use a stronger antibiotic, or give her more of the same one to see if that would work.

We talked about adding antibiotics to our Petri dishes to see what happens to the bacteria growing it, or starting a new experiment to see what happens when we try to grow bacteria when there is also antibiotics in the Petri dish.

We think that if we put bacteria and antibiotics together in the same dish that maybe the bacteria won't grow. We think the antibiotics would kill the bacteria before it can grow. We think maybe none of the bacteria would grow, but we are not sure or maybe it not grow just where we put the antibiotic.

This would be different than our other investigation because if we added antibiotics to what we already have we would be killing unknown bacteria that have already grown, in this investigation we are trying to see if antibiotic keep bacteria from growing in the first place

---

2. (10 min) Engage students in an Initial Ideas Discussion C about next steps - How could students investigate the ideas they had about why antibiotics were not working for Addie? This discussion will start the initial process in planning an investigation by focusing on the reasons we want to go about testing these ideas. Remember the students felt that one reason Addie's treatment was not working was because she needed a stronger dose of antibiotics.

Suggested Prompts:

- ➔ Think about what we have learned about how antibiotics work in our bodies. How this might look in an investigation?
- ➔ What differences in bacterial growth might you expect to see if you added an antibiotic to the

Strategies for this Initial Ideas Discussion

C Our first goal is to motivate students to get to the reason we need to look at bacteria and antibiotics together. As students start to consider what that might look like we need to encourage them to start coming up with some scientific reasoning as to why this investigation will look very different than the previous investigation.

Our second goal is to get students to come to the conclusion that it would be unsafe to experiment on unknown bacteria samples, as this has the potential to cause harm. We want to lead them to the conclusion that we need to start a whole new investigation using a single known bacteria and a single antibiotic. We will then engage them in a brainstorming activity to think of ways to investigate their initial ideas.

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culture?

- ➔ We learned that antibiotics spread out through our bloodstream, but does not disperse evenly. Why would this be good information to consider? Why/how could it affect our investigation?

Listen for *student responses*, such as:

We found out that not all antibiotics reach the bacteria when you take them, not all antibiotics work on all bacteria, antibiotics travel through our bodies and lose their strength as they spread out and that is why we need to take them for more than one day.

We learned from our reading in a previous lesson (Lesson 4) that antibiotics lose concentration as they travel through the body so if we did an investigation where we put bacteria and antibiotics together we think we might see that the antibiotics work better (kill bacteria) close to where we put them, but maybe won't work on bacteria that is farther away.

We also need to think about safety. Students may want to consider using the samples of unknown bacteria they have already collected, and we will need to steer them away from that.

Suggested Prompts:

- ➔ Although we currently have bacteria growing in Petri dishes, should we use these in our next investigation? Why or why not?
- ➔ Do we know exactly what is growing in those Petri dishes? How could not knowing what we are working with be dangerous.

Listen for *student responses*, such as:

We could use them, but I'm not really sure.

We don't know what kind of bacteria is currently growing in these Petri dishes, we there are too many different bacteria growing in a single dish. It might be dangerous because what if we had something growing that was really nasty. We don't want to open up our Petri dishes again.

Suggested Summary:

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It could be really dangerous to use bacteria from around us in an experiment where we treat it with antibiotics because we don't know what kind of bacteria we are working with. That makes it really hard to control what ends up growing and potentially dangerous if anybody in the class got infected with it. The CDC recommends against treating bacteria in the community with antibiotics, so we are going to purchase bacteria that has a known origin from a company.

---

3. (10 min) Next Steps - Brainstorming an Investigation: Now that students have decided that they need to come up with a new investigation to answer the question 'What happens when you put bacteria and antibiotics in the same Petri dish?' Hand out student activity 5a. We want to motivate students to wonder about how antibiotics would travel through the agar.

Suggested Prompts:

- ➔ We know that antibiotics travel through our bloodstream, but how do you think this would look in a Petri dish?
- ➔ When considering how antibiotics travel in order to fight bacteria, how could our investigation model this movement?
- ➔ When we take antibiotics they enter our bodies at a single point and then disperse, how could we show this kind of movement in our investigation? Can anyone think of an example of what this might look like? How could we model this, using water for example? (if students are still stuck ask them why they shake their water bottles after dumping in a flavor packet)

Listen for *student responses*, such as:

We think that the antibiotic would spread throughout the Petri dish, but the antibiotic would be stronger where we put the drop and not as strong as it spreads out

It would look different in a Petri dish because there are no veins but we can still look at how it spreads out

We know that the antibiotic will spread we don't know if it will spread a little or across the whole

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dish.

After a short discussion about the movement of antibiotics, show them a demonstration of how dissolved particles (of a different substance - food coloring) travels through the agar plate. This demonstration will also introduce students to a method for applying a single dose of antibiotic solution. Using forceps or tweezers take a single hole punch piece of filter paper and dip it into a solution that is 1 drop of food coloring and 4 drops of water. Then lay that piece of filter paper in the middle of the agar plate. Ask students what will happen to the food coloring in the filter paper over time.

Suggested Prompts:

- ➔ If we check in a few minutes, will all of the food coloring remained in the filter paper or will some have seeped out?
- ➔ How will we be able to tell?

This observation will take some time to see the coloring spread out if you do it as a demonstration because it takes about 5 minutes for the color to spread (dark colors seem to have a better effect). At about 5 minutes students will see a difference in the color between the edge and the center of the droplet, hinting at differences in concentration based on the edge vs. the center of the drop. While students are waiting you can show a timelapse video of a single drop of food coloring applied to the agar, but emphasize that using filter paper hole punch circles rather than eye dropper can help ensure a more equal application of solution to the Petri dish each time (food color or antibiotic solutions. D

This will give students some ideas about how an antibiotic will spread and allow them to make better predictions later in the lesson. Remind students to pay attention to the movement of the food coloring throughout the Petri dish. Record your observations in your notebook on the movement of the food coloring and what happens to the strength of the color over time. This will give students some direction as to how the antibiotic might spread through the plate, and are important factors to consider when they are planning an investigation.

Differentiation Strategies and Alternate Activities

D Use the video clip of the food coloring demonstration and have students make observations. The clip is located here: https://www.youtube.com/watch?v=eebPrMpKG7c

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When the demonstration is finished ask for questions in order to build understanding, and if needed do the demonstration again. The goal here is to make sure students have an understanding of how antibiotics might travel through the Petri dish in order to make predictions about bacterial growth. When you have answered any questions they might have about the demonstration, give the students 10 minutes to brainstorm out some ideas as to how they could set up an investigation. Remind them that they will be working with live bacteria cultures and they will need to follow specific safety guidelines when thinking of ideas in planning an investigation E.

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4. Building Consensus F Discussion - (20 min) Have students share their brainstorming ideas with at least 3 other groups (2 min each) when they are done have a whole group discussion about the noticings.

Suggested Prompts:

- → As you looked at other investigation plans, what ideas were similar to yours?
- → What did you notice about how other plans were different than yours?

As students discuss their noticings, record their similarities and differences on the board.

When the thoughts have been recorded lead students to agree on the best way to plan the investigation on how to test the strength of the antibiotic affects bacterial growth. This investigation allows for some flexibility when students are coming up with their procedure, however there are some things that we need to make sure the have identified as a must:

1. **Filter paper must all be the same size and placed in approximately the same place within each dish**
2. **Must all use the same bacteria culture and it needs to be plated in the same way, making sure we swab the entire plate with the culture.**
3. **Must all use the same concentrations of antibiotics (1mg, 3mg, and 5mg) in order to collect and compare consistent data**

Strategies for this Building Consensus Discussion

E We want to lead students to agreement on the best way on how to test the concentration of an antibiotic, and also validate their brainstorming ideas. By having them share their ideas with other groups they can see the similarities and differences in their thinking.
By keeping track of information visually, you are supporting students' ability to recognize patterns in ideas in order plan an investigation collaboratively.

Differentiation Strategies and Alternate Activities

F You may decide to have students plan an investigation if you have supplies that would allow groups to do different investigations. Some variation could include: different strengths of antibiotic, same strength of antibiotic but different size filter paper, or same strength different filter placement within the Petri dish.

If materials are limited you can have students section one plate into thirds and have them test all three antibiotic concentrations on a single plate.

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4. **Agar plates must be labeled with the antibiotic concentration**
5. **Cultures must be allowed to grow for the same amount of time**

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5. Making Predictions (10 min) - Now that we have come to a consensus about how to investigate the concentration of an antibiotic we need make some predictions about about what we will see a few days from now. On your activity sheets make some predictions about what you will see in the Petri dishes a few days from now.

Look for *student predictions*, to include:

Some models where bacteria growth becomes less as the concentrations increase

Some models that include almost no bacterial growth at all

Some models where bacteria grows everywhere except where the bacteria is placed directly on the agar

---

6. (25 min) Carrying out our investigation G. First let's review our purpose for this investigation.

- **Our goal is to test different strengths of antibiotics to see if they kill more bacteria, because we think that maybe Addie just needs a stronger antibiotic.**
- **We also want to look at how antibiotics travel through the agar because this will model how it travels through our body. We need to look at the travel patterns and see if they match what we read about in the previous lesson (Lesson 4) about how one dose of antibiotics can't really kill all of the bacteria.**

Next, remind students of lab safety procedures, especially now as we are working with live cultures of bacteria. You will then want to demonstrate the best way for the students to swab the culture onto the Petri dish in order for the sample to grow. Remind student to make sure they label everything because we will need to let these samples grow for a few days and will not

Additional Guidance

G This investigation should be set up on a Wednesday, Thursday or Friday in order for the bacteria to grow over the weekend. There is also an example lab procedure protocol listed on the 5a Investigation Sheet.

Remind students that they will need to set up a way to record their data. What is the best way to record the patterns they see in the bacterial growth? This should include some form of measurement, but picture documentation should also be encouraged.

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be checking them until we get back on Monday. Have students go to their assigned lab tables and review the safety guidelines posted at each table. Students should then proceed with the investigation protocol they designed in the previous class.

Remind students that when they are finished setting up their investigation to work on designing a way to record their data, their data charts should be drawn on the last page of their activity packet.

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7. (5 min) Reflection and possible next steps H (this can be done as students finish their investigations or as homework): Have students read and reflect on the prompts at the end of activity sheet 5a.

Suggested Prompts:

- ➔ Now that we have set up an investigation and made some predictions about what we might see, how does this help us in understanding Addie's case? Relate your predictions to Addie's condition.
- ➔ When we check our investigations in a few days we will be able to collect some data that will help us determine what is happening to Addie, however do you think this one data point will be enough to see a pattern in the bacteria growth? Consider some possible next steps we might need to take in order to figure out what is really happening?
- ➔ We also want to consider the difference in our two investigations with bacteria. If you were a doctor how would you treat the bacteria(s) in the first investigation verse the bacteria in this investigation? Why? Make sure you explain your reason in treating these the same or different.

Formative Assessment Opportunities

H You may decide to collect the last sheet of the activity packet in order to check for understanding. By now students should be making connections based on what they have figured out about antibiotics and how they work. Some key points to look for:

- Does their reasoning match their predictions? Understand that these could still be wrong, which would allow you to check for misconceptions in thinking.
- Are they making logical science based connections back to Addie's case using what they know about patterns and/or cause and effect?
- Are their next steps based in scientific reasoning, do they make sense based on what we have learned so far?

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Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

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Lesson 6: Why did antibiotics stop working for Addie?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been Students wanted to see how different doses of antibiotics impact bacteria and set up an experiment to test this. They also used food coloring to predict how the antibiotic will diffuse through the agar. They decided they have figured a lot out to help answer the question, "Why did antibiotics stop working for Addie?" So they wanted to take stock and regroup.

This Lesson....What we are doing now: Students will take stock of what the figured out so far and use these ideas to try to explain why didn't antibiotics kill the bacteria that Addie had. This attempt at an explanation, will help students identify gaps in what they can't explain, and will surface new questions that they have about this case and how non-resistant bacteria got this way. You will help them go public with their questions and organize them on a Driving Question Board, that will drive the direction of future investigations and lessons over the rest of the unit.

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L6: Why did antibiotics stop working for Addie? (2 periods) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2 & HS-LS4-4*	All previous phenomena so far - taking stock and setting future directions.	**Develop and use a model** based on evidence to illustrate the relationships between components of a system and different scales *(human body systems, population of bacteria, and individual bacteria)* using *scientific principles we have figured out so far,* to explain, *Why did antibiotics stop working for Addie?* **Ask questions** ...that arise from careful observations of phenomena *(all previous phenomena studied in class)* to clarify the *directions we want to head on our driving question board and ways we might go about* seeking additional information *and future investigations* relevant to our questions.	We take stock in what we know so far that can help us figure out why the antibiotic seemed to stop working for Addie: • Addie has pan-resistant bacteria that might kill her (L1) • Other kids have had the same thing happen to them that were otherwise healthy. (L2) • There is data that shows that the antibiotics that used to work in the past - like the 1950s, aren't as effective now at killing the same strains of bacteria. (L2) • Bacteria are everywhere (L3b) • Antibiotics don't kill 100% of the bacteria in a large population, with a single dose. (L4) • Over multiple doses, when antibiotics work, they kill all the bacteria (L4). • When bacteria reproduce, they do so exponentially. They don't need a mate, they just copy their genetic information and split in half (L3b). • A single bacterium can grow and reproduces into billions within a day, so anytime we leave a bacterium behind and unkilled we know it can survive a while waiting for a food source and then when it gets a new food source can make a huge population. (L3b) After thinking about these phenomena, we try to come up with a model to explain them all. We model our answer to the question, "Why didn't the antibiotics immediately kill the bacteria that Addie had?" We're a bit stuck and we have a ton of questions that we put on a Driving Question Board: • *Why are we able to show more bacteria becoming resistant so easily and so fast?* • *What actually is it about the bacteria that makes them resistant?* • *And how did they get that way? How do they become resistant?* • *How come playing outside now seems more dangerous? Why can we pick up resistant bacteria more easily now, compared to when our grandparents were living?* • *Some of us think evolution might be part of the story, but we don't really know how. Is evolution a part of this story?* Together, we group the questions into three big groups: 1. *What makes resistant and nonresistant bacteria different from each other?* 2. *How do these differences matter for whether antibiotics work or not for Addie?* 3. *How did non-resistant bacteria get that way?* **Next Steps: We want to make sure to check in with our antibiotic experiment to see if anything has changed before moving ahead with new investigations related to some of these questions.**

T

Next Lesson....Where we're going Students will check on the antibiotic experiment, as it is an easy first step that might be able to help answer question group 1. They will figure out that there is a ring in the Petri dishes where no bacteria grows, and wonder if the bacteria closer to the antibiotics are different somehow. They will design and begin an experiment where they take bacteria from near the zone of inhibition and away from it and replate them so their growth can be compared.

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Getting Ready: Materials Preparation

Materials For The Whole Class

- Big chart paper or wall space on which to make the Driving Question Board

Preparation of Materials (5 min.)

- Prepare a Driving Question Board and space for a public record of what we've learned in this unit
- Class Slides

Materials For Each Student

- Lesson 6 - Student Activity Sheets (1)
- 3-5 Post-It notes

Safety

- No safety concerns

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Getting Ready: Teacher Preparation

Background Knowledge

This lesson asks, "Why did antibiotics stop working for Addie?" Although students do not know it yet, the antibiotics stopped working because the antibiotics selected for nonresistant bacteria within her body. After she had used an antibiotic for a couple weeks, only nonresistant bacteria were left, and they were able to take over. This complex phenomenon will be investigated further, but in this lesson students simply clarify what they are wondering.

Alternative Student Conceptions

At this point, students may have greatly varied ideas about why the antibiotics stopped working for Addie. In particular, some may be suggesting "evolution" without clearly defining what they mean by that or how it may have occurred in such a short period of time. Push them on this point throughout, and encourage them to posit what they don't know as questions in this lesson.

Linking Our Understanding to Previous Terminology

Throughout this class's discussions, particularly when posing questions, encourage students to use vocabulary they've developed throughout the unit, especially the distinction they identified between "types" and "kinds" of bacteria.

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Learning Plan: Why did antibiotics stop working for Addie? (2 periods of 45 min)

1. (10 min) Warm Up: Have students write down answers to the following question:

"What is your current thinking about why the antibiotics seemed to stop working for Addie? Write down all of the evidence that supports your thinking that we've gathered since we've started learning about Addie, antibiotics, and bacteria. You may want to refer back to your notes for this task. A chart has been provided to help you organize your thoughts."

Direct student to write their responses on their first two pages of Student Activity Sheet 6.1. As they do this, they may have unresolved questions. Encourage them to record these in the space provided.

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2. (5-10 min) Follow up on the Warm Up with a Consensus Building Discussion. This is a stock-taking discussion. Use the suggested prompts to bring out different pieces of evidence.

Suggested Prompts:

- ➔ What kinds of bacteria does Addie have?
- ➔ Do antibiotics today successfully fight off all types of bacteria?
- ➔ How has that changed over time?
- ➔ Where could she have gotten the bacteria?
- ➔ What are some ways that antibiotics work?
- ➔ If someone doesn't get an antibiotic that needs one, what will happen to the bacteria that are growing inside them?
- ➔ How fast did the bacteria grow?
- ➔ Do we have any ideas why bacteria don't work like?

Teacher Supports & Notes

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Listen for *student responses* that refer to what we figured out last time, such as:

Addie had both resistant and nonresistant Staph and Stenotrophomonas.
Antibiotics today aren't effective against all bacteria. In fact, some bacteria are resistant to most or even all known antibiotics. These are called pan-resistant.
She could have gotten the bacteria from the playground and from the hospital itself, particularly from the tubing that was keeping her alive.
Antibiotics have to interact with bacteria in order to kill them. This sometimes uses up the antibiotic.
When antibiotics were first introduced, they were almost always effective against the bacteria they were designed to treat. Over time, more and more antibiotic resistant bacteria appeared.
Antibiotics may explode bacteria or prevent them from reproducing. This often requires binding to or entering a bacterium's cell membrane, meaning that an antibiotic molecule is sometimes used up when it kills a bacterium.
If someone doesn't get an antibiotic when they need it, the bacteria will reproduce exponentially and will be even harder to kill later on due to sheer numbers.

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3. (5 min) Next, shift to a Sharing Initial Ideas Discussion. Use the following prompts to guide students to articulate what they think they should focus on in today's lesson.

Suggested Prompts:

- ➔ How could we take everything we know and show and put it together to see if it helps us figure out why antibiotics stopped working for Addie?
- ➔ How might trying to construct a model to represent why antibiotics stopped working for Addie help us put everything we figured out together?

Listen for *student responses* that mimic the next step in the story line, such as

A model could help us visualize what was going on inside of her over the course of the infection.

It would help us see people's ideas of how they think this happened.

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4a. (10 min) Have the students to work individually to build a model to explain, "Why did the antibiotics stop working for Addie?"[A] Encourage them to include the scientific ideas that they had written down at the beginning of class and that came up in the initial discussion. It may be best to address one idea at a time and seek consensus on if it's important. This is the proposal stage of a Consensus Building Discussion[B].

4b. (2 min) Have students turn and talk to the person next to them to compare models.

Suggested Prompts:

- What was similar or different about your models?
- What new questions did comparing your models raise?

4c. (5 min) Ask students to share out some similarities, differences, and new questions with the whole class. As students are sharing out, be sure to point out how puzzling, weird, interesting the notice and wonderings of the class are to encourage students to be curious about what is actually happening[C] and to set the stage for the next step.

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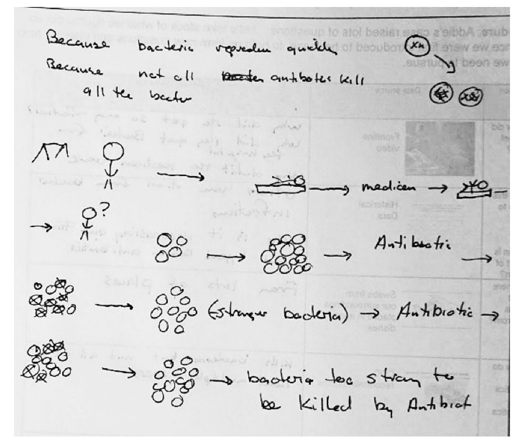
5. (5 min) Suggest that it's time to record and organize the many questions that came up in the modeling discussion and throughout the unit. Give students this time to record their questions in class and continue to think of new questions as a homework assignment[D].

Suggested Prompts:

- Wow, we've shared many interesting ideas that we've never thought about before. These ideas have got us thinking about new questions we want to investigate. Let's individually capture some of those questions on a sticky note before we leave class.
- What have you left class wondering that we haven't answered yet?

Classroom Artifact

[A] This is an example of a model that a student may create. A larger image of this is provided at the end of this lesson (see student artifact 1). It's important to have students complete this individually to get many ideas on the table about what they think it going on. The purpose of this is to get the students dissatisfied with their explanations and want to know more. These models will not be particularly detailed - see note B.



Strategies for this Consensus Building Discussion

[B] Here, students should feel frustrated because they don't have enough information to fully answer the question in their models.

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6. (5 min) Warm Up: Have students answer the following question in Student Activity Sheet 6.1.

Suggested Prompts:

- ➔ Take a look at the questions you were thinking about from last class or any new questions you came up with for homework. Swap questions with a person next to you.
- ➔ What new ideas did your neighbor's questions make you think about? Were your questions similar or different? How were they similar or different?
- ➔ Is there another question you are now thinking about? Write that question down on a Post-it note.

7. (30 min) Build a Driving Question Board with students. Have students come up to the board, one by one, and place their questions on the Driving Question Board E **surrounding the main driving question, "Why Don't Antibiotics Work Like They Used To?" Strongly encourage students to share the question that they most want to answer and to connect their question to a previous question if possible. Make sure each student shares at least one question.**

Student responses may include:

- ➔ *Why are we able to show more bacteria becoming resistant so easily and so fast?*
- ➔ *What actually is it about the bacteria that makes them resistant?*
- ➔ *And how did they get that way? How do they become resistant?*
- ➔ *How come playing outside now seems more dangerous? Why can we pick up resistant bacteria more easily now, compared to when our grandparents were living?*
- ➔ *Some of us think evolution might be part of the story, but we don't really know how. Is evolution a part of this story?*

As the discussion progresses, suggest labeling general questions. The three expected big groups are:

What makes resistant and nonresistant bacteria different from each other?

There should be more questions than answers, which motivates the next task.

Additional Guidance

C The instructor plays an important role in creating setting the stage for many interesting questions to put on the Driving Question Board. One way you might encourage your students to start wondering about things is to say things like, "Wow, I never thought about _____ before, that makes me wonder _____?" "What an interesting comparison! That brings up a whole new category of questions! What's one thing you might be wondering now?" If a good question comes up during the discussion, you might even say in the moment - "Oh! That's an interesting question, would you write that down on a sticky note so we don't lose track of if?"

Additional Guidance

D Step 5 could be made a home-learning assignment if desired, especially if class time is limited in the first period for this lesson. Then have students share those with a classmate when they return the second day. Step 5 will occur on day 2 of this lesson.

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How do these differences matter for whether antibiotics work or not for Addie?

How did nonresistant bacteria get that way?

7. (5 min) Before dismissing students, ask student to brainstorm what our next steps should be in our investigations.

Suggested Prompts:

- ➔ What should we make sure to do in our next class?
    - ➔ Are any of the questions more important to answer before others?
- ➔ What do we need to investigate next time we meet?
    - ➔ Where's an easy place to start?
    - ➔ What would that help us figure out?
    - ➔ Could it relate to our most important question?
- ➔ How might our current Petri Dish experiments be helpful in helping us figure out some of these questions?

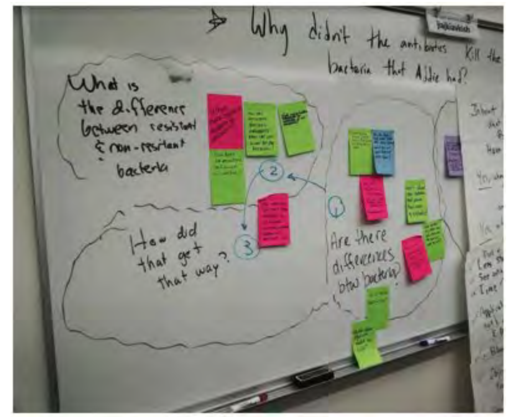
Listen for *student responses* such as:

We should start to tackle the questions by pursuing some new investigations. We're particularly curious what makes resistant and nonresistant bacteria different from each other - it seems like the other big questions depend on this.

First we should check in with our antibiotics experiment, to wrap up that loose end and see if it tells us anything. It might give us some clues - maybe we'll be able to tell if there are nonresistant bacteria in the dish.

Classroom Artifact

E Refer to the Unit's Front Matter about How to construct a Driving Question Board (DQB) with students. This DQB picture below shows the questions grouped, as well as a close-up of the questions in one of the groups. Students may come up with questions that are hard to categorize; these can be placed under the main driving question in their own space.



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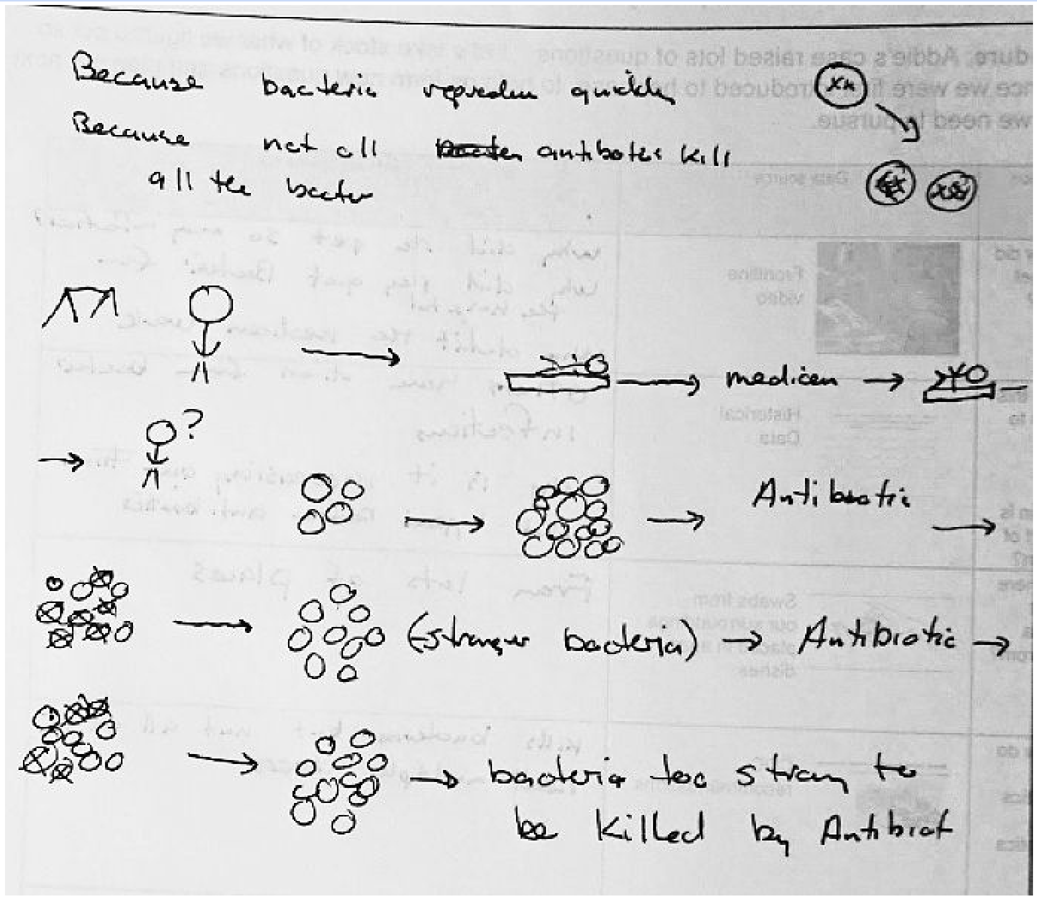
Sample Student Artifact #1



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Alignment With Standards

Building Toward Target NGSS PE

- **HS-LS4-2.** Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- **HS-LS4-4.** Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

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Lesson 5b: What happening with our antibiotics experiment?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been In the last lesson, your students took stock of what they have learned in this unit and organized their questions on a Driving Question Board. They decided to check back in with the ongoing Petri dish experiment.

This Lesson....What we are doing now: Students will figure out that there is a ring in the Petri dishes where no bacteria grow, and wonder if the bacteria closer to the antibiotic are different somehow. They will design and begin an experiment where they take bacteria from near the zone of inhibition and away from it and replate them so their growth can be compared.

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L5b: What's happening with our antibiotic experiment? (1 period) *Building toward* ⬇ *NGSS PEs: HS-LS4-2 & HS-LS4-4*	Our experiment with Petri dishes and antibiotics placed in the same environment shows that the bacteria didn't grow in all parts of the dish.	**Use Mathematics & Computational Thinking** Make claims about what *the specifications for a* computational simulation would need to be *to represent the key components of the system (scientific principles and data from mathematical models we developed from)* investigating related phenomena (*bacteria growth, interactions with antibiotics, and Addie's case*) *in order to further investigate how do different doses of antibiotics affect a bacteria population in a simulated infection?* **Plan and conduct investigations** Consider possible confounding variables or effects and evaluate the investigation's design to ensure variables are controlled.	We noticed some interesting patterns in our experiment: • Bacteria grew in some places in the dish, but not others. • There seems to be a ring (called zone of inhibition) around the antibiotic drop where no bacteria is growing. • The size of the ring isn't the same width for every amount of antibiotic. • The stronger dose of antibiotics have a larger ring and the more diluted antibiotics have a smaller ring. We compare these results to results from earlier Petri dish experiments: • We know the environment isn't uniform throughout the Petri dish. The concentration of the antibiotic is higher where we dropped it in and weaker further away. • From our earlier investigations, we saw that different bacteria grow in different places in the world around us. *We are wondering whether the bacteria near the antibiotic is different from the bacteria growing far away from it. Could we test to see if the bacteria near the ring is the same as the bacteria far away from it? Would both grow equally well starting from the same place in the same environment (repeated dose)? Or would one reproduce faster? Or would one be less affected by the antibiotic?* We agree on the need for a really strict/safe protocol to use in our class and set up our experiments because these sorts of experiments could potentially end up harmful to humans without controlled variables and safe procedures, just like when we work with acids/flames, etc. Then we execute our experimental plan. **Next Steps: We realize that our results will be in a Petri dish and may not capture the same level of complexity of interactions between antibiotics and bacteria in Addie's (or someone else's) body. While we are excited to keep doing experiments with real bacteria in the real world, it would be nice if there was a way we could inspect our experimental environments to see what's going on in slow motion and to see more closely.** We talk about how when scientists want to study more complex interactions between lots of things that are difficult to see first hand (e.g. lots of bacteria and lots of antibiotic) and the time or size scale of all those interactions, they often develop simulations of the system they want to investigate. *We wondered if we could also develop/use a simulation to investigate some of our questions.* **Next Steps: We brainstorm what we'd want in such a simulation, including some of the things that we can't see/find in our Petri dish experiment as well as everything we have figured out about the bacteria & antibiotics so far:** • **Bacteria populations/infections are in different patients (different environments).**

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L5b: (continued)	Same phenomena as above		• Bacteria are living and reproducing in those environments. • Antibiotics are moving through the bloodstream in those environments. • We can see bacteria dying when antibiotics enter through their cell membranes. • Variation in how bacteria can prevent antibiotic death, since we recalled from a previous lesson that bacteria can have different armor. Maybe something with the armor is different. Our teacher thinks he/she might have a simulation that can meet our needs.

S

T

Next Lesson....Where we're going Now that your students have started their experiment and determined how a faster version could be conducted as a simulation, they will explore the simulation and build an initial model of natural selection.

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Getting Ready: Materials Preparation

Materials For Each Group

- Agar plates from 5a
- Two sterile swabs for each plate
- Two agar Petri dishes for each plate
- Ampicillin solution (amount ampicillin determined by group's prior concentration)
- Two test tubes
- Beaker of disinfected water
- Hole punch
- Piece of filter paper
- Access to digital scale
- Forceps

Preparation of Materials (15 min.)

- Arrange materials for each lab group
- Pull out class consensus materials from Lesson 6
- Class Slides

Materials For Each Student

- Lesson 5b - Student Activity Sheets (1)
- And return to recording data in the already partially completed Lesson 5a - Student Activity Sheets

Safety

- Gloves and goggles should be worn at all times
- No food or drink near the lab tables
- Students should wash their hands after handling plates
- Waste should be disposed of in a biohazard bag

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Getting Ready: Teacher Preparation

Background Knowledge

In this lesson, students will see that a zone of inhibition, or area of no or little bacteria growth, has developed around the antibiotic-soaked discs filter paper. The antibiotic has killed all bacteria in this region that are not resistant to it. If any bacteria are left in this area, they are likely resistant to the antibiotic. Similarly, bacteria living around the edge of the zone of inhibition are more likely to be antibiotic resistant. When students culture bacteria from this edge, they will be selecting for antibiotic resistance. In subsequent lessons in the L5 sequence, students will see the zone of inhibition grow smaller as non-resistant bacteria are killed and a larger proportion of resistant bacteria are transferred to new plates.

Alternative Student Conceptions

Students may still be skeptical as to whether or not anything is really different between the bacteria left near the zone of inhibition as opposed to farther away from it. Let that skepticism be a reason we need to do an experiment to test whether or not they really are different. They may have questions about two key differences in the agar plates. First, they may be unsure if environmental differences can account for where bacteria did and did not grow on the plate. Referring to an earlier investigation, they should determine that differences in antibiotic concentration across the dish (therefore, environmental differences as there is less and less antibiotic away from the filter paper, and none at the edge) are a likely culprit. Students can then ask if there is anything different about the bacteria growing in the different environments. That skepticism is a reason to do an experiment to test if the bacteria are different in the different environments.

Linking Our Understanding to Scientific Terminology

- Zone of inhibition

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Learning Plan: What's happening with our antibiotic experiment? (60 min)

1. (5 min) Remind students that last class they decided to check in with their ongoing investigation from Lesson 5a in hopes that it would help answer the biggest subquestion, how resistant and nonresistant bacteria are different. Give students an opportunity to record what they notice about their experiments, as they ended the previous lesson wanting to check in on them.

Suggested Prompts:

- ➔ Where do you see bacterial growth on the plate? Where is bacteria not growing?
- ➔ What else do you notice looking at the plates?

2. (10 min) Begin with a Building Understandings Discussion to help re-orient students in the storyline. Use the following prompts to help students articulate where their experiment currently stands.

Suggested Prompts:

- ➔ What did you notice about your ongoing experiments from Lesson 5a?
- ➔ In Lesson 5a, you thought that the antibiotic might not be "strong" enough to kill all the bacteria in the plate. Do you see any evidence of this in the plates?
  - ➔ How does this compare to what you saw when examining bacteria in Lesson 3?
- ➔ Why do you think there is a ring where no bacteria are growing?
  - ➔ Why is the ring where it is, and why does it vary in size between plates?
  - ➔ Is the rate at which antibiotic seeped out different between the different concentrations?
  - ➔ If the parts of the plate have different amounts of antibiotic and therefore different environments, could the bacteria found be different?
  - ➔ What would the difference be?
  - ➔ In our last lesson we wondered if this experiment could tell us anything about the

Teacher Supports & Notes

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differences between resistant/nonresistant bacteria? Where would we expect to find each?

- ➔ Could there be some overlap in where we might find both?
- ➔ Where would we expect the transitions between bacteria types to occur?
- ➔ How could we figure out whether or not the bacteria are different on different parts of the plate?

Listen for *student responses* that refer to what we see in the experiment, such as:

We see that bacteria grew in some places in the dish, but not others. There seems to be a ring around the antibiotic drop where no bacteria is growing. The size of the ring isn't the same for every concentration of antibiotic - the stronger doses of antibiotics have a larger ring and the more dilute antibiotics have a smaller ring.

We think the concentration of antibiotic was/is higher the closer to where it was dropped in, and then gets less the further away from the center, so the environment isn't the same throughout. This came from Lesson 3 where we saw that bacteria were mostly - but not entirely - killed by hand sanitizer.

If bacteria are different when the environment is different, maybe the change in environment throughout the plate could mean that the bacteria are different as well. Maybe we could test to see if the bacteria along the edge of the ring (or even within the ring, if there are any A *) grow the same as bacteria away from the ring when they're placed in separate plates with the same concentration of antibiotic.*

When students bring up the ring where no bacteria is growing, note that microbiologists typically call this region the zone of inhibition - inhibition meaning that nothing grows there.

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3. (5 min) Next, shift to a Sharing Initial Ideas Discussion. Use the following prompts to guide

Additional Guidance

A There may be bacteria growth within the zone of inhibition. If this is the case, draw students' attention to it and ask them what they think it is. This bacteria, which is a colony of antibiotic resistant bacteria, should be plated separately in Part 4 of this lesson.

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students to articulate what they think they should focus on in today's lesson.

Suggested Prompts:

- ➔ How specifically could we test our idea that bacteria near and away from the ring are different?
- ➔ Do you expect any differences between the two plates when we look at them again? How might they turn out differently, if at all? Explain your answer.

Listen for *student responses* that mimic the next step in the story line, such as

We should repeat our same procedure from when we set up the experiment, except instead of using the culture the teacher had for us, we should use bacteria from our current agar plates. Each group will take bacteria from near their zone of inhibition and make a plate with it, and do the same with bacteria away from their zone of inhibition. Each group will keep using the same antibiotic concentrations as before.

We think that the bacteria near the antibiotic are somehow stronger, so they will survive better in their new plate as well. ***OR*** *The concentration of antibiotic was the only difference, so the plates will be the same.* B

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4. (15 min) Have students prepare the new plates in their groups. The procedure should be the same as in Lesson 5a, except the bacteria will come from the current agar plates as discussed above. Each group will prepare two plates. For one plate, swab around the edge of the zone of inhibition until the of the swab is half-covered. Mix this with 50 mL of water and plate. For the second plate, the group should take a similar amount of bacteria from an area of their plate farther away from the zone of inhibition, prepare a similarly diluted culture, and plate it.

If so desired, each group may vary the concentration of their bacterial culture. However, each group should take a similarly sized sample from the edge of the zone of inhibition as well as from farther away on the plate.

Strategies for this Initial Ideas Discussion

B It is not necessary for students to be in agreement on this point or to have a fully fleshed-out mechanism. They are just putting their ideas on the table at this point.

Here are some additional ways to support students in this discussion. Ask, "Do we think there is something different about the environment where the bacteria were growing vs. not growing?" Most likely students will say yes because antibiotic concentration is higher where it is not growing). Then we can ask, "Is there a difference in the environment as they get closer and closer to where there was no growth? There students might say they are not sure, but we are open to the idea. Then we can ask if we think the environment is different, "Is there

anything different about the bacteria growing in that environment?" Again we can say we're not sure. So then we can ask "How could we test this?"

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5. (5 min) Have a Sharing Initial Ideas Discussion to discuss what we should do while we wait for experimental results.

Suggested Prompts:

- ➔ What could we do while we wait for our bacteria to be ready?
    - ➔ What have we done/worked on that could give us direction?
    - ➔ What do scientists do when they want to perform experiments that take a really long time?

Look for *student responses* such as:

We could return to our Driving Question Board and other resources from Lesson 6 and see what ideas we have.

But maybe there's also a way to speed this experiment up? We don't know how to do it in real life, but a simulation might be able to help. Just like a video showed us how bacteria grow in fast-motion, a computer could show us our experiment at high speed. We should figure out what we want in this simulation.

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6. (10 min) Have a Consensus Building Discussion to help them decide what they want the simulation of the bacteria experiment to look like.

Suggested Prompts:

- ➔ What should our simulation focus on?
- ➔ What did we figure out as important to Addie's case that we want to show up in our simulation?
    - ➔ What does our organizer from Lesson 6 tell us that we figured out in each lesson?

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➔ What did we notice in today's lesson that should go into our simulation?

Listen for *student responses* such as:

Our simulation should focus on a patient (e.g. Addie since she was the reason we started all this). But we also want to see different infections in different patients. (L1, L3b)

The bacteria should live and reproduce in those environments, maybe move through the bloodstream or having the blood stream connecting to where they are located (L4, L3b)

Bacteria should be destroyed when antibiotics enter through their cell membranes (L3b)

In a previous lesson we learned that bacteria have different armor, so we want to see variation in this - some bacteria should be easier to kill (L1, L2)

We want to be able to adjust the antibiotic dosing/dosage (L5b, survey results from L3a)

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7. (5 min) End class with a Consensus-Building Discussion to verify that students are on the same page about what they figured out and what the next steps should be.

Suggested Prompts:

➔ What did we identify as a likely reason for why no bacteria were growing in the zone of inhibition?
➔ Why did we decide to replate bacteria from the edge of and away from the zone of inhibition?
➔ What should we do next class?

Listen for *student responses* such as:

The bacteria were not growing in the zone of inhibition because this is where the antibiotic was most concentrated - where the environment was most hostile to bacterial growth.

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We thought that because the environment varied across the plate, maybe the bacteria were different too. We saw in prior experiments that different bacteria live in different environments.

Because our bacteria will take a long time to culture, we want to do a simulation that will take what we know about bacteria and antibiotics and see if we can replicate what happened to Addie.

Alignment With Standards

Building Toward Target NGSS PE

- **HS-LS4-2.** Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- **HS-LS4-4.** Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

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Lesson 7: How do different doses of antibiotics affect a bacteria population in a simulated infection?

High School Unit: Why Don't Antibiotics Work Like They Used To?

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Previous Lesson....Where we've been In the last lesson, students revisited their Petri dish experiments. Based on their observations, the class decided to keep replating the bacteria. The class identified the limitations of not being able to see what was going on in the dish (as well as in Addie) more closely and in slow motion. This motivated wanting to develop/use a computer simulation of these phenomena.

This Lesson....What we are doing now: Students will need to use a computer simulation using a web browser to conduct 4 investigations. Each investigation will provide them a new piece of the puzzle to helping them develop a model of natural selection to explain certain variations of bacteria (individuals of with few pores in their cell membranes) become far more prevalent (or become the only variation) in the population over time under certain environmental conditions

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L7: How do different doses of antibiotics affect a bacteria population in a simulated infection? (3-4 periods) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2, HS-LS4-3, & HS-LS4-4*	A NetLogo Model (Bacteria & Antibiotics.nlogo) provides platform to experiment with interactions between bacteria growth, trait variations, and antibiotic interactions.  The simulation yields a variety of different outcomes for 4 different investigations, one of which is the emergence of a more resistant population of bacteria over time) depending on the environmental conditions the model is set to run with.	**Plan and conduct investigations** individually and collaboratively deciding on types, how much, and the accuracy of data needed to produce reliable measurements to *figure out how do different doses of antibiotics affect a bacteria population in a simulated infection.*	**We identified things we wanted to include in our simulation, based on what we know about the bacteria so far,** that would help us answer the question, *"How do different doses of antibiotics affect a bacteria population in an infection?"* In investigation 1, we ran the simulation and watched the bacteria grow unhindered. We saw several patterns in the data: • Each variation reproduced and created new individual bacteria that had the same variation as the parent. • The different types of bacteria grew at about the same rates. Sometimes one variation grew a bit faster or ultimately produced more individuals, but no one variation seemed to have advantage over another (over multiple runs) - the differences in outcomes all seemed due to where they were randomly located in the environment (space available). • The growth rate of the bacteria slows down as the amount of space remaining decreases. • Population size increases until they run out of space. From this evidence we argued that bacteria are competing for a limited resource (space) and something similar might be happening in our Petri dishes as well. In investigation 2, we ran the simulation added a single dose of antibiotic with no reproduction and noticed new patterns: • The population size decreases a bit. • Some variations (those with fewer holes) didn't die off in as large of numbers as other variations. • There is noticeable shift in the distribution of traits in the population occurs each time resulting in a higher % individuals with fewer pores in the cell membrane. From this we developed a model to explain this: • There is less of chance that the antibiotic particles into a bacteria cell, when there are fewer holes in the cell membrane for it to get through. In investigation 3, we ran the simulation with reproduction of bacteria and added multiple doses of antibiotics to the patient until all the bacteria were all killed off and noticed some new patterns in the data: • The population was completed eliminated eventually from the environment (extirpated). • There was variation in the results between patients: Sometimes it took only one dose and sometime it took more than one dose of antibiotics to wipe out an infection. From this last finding we argued that we need to conduct multiple trials and statistical analyses to more accurately convey what is a typical experimental outcome.

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L7: (continued)	Same phenomena as above.	**Develop a model** to illustrate and predict the relationships between *heritable trait variation in a population, reproduction, competitive advantages for survival and environmental changes (to the amount of antibiotics in the system)* to a provide mechanistic account to explaining, *"How applying antibiotic in some situations (cause), led to a population of bacteria developing over time that is more resistant to antibiotics then they were initially? (effect)"*	In investigation 4, we conducted our experiments with the simulation to explore how changing the environmental conditions in four different ways affected the population - smaller amount of antibiotics in a dose, less frequent doses, less regular dosing, and higher reproductive rates. From the results of different groups, we noticed some new patterns in the data: • There was a noticeable shift in the distribution of traits in the population occurs with each new dose resulting in a higher and higher % individuals with fewer pores in the cell membrane. • Certain variations (individuals of with few pores in their cell membranes) become far more prevalent (or become the only variation) in the population over time. This raised the question, *"How is it possible that applying antibiotic in some situations, led to a population of bacteria developing over time that is more resistant to antibiotics then they were initially?* We developed a model to answer this question, that shows how individuals with certain trait variations that grant them a competitive advantage for survival over others in environments with lower doses of antibiotics, could lead to this outcome. We compared two systems, the simulation and Addie world, and notice some general similarities in both systems: • Heritable trait variation in bacteria ○ There is variation in cell membrane structure. • Initial population ○ There is an equal % of individuals of each variation to start with. • Reproduction of bacteria: ○ Bacteria of a given kind reproduce more of the same kind. ○ The overall reproduction rate affects all bacteria. ○ Which bacteria are left to reproduce affects which ones reproduce. • Environment:" ○ The amount of chemical in the environment (more chemical increases the odds it getting to a bacteria. ○ Where the bacteria located in the environment (e.g. surrounded by other bacteria make it harder for antibiotic to get to you) We use our model to argue how and this process (natural selection) • Might be what happened inside of Addie (or other patients) • Might be what will happen in our Petri dishes. • Might relevant to our infographic to help explain what antibiotic resistance is and what causes it. **Next steps: We 'd like to take stock of what we figured out and add it to our discoveries on driving question board, because it could be key to helping us answer the DQB, could be relevant to our Petri dishes, and seems potentially useful for our infographics.**

Next Lesson....Where we're going The class will use systems thinking to compare what is similar and generalizable in the mechanisms that a part of the simulation vs. what is happening in Addie's world, which become the foundation for their model of natural selection. But they also identify areas of the model that they have more questions about (e.g. reproduction, interactions with other things in the environment), which will motivate the need to investigate a new population (a new system) whose population is also changing over time, but that we can see these type of interaction up close to study them further.

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Getting Ready: Materials Preparation

Materials For The Class

- Projector with speakers to play the Lesson 7 - NetLogo Bacteria&Antibiotics Introduction Video

Materials For Each Student

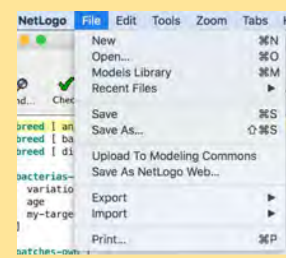
- Lesson 7 - Student Activity Sheets
- Computer with a web browser on it and the ability to download a file to the desktop or google drive.
- Lesson 7 - Extension Assessment (Optional, if needed after the last activity in Lesson 7 Student Activity Sheets)

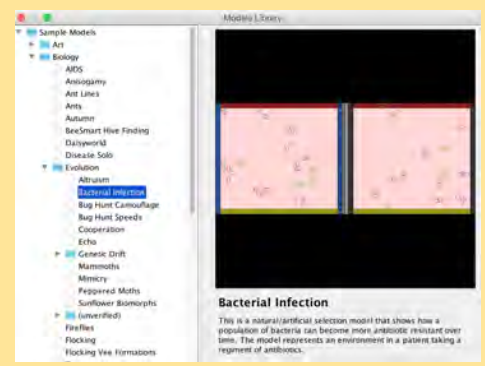
Preparation of Materials (15 min.)

- Test the NetLogo Lesson 7 - NetLogo Bacteria&Antibiotics Introduction Video
- Test running the student model through a web browser at this url http://inquiryhub.dls.ucar.edu/bio/BacterialInfection.html

Alternate Method for Running the Simulation (start a week before hand in coordination with your IT department)

- Note: The video and student directions use a web based interface to run the computer model. This allows students to run the simulation on chromebooks and other devices that have a web browser but not a lot of disc space. BUT… there is a second option for running the simulation, which allows it to run a lot faster on machines that have NetLogo Software installed on them. The software comes with the Bacterial Infection model as part of the Models Library, and can be downloaded for free from https://ccl.northwestern.edu/netlogo/ If you are interested in this option, talk to your IT department about downloading and installing the software on student computers before this lesson.
    - After installing it, launch the program and from within it go to the File>Models Library menu (see image to the top right).
    - Within that menu open the Sample Models>Evolution folder. Within there open the Bacterial Infection model (see image to the right).





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Getting Ready: Teacher Preparation

Background Knowledge

- *NetLogo web (http://www.netlogoweb.org/) is freely available. It was developed the the Center for Connected Learning at Northwestern University.*
- *See next page for Additional Information on NetLogo Simulation Results for the 4 investigations that students will do.*

Linking Our Understanding to Scientific Terminology

- Slope
- Exponential growth
- Rate of change
- Mode
- Mean
- Median
- Range
- Extirpated

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Getting: Teacher Preparation: Additional Information on NetLogo Simulation Results

The following summary table describes what is similar and different between the four simulations that the students will run. This table is for teacher reference only as additional background information, so that if students are struggling with seeing differences (or similarities) between the four investigations, you will have some potential ideas for additional prompts you can use to guide their thinking:

Comparing system characteristics in each investigation:	Investigation						
	1	**2**	**3**	**4A**	**4B**	**4C**	**4D**
Any heritable trait variation in the initial population?	• *Yes, there are variations in cell membrane pores.* • *There is an equal % of individuals of each variation to start with.* • *Heritable: When reproduction happens, the 2 offspring cells have membranes that are identical to their parent cell.*						
Did the environment change?	*No*	*Yes, a single light dose of antibiotic*	*Yes, but heavier dose of antibiotic than in 2 and it is repeated regularly.*	*Yes, but lighter doses than in 3.*	*Yes, but not as often as in 3.*	*Yes, but not as regular as in 3.*	*Yes, same as in 3, but faster growth due to more food.*
Is there any competitive advantages for which individuals survive?	*Yes, but only due to where they are located*	*Yes, due to two things:* • *Their cell membrane matters: Those that have less pores tend to survive longer, because antibiotic particles get inside of them less often than those with more pores.* • *Where they are located matters: Those that have other bacteria near them tend to less often than those that are on the edge (or top edge) of a bacteria cluster.*					
Is there any competitive advantage for who is reproducing?	*Yes, those that have space available next to them.*	*No*	*Yes, due to two things:* • *Those that are still alive can reproduce, those that are dead can't.* • *Those that have space available next to them.*				
Interesting Outcome(s)	• *Population size increases until reaching a maximum carrying capacity due to limited space.* • *Sometimes one variation did better than others, but no one variation seemed to have advantage over another (over multiple runs)*	• *Population size decreases a bit.* • *A noticeable shift in the distribution of traits in the population occurs each time resulting in a higher % individuals with fewer pores in the cell membrane.*	*The population was eventually completed eliminated from the environment (extirpated).*	• *In certain conditions, a noticeable shift in the distribution of traits in the population occurs with each new dose resulting in a higher and higher % individuals with fewer pores in the cell membrane over time.* • *It appears that in these situations we are making the later population more antibiotic resistant than the initial population.*			

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Learning Plan: What Exactly Is Traveling Across The Medium (2 periods of 45 min)

1. (5 min) Begin with a Consensus Building Discussion to help re-orient students to why we wanted to do a computer simulation today. Use the following prompts to help students articulate what the class wanted the simulation to include and why:

Suggested Prompts:

- ➔ How might simulating a bacteria population with lots of bacteria and lots of antibiotic particles on a computer help us see what is happening at time scales or size scales in an infection, more easily than we could see in our petri dishes?
- ➔ Why did we think it would be important for that simulation to include things like:
  - ➔ Bacteria populations/infections in different patients (different environments).
  - ➔ Bacteria living and reproducing in those environments.
  - ➔ Antibiotics moving through the bloodstream in those environments.
  - ➔ Being able to see bacteria dying when antibiotics effectively enter through their cell membrane?
  - ➔ Structural variation in the bacteria, related to something about different armor, that is connected to death from antibiotics.

Listen for *student responses* [A] that refer to what we figured out last time, such as:

We thought that in a computer simulation we could maybe zoom in to see the actual bacteria (like under a microscope), and we could slow down the simulation or pause it to watch what is happening, or speed it up to run lots of simulated experiments.

It is important to be able to simulate different patients, because Addie isn't the only person who has suffered from an infection of this sort, and not everyone who is infected has the same outcome that Addie had.

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A The goal of this discussion is to share out a wish list of what objects and interactions we would need in a computer simulation, that we know are important to include, so that when students start using the simulation, they have already thought through some of what they expect to see in it. This will help orient them to the simulation, before ever starting it, as well as motivating why using the simulation might help us understand an answer to the question that we have been investigating in previous lessons.

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It is important to have bacteria reproducing in those environments, because if they have available food just like in the petri dishes, they should reproduce pretty fast. And we know that there is food available in the human body, moving through the bloodstream.

It is important to have antibiotics moving through the bloodstream, because that is what we modeled in an earlier lesson, when we trying to figure out why a single dose of bacteria might not kill every bacteria.

It is important to have antibiotics moving through the bloodstream, because that is what we modeled in an earlier lesson, when we trying to figure out why a single dose of bacteria might not kill every bacteria.

We want to be able to see bacteria dying, similar to what we saw on the video clip of bacteria cells "popping" when antibiotics kill them.

We want to be able to see some sort of variation in cell armour or cell membranes, because we heard about this in the first lesson.

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2. (5 min) Post the Bacteria and Antibiotics link to a location where students can click it or enter the URL in their web browsers. Have students go to the simulation.

Play NetLogo Bacteria & Antibiotic Model Introduction Video to the entire class to give them a general orientation to using NetLogo Web to show how to run the Bacteria and Antibiotics simulation from their computers.

Tell students that they will be conducting four investigations over the next couple of days. The procedures first three investigations can pursued independently, but parts of the making sense and conclusion sections for the activities will be done with partners or the whole class B

Additional Guidance

B It is recommended that you set a timer to limit the time for each suggested section outlined below.

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Investigation 1 : What do bacteria do when they infect a person?

3. (15 min) Have students complete the prediction questions and read through the procedure on the first page to make sure they have uploaded the file to netlogo onto the second page.

Then have students complete the procedure and observation section for investigation 1. C

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4. (5 min) Working with partners, have students complete the making sense section of the investigation together. D

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5. (5 min) Bring the class together to for the conclusion section. Use the two questions in this section as suggested prompts. If time is limited, discuss the first question only. Project a sample image of these graphs to refer to in this discussion.

Suggested Prompt:

➔ What part of the population vs. time graphs, provide evidence to support the claim that, "Bacteria are unintentionally competing for space in these environments"?

➔ How is the slope of the graph changing in that part of the graph? E

Listen for *student responses:*

The right part of the graph supports this claim, where the slope of the graph starts decreasing all the way until it eventually reaches zero.

Suggested Prompt:

➔ Would you expect the bacteria that are growing in the petri dishes in your classroom to follow a similar pattern of growth? Explain.

Listen for *student responses:*

Formative Assessment Opportunities

C Check student sketches of their graphs to look for this non-linear shape. It provides evidence for the conclusion section of: exponential growth at first, and then decreased growth rates due to a limited resource (space).

Supporting Students in conducting investigations and analyzing and interpreting data.

D When students are conducting these computer investigations, they will be reluctant to want to discuss their work with a teacher or partner. Give them space to investigate here on their own. But when you switch to having students work on the making sense sections of each investigation with partners, you can take a more active role in listening to their conversations and mining them for ideas to bring together in the conclusion section.

Supporting Students in using mathematical thinking

E The Appendix F matrix for the science and engineering practices for NGSS calls for students in high school to apply concepts of

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Probably, because:

the left part of the graph looks like the growth is exponentially increasing. And that is what we predicted in earlier lessons with a doubling every 20-30 minutes. And we also saw bacteria colonies appearing really quickly in the dishes from swabs where we couldn't see anything initially.

And maybe only the bacteria near the edge of the colony can keep growing into open space, so in that way, they too would be competing for space.

And at some point the bacteria would also run out of space (or food or other resources it needs to reproduce) in the dish. So, at that point they would stop growing and reach a maximum population size.

Investigation 2: How does the antibiotic interact with the bacteria?

6. (10 min) Have students independently complete the prediction question, and the procedure and observation sections for investigation 2.

7. (5 min) Working with partners, have students complete the making sense section for investigation 2. F

8. (5 min) As a class, discuss question 3 of the conclusion section for investigation 2 together.

Suggested Prompts:

➔ Based on the results from this investigation, which trait variations of bacteria tend to have a higher chance of surviving exposure to antibiotics from their surrounding environment?

➔ How are the chances of an antibiotic particle getting into a bacteria cell related to the number of pores it has on its cell membrane? Why? Could someone draw what we mean?

➔ How could you (or we) show why the structural differences in the cell membranes of different

statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems.

Here is an excellent opportunity to have student identify the parts of the graph that show exponential growth, as well as discussing how the slope of the graph increasing through the range of exponential growth and then starts decreasing as bacteria run out of more and more space, until the slope levels off to zero.

Supporting Students in using mathematical thinking

G The results from a small number of runs will have a lot of variation in them, and won't provide enough data, to make a strong claim, that the bacteria with less pores have a higher chance of surviving exposure to antibiotics.. But if you pool all the classes results, or ask the students to report out which variation (3, 4, 5, or 6) did best for 2 model runs, and tally up the results, the class will see a clear pattern to the mode in data. This pooling of data will motivate the argument that "more data makes us more certain." And it will motivate the need to collect multiple trials

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variations of bacteria affect their chances of surviving a particle of antibiotic that reaches them and why is that important?

Listen for *student responses:*

The bacteria with less pores tend to have a higher chance of surviving being hit by an antibiotic. The bacteria with more pores tend to let antibiotics get into them more often (because of more openings) which then kills the bacteria, but the bacteria with less pores tend to have antibiotic particles bounce off them (or get deflected). Student drawing should reflect more antibiotic particles getting into a bacterial cell with many pores and antibiotic particles bouncing off bacterial cells with fewer pores.
When the antibiotics get into the cell, they kill it. So if there are no or few openings and the antibiotics bounce off, those cells are more likely to survive.

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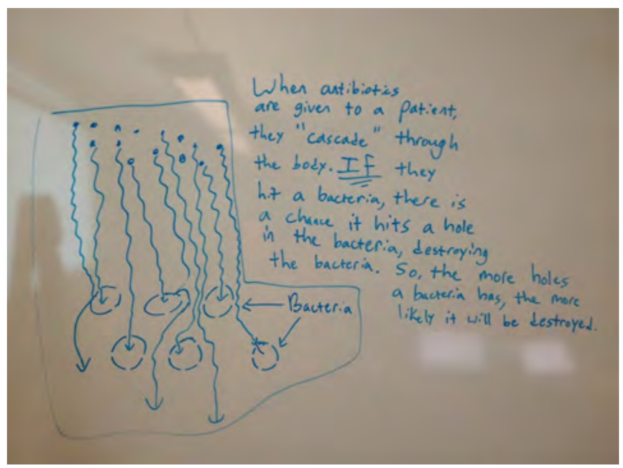
9. (15min) Tell students that they will try to model this next. Have students complete the last two questions of this conclusion section individually. G

Sample *student response* for question 4 of the student activity sheet*:*



and calculate statistical measures of the results in future investigations.

Formative Assessment Opportunities

G This is a good opportunity to see if students are making a connection between the structural variations in the cell membranes of different bacteria and how these structures influence the relative competitive advantage the bacteria has for surviving an interaction with an antibiotic particle.

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Sample *student responses* for question 5:

The bacterium on the left is less likely to die when the antibiotic is applied, because the antibiotic is likely to explode one above it and get used up. (Antibiotics get used up when they explode a bacterium.) The one on the right does not have anything protecting it, and so the same amount of dose of antibiotic applied would be more likely to kill that one.
If there are more bacteria nearby, protected from the dose of antibiotic going through, then it has a lower chance of dying than the bacteria that are more exposed.

Investigation 3: How will the combination of both reproduction and antibiotic application affect the bacteria population?

6. (15 min) Have students complete the prediction question, and the procedure and observation sections for investigation 3. Remind them to work with partners for completing the making sense section for investigation 3.

---

7. (5 min) As a class, discuss the questions in the conclusion section for investigation 3 together.

Suggested Prompts:

- Which statistical measure (range, mode, median, mean) would most useful for determining an answer to the question, "What is typical number of doses that a person needs to take in order to wipe out their bacterial infection?"
- The results of computer simulations are often used as evidence in claims that scientists and engineers make. Why might it be necessary to report more than one of these statistical measures in order to not mislead people who use and prescribe antibiotics (like patients and doctors)? H

Supporting Students in using mathematical thinking

H Help students see that providing more statistics can give people a better sense of what is typical by providing a way to picture multiple features of the distribution of the results.

The Appendix F matrix for the science and engineering practices NGSS calls for students in high school to apply concepts of statistics and probability to scientific and engineering questions and problems.

You may want to post a general principle in the classroom based on this conversations that says something like "Providing more than one statistic can help people make more informed decisions about what is typical in the data."

Students should be fluent at using " mean, median, mode, and variability) to analyze and characterize data" from middle school.

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Listen for *student responses:*

Range is useful for describing the variance (extreme values) in what you could expect.
Mode is useful for describing what is likely to happen most often
Both median and mean are useful for describing where the center of the data tends to be found.
If you only report one statistic, then doctors and patients might take too few doses because they don't have enough information to tell them they should do otherwise (e.g. assuming that taking the mean or median dosage it takes to wipe out an infection will always work for them, or not knowing what a reasonable maximum number of antibiotics are to take for the extreme range of possible outcomes).

Investigation 4: How does changing the conditions in the environment affect the population?

8. (10 min) Have students complete the prediction question.

Then assign groups of 3-4 students to a research team. Assign these separate research questions to different research teams:

A. **How will decreasing the amount of medicine per dose affect the population?**

B. **How will taking doses less often affect the population?**

C. **How will skipping a regular dose affect the population?**

D. **How will increasing the rate of bacteria reproduction (from more food) affect the outcome?**

Tell students that groups will present results of the investigations to the class. Emphasize the need for the group to first plan for how to conduct a controlled experiments for your group's

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research question amongst all group members. Have students complete the experimental design plan on the next page before starting their experiments.

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9. (15 min) Working with teams, have students collect data for presenting to the class and summarize the discoveries they made in the making sense section.

---

10. (20 min) Have groups that volunteer to present, give a short (under 5 min) presentation. Limit presentations to one group from A, B, C, and D, but encourage other groups that also investigated these questions to explain how their findings connected to the other group's.

---

11. (10 min) Summarize the first two conclusion questions for investigation 4 together.

Suggested Prompts:

➔ Many groups discovered that a certain type of bacteria tended to become more and more common in the population under certain environmental conditions. What type(s) of bacteria tended to become the most common in these populations?

➔ If a patient was infected by a population made up of 16 bacteria of that type (decided in previous question), would they be as easy, as hard, or harder to eliminate with antibiotics compared to the population of the 16 bacteria you started with (4 bacteria of each type - 3, 4, 5 and 6 holes)?

Listen for *student responses:*

The bacteria with variations that had less pores (holes) in it become way more common. For example purple bacteria (with 3 holes) becomes the most common (and in some cases becomes the sole remaining variation in the population).
If a patient was infected with 16 of these bacteria, they would be harder to eliminate with antibiotics than the 16 we started with. We can actually test this by adjusting the initial bacteria sliders for one patient vs. another and running the simulation again.

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Suggested summary:

We now have a really odd outcome that we need to explain: Isn't it strange that when we applied something that was meant to kill off a group of bacteria, seemed to actually make the population stronger? We started out with a variety of different bacteria (16 bacteria, 4 of each type), and sometimes we ended up with only one type of bacteria in the end. And when we get infected with those descendants (all being the same type - purple) they are a lot harder to kill with antibiotics now. "How is it possible that applying antibiotics can lead to a population of bacteria developing over time that is more resistant to antibiotics then they were initially?"

Give students a few minutes to individually complete a stop and jot with their ideas in the 3rd question in the conclusions for investigation 4.

---

12. (20-25 min) Again emphasize that this is a really odd outcome that we need to explain: How is it possible that applying antibiotics in the environmental conditions of 4a, 4b, 4c, and 4d seems to lead to a population of bacteria where the most resistant variation became the most prevalent variation (or only variation) in the population? Read through the directions on question 4 of the conclusion section together and have students work in groups to create a model that answers this question.

Two *sample student responses* are included at the end of this lesson. I

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13. (10 min) Have students work either in groups or independently on their responses to questions 5-7. Or if time is limited discuss these questions together. J

Suggested Prompts:

➔ Imagine you want to add a single, completely antibiotic-resistant bacterium to our simulation. Draw a picture of what it would look like. Why would it look that way?

Formative Assessment Opportunities

I Check to see that students are developing a model that includes mathematical representations of their thinking. A larger image of the example student model shown on the right is included at the end of this lesson.

Strategies for this Consensus Building Discussion

J The goal of this discussion around this last page of questions is to help students to start thinking about how the ideas they put together in the previous model could be relevant helping us answer the driving question, could relevant to our petri dish experiments, and could be really useful for our infographics work. This in turn, motivates the next lesson.

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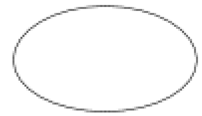
Listen for *student responses* such as:

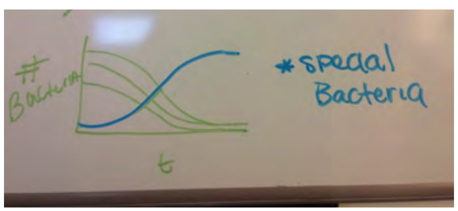
The bacterium looks the same as the others, but it has no holes. We saw that the fewer holes a bacterium had, the more likely it was to survive an antibiotic because it had fewer holes for the antibiotic to get in through and kill it. So if a bacterium had no holes, antibiotics would have no way to get in and the bacterium would be totally resistant



Suggested Prompts:

➔ How would the introduction of a single bacterium of that type into the environment: (a) change overall size of the population of bacteria and (b) change in the proportions of different types of bacteria in the population? (Sketch a graph showing # of bacteria of each type overtime)

Look for *student responses* such as:



Suggested Prompts:

➔ How might what you figured out: a) help us answer our driving question? b) help us predict what might happen in our Petri dishes ? c) help us develop and produce a more effective infographic?

Formative Assessment Opportunities

K Since students had developed their explanatory model for the simulation results in groups, here is an opportunity to

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Listen for *student responses* such as:

Maybe something similar happened in Addie's body (or in other patient's bodies)
Maybe populations of bacteria get more resistant through exposure to antibiotics, because antibiotic treatment ends up killing off the variations that have traits that make it susceptible to the antibiotic (e.g. the structure of their cell membranes).
Maybe we will see something similar happen in our Petri dishes! Maybe they will get harder and harder to wipe out with each application of antibiotic and take over the whole petri dish!
It could be really useful to include these ideas in our infographic to help explain some important reasons (how) for taking all your antibiotics and not taking antibiotics when you don't need to.

Emphasize that it seems like we have some really important discoveries to summarize and add to our driving question board next time, because these could be key to helping us answer the driving question, could be relevant to our Petri dish experiments, and could be really useful for our infographics work.

An optional additional extension activity (Lesson 7 - Extension) is provided in the unit, to give students and teacher an opportunity for individual practice and feedback using the model that students developed in this lesson at the end of this lesson. J

see what students can explain on their own in a slightly different set of environmental conditions.

This extension activity has students apply the model they developed to a related situation to predict and explain what would happen to the distribution of trait variations in a population of simulated bacteria, with no antibiotics and where bacteria need to absorb food particles through their cell membranes in order to have enough building blocks to reproduce.

This can be assigned as home-learning at the end of this lesson., and/or additional time can be set aside in class to have students complete this as an individual assessment. In either case, emphasize to students, that this extension will also help us think more about how a population of bacteria might interact with food in an environment like an infection or in our Petri dishes. This will help establish coherence between this activity and other lessons and investigations in the unit.

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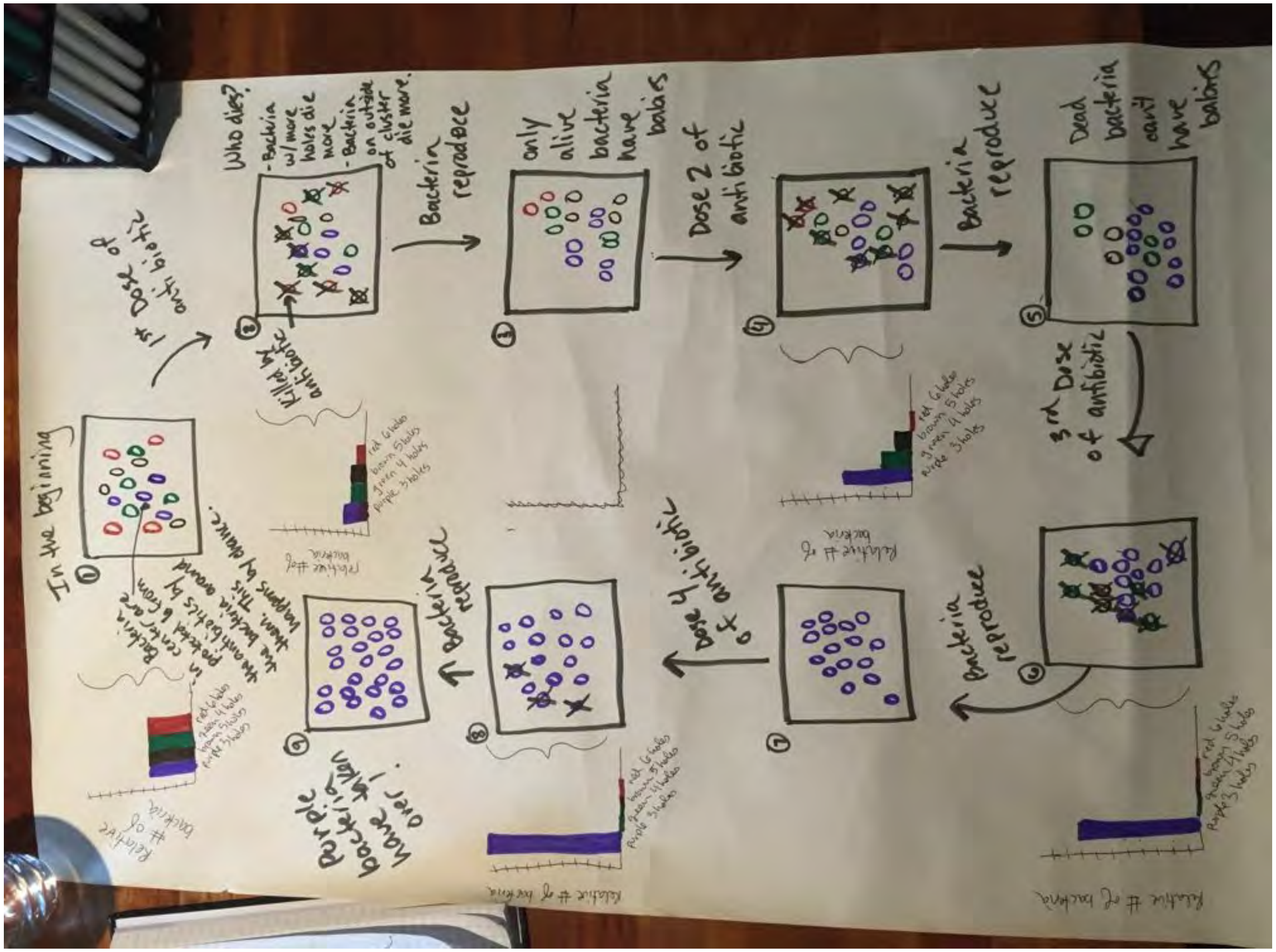
Sample Student Artifact #1



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Sample Student Artifact #2

Alternate sample *student response:*

The purple ones with 3 holes are the ones that are most likely to take over. Here's why.
(Numbers correspond to the numbers in the model) In the beginning, four types of bacteria are present / Percent of the population. I chose to start with 16 bacteria and they are all equal in proportion.
4-Red - 6 holes /25 %
4-Brown - 5 holes /25 %
4-Green - 4 holes /25%
4-Purple - 3 holes /25 %

They are reproducing at a certain rate which is the same for all four types. In other words, green reproduces just as fast as purple, red and brown. In the example here, they double after dose of antibiotics.

Then, antibiotic is given. If the antibiotic gets into one of the holes of the bacteria, it dies. Because there are limited amounts of antibiotics (like only a certain number of dots) and we know that when an antibiotic kills a bacteria, it has to get inside the bacterium and gets used up, then there are only a certain number of bacteria that can get killed with each dose of antibiotic. So the antibiotic can only kill a certain number of bacteria each round. But each type of bacteria has a different chance of being killed based on the number of holes (trait) and the position in the environment. Since the red ones have the most holes - they have the greatest chance of dying because the antibiotic can get into them easier, the brown ones have the next greatest chance of dying because they have 5 holes, then green, and the purple has the least chance of dying because it has only 3 holes, making it the hardest for the antibiotic to get inside. There is one other factor in the bacteria surviving - it's the chance of being protected by other bacteria around them and where the antibiotics are. If a bacterium is more likely to be killed, it is less likely to reproduce. Even though the purple ones are least likely to be killed because of their holes, sometimes the purple ones get extra lucky by being inside the cluster, which makes them really unlikely to be killed. The new proportion of bacteria is something like 13% red, 25% brown, 25% green and 38% purple. I showed these proportions as relative number of bacteria in my graph.

Now there are more purple ones left in the population, about the same of brown and green ones and fewer red ones left. Bacteria that are alive reproduce (dead ones can't reproduce). So they double in this case. The proportion of bacteria stays the same after reproduction.

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Then dose 2 of antibiotic is given. The purple ones have the greatest chance of surviving … least the red so… All (2) Red ones die, 3 brown ones die, 2 green ones die, 1 purple one dies
Bacteria that are left:
0 red left /0%
1 Brown left /12.5%
2 Green left /25%
5 Purple /62.5%

Bacteria that are still alive reproduce:
0 red left / 0%
*2 brown ones (4-3 *2) /12.5%*
4 green / 25%
10 purple / 62.5%

Then dose 3 of antibiotic is given
The purple ones have the greatest chance of surviving still.
All (2)Brown ones die, 4 Green ones die, 2 Purple ones die
Bacteria that are left:
0 red left /0%
0 Brown left /0%
0 Green left /0%
8 Purple /100%

Bacteria that are still alive reproduce
Bacteria that are left:
0 red left /0%
0 Brown left /0%
0 Green left /0%
16 Purple /100%

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Then dose 4 of the antibiotic is given. Some of the purple bacteria die, but only a few because only having 3 holes makes them hard to kill.

Bacteria that are left:
0 red left /0%
0 Brown left /0%
0 Green left /0%
13 Purple /100%

Bacteria that are left reproduce
0 red left /0%
0 Brown left /0%
0 Green left /0%
26 Purple /100%

The red, brown, and green bacteria did not turn into purples. The purple bacteria were always there in the population. The purple bacteria have taken over because they had an advantage against the antibiotics by only having 3 holes, making it harder for the antibiotic to get inside and kill them. The purple bacteria don't always take over, however, because when there are different types of bacteria at the beginning the purple bacteria can get unlucky by being on the outside where antibiotic is more likely to reach them, and all get killed off while other types of bacteria survive.

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Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.

Building Toward Common Core Standard(s)

- CCSS.MATH.CONTENT.HSF.LE.A.: Distinguish between situations that can be modeled with linear functions and with exponential functions.

- CCSS.MATH.CONTENT.HSF.LE.A.1.C: Recognize situations in which a quantity grows or decays by a constant percent rate per unit interval relative to another.

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Lesson 8: What's in Addie's world that is or isn't in our simulation?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been In the last lesson, your students developed a first pass at a model for natural selection using a simulation that allowed them to experiment with some bacteria, antibiotics, and a simulated environment. They figured out that trait variation in a population can have a huge impact on which types of bacteria survive and which are killed off by the antibiotics.

This Lesson....What we are doing now: Students will need to see if this is something that happens elsewhere or if this is something that just happens in bacteria. They will identify what is similar between the simulation and Addie's world, as well as what might be missing or oversimplified. By identifying some of the limitations in observing bacteria directly and limitations of the simulation, you will help students outline the characteristics of a new system whose population is changing over time. This series of lessons will help them observe and investigate some of interactions that they couldn't directly observe with bacteria.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L8: What's in Addie's world that is or isn't in our simulation? (1 period) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	All previous phenomena	**Develop and use a model** based on evidence to illustrate the relationships between components in two systems *(the simulation vs. in Addie's body)* and generalize the components across both systems *(related to natural selection)* to help identify the characteristics of a third potential system to investigate that could address limitations in our current model.	We summarized what we thought the most significant outcomes from the NetLogo investigations were, and then compared the similarities and differences across investigations, and noticed some patterns: • In all investigations there was one initial population that always had variation within that population. • In some investigations bacteria reproduce more offspring if they had enough space. • In all investigations the amount of antibiotics in the environment varied (added at different times and/or different doses). • Applying antibiotic in some situations leads to a population of bacteria that over time is more resistant to antibiotics than they were initially. We made a summary chart of what were some key conditions and outcomes that we know were important parts of both the simulation and what was happening in Addie's case. This led us to recognize some similarities across both systems: • There were heritable variations (different types) in the bacteria population to start with. • The amount of antibiotics and space in the environment changed over time. • Some variations survived more often than others. For example, one variation they possessed granted them a competitive advantage (i.e. a better chance) for surviving over those without this variation when antibiotics were present in their environment. • Survivors can reproduce, passing on their heritable trait variations to their offspring. Dead individuals can't reproduce and so can't pass on their trait variations to anymore offspring. Bacteria reproduce asexually such that the offspring cells will have variations identical to the parent cell (we think). • The distribution of proportions of individuals with different trait variations shifts over time-bacteria with certain variations (more resistance) become more common. Therefore, the bacteria population as a whole becomes more resistant to antibiotics over time in an environment where antibiotics are present. Then we identified some limitations in the model that may be leading us to oversimplify what might have happened in Addie. And let's keep track of any new questions we have related to each of these: • *What are the differences among bacteria?* • *What things in the environment, other than antibiotics, might affect the survival of bacteria?* • *What resources, other than space, do bacteria need?* • *What other things might affect the rate of reproduction or the results of reproduction?* We identified some of the questions that our Petri dish experiments might help us answer, but noted that some questions could not be answered yet.

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L8: (Continued)			Next steps: We decided it might it be useful to study another system besides our Petri dishes, Addie, and the computer simulation in order to answer some of our remaining questions, in light of the limitations we identified. We reached consensus that we want to study an organisms that • is larger • has different "types" and "kinds" • Is interacting or has interacted in its natural environment • Lives in an environment with differences in the resources that it needs to survive (space, food, temperature) • Has other things in the environment that can attack it or can destroy it (even if it is not a white blood cell or antibiotic particles) • Reproduces in a way where we would be able to directly see the offspring after they are born. One potential system of study we came up with was bird populations that live in the outdoors. We think we should start investigating a new system like this next time to help us figure out what, if anything, is missing from our explanation of why bacteria populations change over time (both in Addie and over the last ~60 years)?

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Next Lesson....Where we are going Your students will be introduced to another kind of organism (juncos) that will allow them to work on some of their unanswered questions about changes in the bacteria population in Addie and changes in bacteria populations in general over the last 70 years.

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Getting Ready: Materials Preparation

Materials For Partners

- None

Preparation of Materials (5 min.)

- Prepare a space (dry erase board, chart paper, etc.) to compile student responses about conclusions drawn from the simulation (refer to student handout 8.1 "Connecting to Previous Lesson").
- Prepare a chart paper or word processing document (to be projected) to collect student responses for the class discussion in the Similar/Different Activity
- Class Slides
- Answer Key/Anticipated Student Responses

Materials For Each Student

- Lesson 8 - Student Activity Sheets (1)

Materials shared between classes.

- Clip magnets to hold papers to board and to move them around (if necessary)
- Roll of tape (if necessary)

Safety

- None

Materials per class

- Blank poster papers (3)

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Getting Ready: Teacher Preparation

Background Knowledge

From the FRAMEWORK:

LS4.C: Adaptation by natural selection is ongoing. For example it is seen in the emergence of antibiotic-resistant bacteria.

Cause and Effect: Mechanisms and Prediction Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures. It is also useful to look for similar patterns in different species of organisms for evidence to confirm or revise an explanatory model of a process that occurs in the natural world.

Other information:

Models of all kinds have limitations in how they function to explain a phenomenon. It is both important and valuable to recognize those limitations as it necessitates pursuing additional questions and probing deeper into evidence that may support the development or revision of a model.

Alternative Student Conceptions

Students will come into this lesson having investigated a simulated environment in which they were able to manipulate various conditions and collect data on how the bacterial population changed in differing conditions.

In this lesson, students will be challenged to identify components of a system and utilize that in order to (1) identify gaps in current understanding and (2) demonstrate a need to pursue studying another organism (Juncos).

Students may be unfamiliar with what a "system" is and components of systems. Discussion prompts and teacher supports include guidance on how to scaffold a discussion about systems and use it to pursue other questions.

Linking Our Understanding to Scientific Terminology

- Systems

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Learning Plan: What's in Addie's world that is or isn't in our simulation? (55 min)

1. (15 minutes) As students enter the classroom, ask them to complete the first section on Student Activity Sheets "8.1- Connecting to the Previous Lesson" individually (5 min). Then share them with a partner (3 min). A **Then bring the class together to help students start share similarities and differences across the investigations (7 min).**

Suggested Prompts (these mirror the questions in section 8.1 of the student activity sheets):

- ➔ What was the most significant outcome(s) of investigation 4 compared to the outcomes at the end of investigations 1-3.
- ➔ What was *different* about the conditions between investigation 4 and investigations 1-3 that seemed to have contributed to the significant outcome(s) of investigation 4?
- ➔ What was *similar* about the conditions between investigation 4 and investigations 1-3 that seemed to have contributed to the significant outcome(s) of investigation 4?

Listen for *student responses* that refer to what we have figured out and what we still wondered about last time, such as:

Applying antibiotic in some situations, leads to a population of bacteria that over time is more resistant to antibiotics then they were initially.

One difference was: The amount of antibiotics in the environment changed across all four investigations [investigation 1 had none, investigation 2 had a single dose, etc.. and investigations 3 & 4 (added at different times and/or different doses]

One difference was that when you applied antibiotic less frequently or in smaller doses than in investigation 3, it allows some bacteria to survive (those with certain trait variations) long enough to reproduce.

One similarity in all the investigations was there was one initial population that represented a

Teacher Supports & Notes

Strategies for this Building Understandings Discussion

A As students are writing take a peek at some of the student responses and as students share with a partner listen in. Strategically call on students to share ideas that help foreground some of important similarities and differences between conditions in the 4 investigations: initial trait variation in the population

Call on more than one student to add to the idea that was last stated by another student, or restate or rephrase it. There will be multiple opportunities in this lesson for students to do this in different ways. Try to bring every student into this discussion, as it is laying the groundwork for developing consensus in the rest of the lesson.

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single infection. There were four different types variations of bacteria present in that initial population.
One similarity between investigations 1 & 4, was that bacteria... reproduce more offspring like them if they had enough space.

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3. (10 min) 8.2 -Activity "Our simulation vs. Addie" Tell students that in order to determine how the simulation helps us understand Addie's environment, it may help us to map out what was similar and different about the NetLogo simulation in investigation 4 and what we know about Addie.

Suggested Prompts (these mirror the questions in section 8.1 of the student activity sheets):

➔ As a class, let's make a summary chart of key conditions and outcomes that we know were important parts of both the bacteria simulation and Addie's World.

Start filling out the graphic organizer (8.2 - Addie vs. our Simulation) as a class. Do row one, column B together (class response typed in BOLD), then tell students that we will fill out column C together later as a class. Example response shown in italics below:

A. NetLogo Simulation - Investigation 4 *(System #1)*	*B.* Addie's World *(System #2)*
1. There was one initial population that represented a single infection. There were four different types variations of bacteria present in that initial population.	1. There were... **two different populations of bacteria that infected the patient. Each had a least two types (variations) of bacteria in it (resistant and non-resistant)**

Instruct students to work in small groups to fill out the rest of cells in column A and B for the remaining rows, where there is a "..." in the cell, indicating the need to complete the idea in their own words (as in row 3, columns A and B), or fill in the entire cell with the corresponding idea (as in row 2, column B). Remind students to leave column C blank, as we will decide as a class

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how we want to summarize that column. B **Examples of *student responses* are shown below:**

A. NetLogo Simulation - Investigation 4 *(System #1)*	*B.* Addie's World *(System #2)*
2. The amount of antibiotics in the environment changed over time. The amount of space available in the environment changed over time.	2. ……..*The patient at different times and/or different doses, and using different kinds of antibiotics after each infection.*
3. Some variations of bacteria died off more frequently than others because... *….Some had less holes in the cell membrane that made it harder for the antibiotic to get into.* *...Some were in places that were harder for the antibiotic to get to.*	3. Some of the bacteria died off at first (Addie got better for a bit) because... *...we think there was some similar physical trait variations (armour? = structure of the cell membrane)* *...We know that it was hard to kill the bacteria that were in her lungs even with a blood machine to deliver the antibiotics.*
4. The bacteria that reproduced more were the ones that…. survived *more (and had enough space).*	4. Some bacteria reproduced more (after the initial antibiotics treatment). We know this because ... *...her infection got worse after initially getting better and then it spread to other parts of her body (boils etc..).*
5. The bacteria population seems like it is changing by... *...There is a shift in the distribution of traits in the population with each new dose resulting in a higher and higher % individuals with fewer pores in the cell membrane /* *...The later population is more antibiotic resistant than the initial population was.*	**5.** ….*The doctor's eventually say that the type of bacteria remaining in Addie's body is pan-resistant (whereas earlier in her infection there must have been some that were not - they were killed by the different antibiotics).*

Differentiation Strategies

B Seek out small groups with members who may not have shared their ideas publicly yet and join in their conversations as they complete a row of the table. Select students you haven't heard from to help prime them for being willing to go public in the next Consensus Building discussion (in the next part of the lesson) by:

1. asking different group members to articulate what is similar between Addies World and the NetLogo simulation (this will help students practice articulating their first draft ideas they have on that question)
2. Following up with reinforcement like, "that is a really cool noticing. Would you be willing to share that in a little bit with the rest of our class when we talk about what we want to put in column C as a whole class?"

This process can help students try out their ideas in a smaller group setting, get positive feedback on the value of the idea, and have time to get themselves ready to go public to the whole class with that idea. In particular, pay attention to the net logo column box 5. We really want students to flesh out what they are considering a change in the population. Hopefully students will see that

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4. (10 min) After students have worked in pairs or small groups to fill in their graphic organizer for column A and B, call everyone's attention for class discussion. Direct students to look at column heading C. C

Suggested Prompts:

- ➔ You'll notice your graphic organizer uses the term "system"(referring to the column C of your graphic organizer). Before comparing both systems, let's talk about what we mean by a system. If I compared two different home entertainment systems, that different people have in the homes, what are some parts or components that I might expect to find common to both of them?
- ➔ How do these parts work together? What outcome is similar in both, when the parts of these system work together?
- ➔ If I compared the circulatory systems of two different animals (a cat and a dog), what are some parts or components that I might expect to find common to both of them?
- ➔ How do these parts work together? What outcome is similar in both animals, when the parts of these system work together?

Listen for *student responses* such as:

There might be a TV or monitor in both. Probably speakers in both. Maybe other things like cables and cords, gaming devices, etc
The parts work together to display images and sound to entertain you.
There probably is blood, a heart, tubes that carry the blood around the body (e.g. veins, arteries, capillaries).
The parts work together to move blood around the body to carry food, water, oxygen, waste to and from the cells of the body of both animals.

Summarize the idea that systems have multiple parts working together, and the way these parts work together produce certain outcomes. Emphasize that thinking of any process, or thing, or a

the bacteria themselves are not magically changing, but rather there is a shift in allele distributions in the population which changes overtime.

An additional strategy that may be useful is to have students share what their PARTNER told them, not what they wrote on their papers. This assists in facilitating discussion because students know they will be held accountable for the ideas their partner shared with them. In turn, they will be more engaged listeners and more active classroom discussion participants. This type of discussion also lends itself nicely to talk moves such as "Do you agree with what he/she said? Why or why not?" or clarifying questions such as "Is there anything you misunderstand about what he/she said?"

Supporting Students in the Crosscutting Concepts

C The objective of the similar/different activity, and the subsequent discussion, comparing Addie's world to the simulated environment is to have students identify commonalities between the two systems. In identifying things that are similar among the systems, students will be identifying components of a system. The goal of this particular discussion is twofold. (1) Using the language of "systems", help students to

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set of things like as a system, often allows us to see how parts in other systems might work together in similar ways. Ask students for what is common between the two systems (the computer simulation in investigation 4 and Addie's world). Record column C together publicly on a projected word-processing document, chart paper or overhead that is identical to the organizer in their handout. Listen for and summarize *student responses* such as: D

C. Conditions or Outcomes Common to both Systems
1…. *There was heritable variations (different types) in the bacteria population to start with.*
2…. *The amount of antibiotics and space in the environment changed over time.*
3. ...*Some variations survived more often than others because….* *… a trait variation they had them granted a competitive advantage (better chance) for surviving over others when antibiotics were present.* ** Differences across local environment conditions also contributed to giving some individuals a better chance of surviving.*
4…. *Survivors can reproduce, passing on their trait variations to their offspring if they have enough space.* *Dead individuals can't reproduce and so can't pass on their trait variations to anymore offspring.* *We think that if bacteria reproduce asexually, that the offspring cells will have variations identical to the parent cell.*
5…….. *The distribution of proportions of individuals with different tait variations shifts over time - bacteria with certain variations (more resistance) become more common.* *...The bacteria population therefore as a whole, has become more resistant to antibiotics over time in an environment where antibiotics are present.*

build a working understanding of what a system is and components within one. (2) Use evidence from the simulation to generate or build upon previous understandings of Addie's system.

Strategies for this Consensus Building Discussion

D The goal of this discussion is to have students pull together the main ideas from using the NetLogo simulation and begin to start thinking about how those ideas help us to connect back to Addie's situation. At this point we should have a number of questions still on our Driving Question Board about Addie and how her interactions with the environment caused her to get sick. You will get to the differences between Addie and the simulation next. At this point, you want help students see that there are similar conditions and outcomes in our simulation that help us explain Addie's situation and that may be applicable to other situations beyond just this one patient.

It may be helpful to record student ideas publicly on chart paper, a dry erase board, or overhead to help facilitate this discussion. Making ideas visible for other students as they are shared may assist them in participating in the discussion.

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5. (10 min) Introduce section 8.3 as another part of doing systems thinking. Record a few of the questions that students pose for each part of the system on a piece of paper to add to the driving question board.

Suggested Prompts (this mirrors the question in section 8.3 of the student activity sheets):

- ➔ Comparing the simulation to Addie's environment helped us to identify elements common to both systems. Though this helped us seem similarities, let's now identify some limitations in the model that may be leading us to oversimplify what might have happened in Addie. And let's keep track of any new questions we have related to each of these. What limitations were in the model that didn't fully capture what might be going on with Addie? What remaining or new questions do we have about
- ➔ (1) differences between bacteria?
- ➔ (2 & 3) other things in the environment, besides antibiotics, that might affect the survival of bacteria?
- ➔ (2 & 3) Other resources, besides space, that bacteria need?
- ➔ (4) other things that might affect the rate of reproduction or the results of reproduction?

Listen for *student responses:* E

What exactly is different between 2 kinds of bacteria (staff vs. .) vs. two type of bacteria for each kind in Addie (or other patients who get other kinds of infections)
Why are some differences in bacteria, differences in "type" but others are differences in "kind".
How different do things need to be, in order to be considered a different kind rather a different type, but the same kind?
We need to think about the playground and the hospital because Addie got bacteria from both of these places. Are there other things in those environments that are important difference? Light, temperature, other organisms?
We don't know if in the world the reproduction rate of all of the bacteria was the same. Maybe the

Additional Guidance & Possible Student Responses

E The objective of this discussion is to elicit the idea there is still a lot we don't know about Addie. The simulation helped us, but we have some limitations to that as well. Thinking about questions we still have about Addie helps us to identify we need more.

There is an teacher support document (Lesson 8.3 - Additional Teacher Support) to help think about possible student responses that will be helpful for driving this unit. You may only get subset of these questions and responses. That is ok.

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bacteria that was bad for Addie survived but reproduced at the same rate. Or, maybe they had a faster reproduction rate?
We don't know what might limit bacteria growth in Addie, including resources available to the bacteria in her body to keep them growing. If bacteria takes up space in her thigh and lung.
We don't know the resources that the bacteria depend on, that are in Addie's body. (We think bacteria must be getting food in Addie, because our bacteria in petri dishes needed a source of food.)
We don't know what happens over timescales that are longer -- how is it different now than in 1944, when the antibiotic would have worked.
How do things in Addie's body (like white blood cells) that do (or don't) attack the bacteria affect the outcome in a patient?
How does the temperature of the body (a fever as a response to help fight infection) affect the outcome in a patient like Addie?
How would the amount of food in the body (or in the petri dish) affect survival and reproduction?
Does blood flow and/or what the patient east affect the survival and reproduction of bacteria cells?
Are all bacteria really reproducing at a constant rate in Addie (or other patients)?
Do things like food, water, temperature affect bacteria growth and be another reason the antibiotics can't keep up in Addie?
Are offspring of bacteria really exactly identical to the parent bacteria?
Are their other traits (besides cell membrane structure) that are heritable in bacteria that would help explain why the population changed?

Then have students identify which of these limitations or questions does it seem our Petri dish experiments will help us address or answer? Put a star near those questions. And identify, "Which of these questions does it seem really unlikely that our Petri dish experiments will help us answer?" Circle those.

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6. (8 min) Motivate the idea that we might need to study another system in order to answer some of our new questions and/or to address some of the limitations we have identified.

Suggested framing: "When scientists encounter these sorts of limitations, they often select a different system to investigate where they hope to see certain interactions within the system more easily. Suggest to students that we might need to do a comparison study to better answer our remaining questions. As a class, let's brainstorm our ideas for a new study in a Comparison Study Criteria Poster."

Suggested Prompts:

- ➔ Why might it be useful to study another system besides our Petri dishes, Addie, and the computer simulation in order to answer some of our remaining questions, in light of the limitations we identified?
- ➔ Why might it be useful to study a larger organism instead of bacteria? What sort of similar interactions with its environment would we want to be able to observe?
- ➔ What about time scale (perhaps refer to DQB)? Does our bacteria simulation account for us figuring out why antibiotics don't work like they used to 70 years ago? What could be helpful

Listen for *student responses:* F

Accept all responses.

As class build a list of the criteria that lists version of the following five things:

1. ***There are differences in types (and kinds) of this organism in the population(s).***
2. ***The environment(s) the it lives in has differences in space, food, temperature . We want to be able to see it interact with the environment up close.***
3. ***There might be other things in the environment that interact with organisms that affect its survival (besides antibiotics or antiseptics). We want to be able to see these interactions up***

Strategies for this Building Understandings Discussion

F Students will probably say bacteria are small, and in a complex environment like the simulation, may be hard to keep track of. It may be easier to look at something larger, more macroscopic. We also want to draw their attention to previous discussions we've had about bacteria having different "types" and "kinds". In order for looking at another organism to be useful, we need to make sure there are some common elements among whatever we choose and bacteria.

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close.

4. ***When they reproduce we can see their offspring after they are born.***
5. ***We need to look at differences in populations over a longer time span than a few days/weeks.***

Add these five ideas on a piece poster paper labelled "Comparison study Criteria". G **If time permits, have students record these in the last page of their student activity sheets at the start of their Home-learning section. Or alternatively post a photo of this or have students take a photo (using their tablets, ipads) to refer to for their home-learning tonight.**

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7. (2 min) Tell students we've reached consensus that looking for similar patterns in another organism would be helpful in answering questions we still have about Addie.

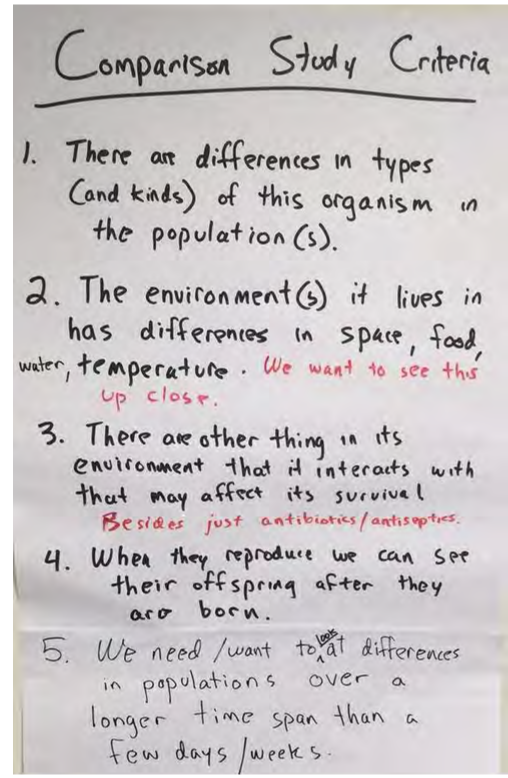
Home learning: **Have students brainstorm in section 8.5 of their handout other candidate organisms that could help us answer more of our questions that might meet these criteria. Remind students of the previous discussion in which we identified it would be helpful to look at something larger, that has different "types" and "kinds", and is interacting or has interacted in its natural environment around us. These brainstorm ideas will be used to facilitate discussion in which birds are one possible candidate, to motivate using Juncos as a new phenomenon to investigate.**

Suggested Prompt:

➔ Some of us have been wondering if these things we have identified about bacterial populations are true in other populations as well. For your home learning, identify what other sorts of organisms are out there that a) have different "types" and "kinds" b) are easy for us to see (larger organisms) interacting with the natural environment in our world around us? Write these ideas down at the end of section 8.5 of your student handout for home-learning tonight.

Mock-up of Classroom artifact

G An example poster is shown here. Students will need to reference this in their home-learning assignment tonight and in lesson 9.



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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 9: Can studying some other creatures help us figure out what we think is missing from our explanation for why bacteria change over time?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been In the last lesson, your students learned that the simulation only went so far to answer the questions about what was going on in Addie. So they decided to study a different population of a larger organism in a new system whose interactions with its environment are easier to directly observe.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L9: Could studying some other creatures help us figure out what we think is missing from our explanation of why bacteria have changed over time? (1 period) *Building toward* *NGSS PEs: HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	A video clip on juncos provides footage (and some descriptions) of them in an environment (a college campus in a city) that they stay in year-round now, but that they used to only visit in the winter in the past (and then would return to the mountains in the spring). Patterns in the reproduction rate between the populations are seen across 3 different data sources.	**Ask questions** that arise from careful observation of *patterns in the behavioral and physical traits of juncos on the UCSD campus vs. juncos in the mountains* to determine if this phenomena meets our criteria for a *comparison case study*.	We remind ourselves of what our criteria were for selecting a new case study to look at and decided that birds were one viable candidate. We are introduced to a new organism (juncos) in a video and we notice some initial patterns in this system and population: • The first noted citing of juncos on the UCSD campus was in 1983. • Some juncos have been staying at UCSD starting in the 1980s to reproduce year-round instead of flying back to the mountains to reproduce like their recent ancestors did. • There are some obvious environmental differences between the city and the mountains - the UCSD juncos live in the city with noise, artificial light, cars, and many students which are largely absent in the mountains The campus area may have been unsuitable for breeding before the campus was built there. • Juncos seem to be interacting with lots of things in their environment on the campus (water, food sources, humans). • We're told that the area between the mountains and campusisn't suitable for year-round living. When we think about all the things we noticed that are different between UCSD juncos and mountain juncos, it seems like anything that has changed about them has happened over a few decades. The changes in antibiotic resistance have also occurred from 1940s to 2010s, so maybe the relative similarities in the timescale can help us draw some comparisons between what caused the type of changes that emerged in the bacteria and the juncos. Before diving into this case in depth, we would like more information about these birds to make sure they fit our criteria. We will look at three other pieces of data related to this case as part of our home-learning.

Next Lesson....Where we're going Now that your students have decided that the differences between the city and mountain juncos meet many of the criteria they identified for studying a population easier to observe interacting with its environment than bacteria, they will investigate what might be responsible for those differences. Students will use information they analyze from their home-learning assignment (which they complete before the next lesson) and their ideas about what might have caused these differences, to motivate taking a closer look at how these environments are different and what those differences mean to the juncos.

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Getting Ready: Materials Preparation

Materials For Each Group

- None

Preparation of Materials (15 min.)

- Need a LCD projector and computer to preview Junco Video (Do NOT show title "Evolution in Action." Be sure to click full screen before showing video to students). Start video at 0:08 and run to 6:21 and then skip to 8:04 and run to 10:00. Then stop.
- Create a set of materials for each group of 3 students in advance.
- Post "Notice and Wonderings" chart from previous lesson.
- Class Slides

Materials For Each Student

- Lesson 9 - Student Activity Sheets

Safety

- None

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Getting Ready: Teacher Preparation

Background Knowledge

From the FRAMEWORK:

- **LS4.C:** Adaptation by natural selection is ongoing, and genetic variations among individuals in a population survive and reproduce and others do not (this is what we are starting to see in our bacteria/antibiotic investigation). Natural selection changes the proportions of individuals with particular traits over time (like we saw in the simulation).
- **Cause and Effect: Mechanisms and Prediction** Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures. It is also useful to look for similar patterns in different species of organisms for evidence to confirm or revise an explanatory model of a process that occurs in the natural world.

Alternative Student Conceptions

Students will come into this lesson having investigated a simulated environment in which they were able to manipulate various conditions and collect data on how the bacterial population changed in differing conditions.

In this lesson, students will come to identify an organism (Juncos) that can be studied in nature and begin to identify specific characteristics that have changed over time due to environmental factors.

Students may be unfamiliar with what a "system" is and components of systems. Discussion prompts and teacher supports include guidance on how to scaffold a discussion about systems and use it to pursue other questions.

Linking Our Understanding to Scientific Terminology

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Lesson 9: Can studying some other creatures help us figure out what we think is missing from our explanation for why bacteria changes over time? (26 min)

1. (5 min) Building Consensus, group discussion: A **As students walk in have them get out packet 8.1, from the previous day, and start to share their brainstorming ideas from the last section (8.4) in small groups. Remind students that they are looking for an animal that they can study in order to make some comparisons to the bacteria investigation. After a few minutes have them share their ideas as a large group discussion.**

Suggested Prompts:

➔ What were some of your ideas, what animals do you think we could study in order to make some comparisons to the bacteria investigation?

➔ What animal do you feel would be easy to study in its natural environment that we could compare to our bacteria experiment?

Listen for *student responses* such as:

Targeted and potential student responses:

Some of us thought that it would be easy to compare dogs or cats (or other animals) since many of us have as pets and they demonstrate variation and are larger than bacteria. B

We think it would be easy to study animals we see everyday like squirrels (this may vary depending on location). We have noticed a lot of squirrels living around our school so we could look at those.

Students may bring up birds. Because the introduction of juncos follows, have students expand their thinking through discussion about why looking at birds, or a certain type of bird, may be

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A The goal of this discussion is to put students in the driver's seat and give validation to their ideas. It also give you an idea of what they are thinking and if they understand that they will need to look at the whole population in nature and not just a solitary or small group of animals.

Additional Guidance

B Domestic animals are not functioning in an environment that would influence their population change so that would be exclusionary criteria for household pets. As student responses are shared, make sure to continuously refer to criteria generated from the discussion above if necessary. Emphasizing the "interacting with the natural environment in our world around us in ways that affect its survival or has differences in food/temperature/water," may, or may not, elicit a response about birds, or a particular type of bird.

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helpful. C

As students voice their ideas start a list on the board as this gives students validation. At this point if someone has mentioned birds you can switch your discussion focus in order to lead students to the understanding that birds would be the best animal to study. If no one has mentioned using birds yets you will need to guide your discussion to include them as a possible candidate, "Nice ideas, and I can tell you all put a lot of thought into your ideas, but let's think about what our goal is; why did we want to look at an animal in the first place? What criteria did we decide we needed our animal group to meet?

Listen for *student responses* such as:

We want to study something we could actually see. Bacteria is really small and we can't see it or see what it does. We thought if we studied an animal we could watch what it does, see its offsprings, and/or see if it has changed over time, like we think the bacteria is doing.

Share with students this idea and ask this question: "Animals have been used in studies like these for a long time, but when deciding which animals to study we need make sure we can observe them in their natural environment. With this in mind let's take another look at some of the animals on our list. Many of you mentioned animals that you have as pet, would these be good animals to do this kind of a study on? Why?"

Listen for *student responses* such as:

We thought it would be easy to study an animal we already have, but no one in the class has a large group of cats or dogs (or other pet) that run around in their natural environment. We thought maybe we could use squirrels, deer, or birds. Could we use one of those animals?

Make sure you acknowledge all of their ideas, but lead the discussion to the conclusion that birds[2] would at least be a viable candidate for investigation. You could even discuss the amount of information that is readily available because of hobby birdwatching and other websites like

The idea of this discussion is to get students to generate ideas about observing other organisms and use those ideas to provide motivation for at least taking an exploratory look a bird population, like the Juncos. Students will figure out (in this lesson and the next) that the Jucos population will turn out to meet all the criteria we have identified.

Additional Guidance

C If student responses do not include anything about birds, be sure to honor how their contributions met some of the criteria. For example, "Dogs is a great idea, but their environment is more or less domestic and controlled by their caretaker. Did anyone else think of an organism that is maybe in a more natural environment?"

If students struggle to get to birds you might want to ask them about animals they can see on a regular basis that they know always return to their 'home'. Most student will be familiar with birds building nest or might watch the same birds visiting feeders.

If student responses do include something about birds, or a particular type of bird, this is the time to bridge to Juncos. You could say something like, "It is interesting you

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Birds in Backyards.

2.(8 min) Frame the motivation for showing the video clip by saying: "Since we have come to the conclusion that birds could be one possible candidate, I have have found a case study the we could evaluate to see if it meets our criteria. Let's take a look at this video so we can make an informed decision. As you watch the video please record noticings and wonderings and be prepared to discuss them after the video." **Then show the video clip.**

3.(10 min) Have students compare the notice and wondering in their table groups, but after 5 minutes, pause their discussion and ask them to identify some of the criteria we had for our comparison study, from the last lesson, that this case looks like it might potentially meet. Remind students to look back at lesson 8 (last page of the student activity sheets) or at the Comparison Study Criteria poster in the classroom.

4.(10 min) Building Initial Ideas Discussion: Have students share out some of the criteria that it looks like the case might meet. Put check marks these off on the Comparison Study Criteria poster.

Large Group Discussion: Have groups share out their noticing and wondering with the whole class. As students share their ideas post them on the board or chart paper as we will need to return to them in the next lesson. C

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5. (5 min) Next Step: Point out to the students, that these fantastic initial observations and questions can help us take a first pass on deciding if this case might meet the specific criteria we

brought up birds, because I was thinking the same thing.

Strategies for this Initial Ideas Discussion

C In this discussion it is important to list all of the groups noticings and questions as this will allow for a deeper discussion in the next lesson. This will also allow you to see what the students are thinking in order to guide them to look more in depth at specific environmental factors that may cause a population to change, during the next lesson.

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decided on for our comparison study.

Summarize some of the criteria we wanted this case to meet related to reproduction. Have the students add those to their activity sheet.

Suggested Prompts:

➔ What "What was it about reproduction that we wanted to investigate in this new case? What criteria were we looking for related to it?

➔ Do we know, for sure, yet whether these Juncos will meet our criteria for this?

➔ What additional data would we need to determine whether it meets the part of criteria related to reproduction (#4)?

Take a few responses and then explain that you have a few more pieces of data that might be helpful to evaluate in order for us to determine this.

Assign students the home-learning activity. In this, you would like them to analyze additional data about these Juncos for a home learning activity to answer the question, "What does this additional data on the Juncos tell us about whether it would be a useful comparison study?"

Point out to students that the home-learning section is part of end of the activity sheets for this lesson. Let student know what they figure out from the home-learning will be things we will want to share out at the start of class discussion tomorrow.

Help students transition back to checking in on their bacteria experiments, "Now that we have come up with some initial ideas about what is happening with the birds and are excited to see what is going on with them, we can not forget about our bacteria investigation. It has been a few days so we will need to check them today and see what we find, are they doing what we predicted? "

Have students get out their investigation packet (or notebook) and transition to lesson 5d.

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 5c: What's happening with our antibiotic experiment?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been: Students were introduced to a new organism (juncos) and determined that it will be a good comparison study to be able to observe traits and interactions with the environment, than with something microscopic like bacteria. In lesson 5b, students decided they needed to re-plate their bacteria into another dose of antibiotic in order to figure out what was happening in Addie's case with her antibiotic treatments.

This Lesson....What we are doing now: Students will continue to carry out their investigation, make observations and record their data about the bacteria population exposed to another round of antibiotics. They will find that in some cases the inhibition zone is getting smaller, but in others it is staying the same. They will decide that they need more data, and will replate the bacteria, giving it another dose of antibiotics and make another round of predictions.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L5c: What's happening with our antibiotic experiment? (15 min) *Building toward* ↓ *NGSS PEs: HS-LS4-2, HS-LS4-3, & HS-LS4-4*	Results from previous experiment set up in lesson 5b.	**Carry out an investigation** to produce data to provide evidence to help explain why *some lines of descendants of a population of E.coli bacteria growing in different parts of a Petri dish (different environments) appear to be growing further and further into a zone of higher concentrations of antibiotics after each additional dose (patterns)*.	We take a picture of our Petri dishes and measure the inhibition zone in centimeters. Whoa! It seems like the inhibition zone is getting smaller from what is was previously. *Will this trend continue? What does this mean for our bacteria if the inhibition zone is shrinking?* After having a class discussion, we made predictions about what it might mean if the inhibition zone is shrinking. Some of us think this means the bacteria are getting used to the antibiotics - *but what does that really mean? Some of us think that we are seeing more bacteria become resistant to the antibiotics! How can this be? Is this just like what happened to Addie?* **Next steps: We want to continue comparing bacteria close to the inhibition zone to the bacteria far away from this zone. We select bacteria close to this zone and re-plate them in a new Petri dish with fresh antibiotic at the same concentration used previously. Then we also select bacteria far away from the inhibition zone and follow the same procedure as noted with the bacteria close to the zone.**

Next Lesson....Where we're going Student will use information they analyze from their home-learning assignment in lesson 9 (on reproduction) and their ideas about what might have caused these differences to motivate taking a closer look at how these environments are different and what those differences mean to the juncos.

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Getting Ready: Materials Preparation

Materials For Each Group

- Agar plates from 5b
- Agar Petri dishes (6)
- Cotton Swabs (6)
- Filter paper (1)
- Hole puncher (1)
- Tweezers (1)
- Masking Tape (1)
- Sharpie (1)

Materials For Each Student

- Lesson 5c. - Student Activity Sheets (1)
- Pair of gloves for each student (1)

Preparation of Materials (15 min.)

- New Agar Petri Dishes - to be prepared and stored ahead of time
- Incubating Agar plates from lesson 5b - look to see if there are any groups with colonies growing inside the zone of inhibition. This will be an observation we want to make sure students pull out. If there are none yet, that is fine.
- Ampicillin mixtures
    - 1mg ampicillin mixed with 10ml water
    - 3mg ampicillin mixed with 10ml water
    - 5 mg ampicillin mixed with 10ml water
- Post Student Investigation Sheets (Safety Guidelines) on lab tables
- Class Slides

Safety

- Lab safety is everyone's responsibility. We must take precautions especially when working with live bacteria samples. Make sure that when we work with these samples that we keep them contained and that we are not exposing them to ourselves or the environment. Remember that we are looking for answers as to how bacteria become antibiotic resistant so we do not want to introduce one of these bacteria into the environment by accident.
- Don't even think about having food or drink in the lab space
- Clear your lab space and wipe it with disinfectant
- Put on gloves and safety goggles
- Leave everything at your desk, you don't want to risk getting our sample on your pens, pencils, or anything else
- If you should have an accident please get your teacher right away
- When you are finished you will need to put your tweezer in the disinfectant and dispose of your swabs and any other paper product you may have used in the BIOHAZARD bag
- Spray your table with disinfectant and wipe it down
- Remove your goggles and put them in the cabinet to be disinfected
- properly take off your gloves properly and dispose of them in the BIOHAZARD bag.

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Getting Ready: Teacher Preparation

Background Knowledge

LS4.C from the FRAMEWORK:
"Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions."

- Our investigation of bacteria that are resistant to antibiotics is the entry point for students into the concept of adaptation by natural selection. Those bacteria that are resistant to antibiotics are killed, while those that are resistant can reproduce and pass on their resistant alleles.
- By introducing the Juncos we have brought up the idea of environment. Students can see how the environment affects the birds, but could environment affect our bacteria. Although our bacteria is growing in a small contained space we need to consider that there are different environments within the Petri dish. In this respect our original environment would be the Petri dish with only E.Coli and our new environment would be the introduction of the antibiotic.
- What students are seeing is natural selection in action, they might not recognize it yet but they can relate to the fact that something is changing - the environment has changed in both examples and thus the allele distribution in the population changes overtime.

Alternative Student Conceptions

Students may be unsure if there is anything different about the bacteria left near the zone of inhibition as opposed to farther away from it. Use this uncertainty to guide them to needed to conduct additional experiments to see selection at work.

Linking Our Understanding to Scientific Terminology

- Trend

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Learning Plan: What's happening with our antibiotic experiment? (25 min)

Teacher Supports & Notes

1. (5 min) Re-engage students in our bacteria/antibiotic investigation by saying, "In our last lesson we were introduced to Juncos, but we don't want to lose sight of our ongoing bacteria investigation. It has been a few days since we replated our bacteria so let's check in to see what the data show."

Have students independently take a few minutes to review what we are trying to figure out in this investigation by answering questions 1 and 2 in their Student Activity Sheet 5c.1.

Suggested Prompts taken directly from the activity sheet:

- Why did we decide to replate the bacteria during the last investigation?
- What are we looking for in our plates, and what do we think we will see?

Listen for student responses such as:

- We thought we needed more information to figure out what was going on with Addie so we wanted to continue our experiment. We wanted to figure out if the different concentrations of antibiotics killed more bacteria, we thought that maybe Addie needed to be treated with a stronger antibiotic. We think that the stronger concentration of antibiotic will keep killing more bacteria but we want to test it again to see for sure.

- When we looked at our investigation the first time we noticed that there were places where bacteria didn't grow, we think the bacteria close to where we put the antibiotic is weaker and does not grow as fast as the bacteria that is around the outside. so we decided to see if the bacteria was changing depending on where our sample came from. We wanted to see if the bacteria around the outside of the petri dish (away from the antibiotic) were the same as the bacteria growing around the zone of inhibition.

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2. (10 min) Give students an opportunity to document and record their bacteria/antibiotic investigation on the data table they created on Student Activity Sheet 5a.1 and transition into a brief Building Understandings Discussion in Small Groups by answering and discussing questions 3-4 on Student Activity Sheet 5c.1 (5 min). A

Listen for student responses that refer to what we see in the investigation, such as:

- ➔ We see that bacteria grew in some places in the dish, but not others. There still seems to be a ring around the antibiotic filter paper where no bacteria is growing, but the size of the ring is smaller than the first time from the sample we took from around the zone of inhibition for the bacteria we cultured close to the last ring of inhibition. The size of the ring is still bigger with the higher concentrations of antibiotic, but these are a still smaller than in the first trial at least with the culture we grew from the zone of inhibition.
- ➔ The size of the zone of inhibition that we plated using a sample from the outside rim of the Petri dish (away from where the antibiotic were dropped) are still almost the same size as the original plates. So, it seems like the ring of inhibition seems about the same, but it's really too hard to exactly tell.
- ➔ We think the antibiotic is spreading out like we thought (concentration becomes less as it moves away from the disc) just like the concentration become less as it travels through our bodies, but we noticed that the zone of inhibition is not as big as it was before so maybe it is not working as well as it did the first time.
- ➔ We think the antibiotics are not working as well or maybe the bacteria that we used from the different parts of the petri dish are different somehow. We know that something is going on, but we are not sure what is going on because not all the zones of inhibition are getting smaller.
- ➔ We think the bacteria growing around the outside of the Petri dish is different than the bacteria growing around the zone of inhibition, we think maybe is has something to do with the antibiotic not spreading all the way to the edge of the dish

Strategies for this Building Understandings Discussion

A Our goal here is to guide students into noticing the patterns that are starting to emerge in their data. This will eventually allow them to see the cause and effect relationships between bacteria and antibiotics that lead to antibiotic resistance, which will give us more insight into why Addie's treatment is not working. Noticing patterns is vital in scientific research, however we want students to start to see these patterns on their own. Using this data along with the looking at the patterns in Junco behavior help to reinforce this cross-cutting concept but also allow for students to use understand patterns through different lenses.

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- ➔ We know that that the antibiotics spread out from the disk, we also know that it doesn't reach all the bacteria - just like in our bodies, and that is why we have to keep taking antibiotics until they are gone. We think maybe we have two different environments in the dish and some bacteria is changing because where they are growing in the dish. Could this really happen?

Students should start noticing some patterns in their data. Some students will also bring up some noticings about cause/effect relationships. It's okay if their ideas are only partial understandings at this point.

Next, we want to guide them into determining that they should replate the bacteria again to see if the current trend in data continues (5 min).

Suggested Prompt:

- ➔ Are two data points enough to get a clear understanding of what is happening in our investigation? Do we need more data?

Potential student response:

- ➔ We think we need more data to see if the zone of inhibition will keep getting smaller. If we have more data maybe we could figure out an explanation of why antibiotics are not working for Addie

Students should notice that the samples cultured from different places are different from each other, but it might be difficult to detect any difference just yet. The cultures grown from far away from the zone of inhibition should result in similar zone of inhibition as the first trial. The cultures grown from around the original ring of the zone of inhibition from Lesson 5b should result in a decrease in zone size.

This discussion should lead into the class deciding to replate again since it might be too hard to tell what's going on. We want to know if the inhibition zone is really decreasing, will this trend continue? A suggestion is to replate from the three cultures (one from each antibiotic

Differentiation Strategies and Alternate Activities

B Depending on space and materials you may choose to continue this investigation in several different ways, some other ideas include:

- To replate from the zone of inhibition and the outside of each plate and continue to record data from each plate. Plate use would be exponential.
- Have each lab group only replate one or two of the antibiotic concentrations and then share their data with the rest of the class *note that the most dramatic results will come from replating the lower concentrations
- If you have multiple classes, have each class work with a different concentration and share data across all the classes.

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concentration) and their control group, a swab away from the zone of inhibition. B

This would mean replating six dishes: Dish 1.) 1mg zone of Inhibition (ZOI); Dish 2.) 1mg away from ZOI; Dish 3.) 3 mg ZOI; Dish 4.) 3mg away from ZOI; Dish 5.) 5 mg ZOI; Dish 6.) 5mg away from ZOI

When we go to replate we will only take samples from the three samples that were grown from the ZOI (dishes 1, 3, and 5) From these three plates the students will again grow bacteria cultures from around the outside of the Petri dish and from around the zone of inhibition.

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3. (5 min) Carrying out an investigation: Have students prepare the new plates in their groups. The procedure should be the same as in Lesson 5a, except the bacteria will come from the plates indicated above. Again we want to plate samples from around the zone and from around the outside in order to try to figure out if the decreasing ZOI trend continues and why would that be happening differently with the bacteria cultured close to the ZOI compared to the bacteria cultured far away from the ZOI. C

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4. Assign the Home-learning section of the student activity sheets D **But, if time permits, before dismissing students, ask student to predict what will happen with the ongoing re-plating experiment. Students may want to adjust or add to their original drawing they made on the 5a.1 activity sheet (or they may add another sheet to this). Then have them answer the following prompts either on an additional sheet or in their science notebooks**

- **How has your hypothesis changed based on our new evidence?**

Look for student written responses to refer to what we see in the investigation, such as:

➔ New evidence shows that the zone of inhibition got smaller when we replated using a bacteria

Strategies for this Building Understandings Discussion

C If students come up with the idea that the population of bacteria is changing we need to use questioning to gain a better perspective of what they are thinking. Why do they think the bacteria is changing? It's important to separate out if they think the actual bacteria themselves are changing (partially incorrect explanation) or if they think that the population of bacteria at large is changing (Some bacteria are resistant to the antibiotic. Those bacteria survive and pass on genetic info to the next generation. The bacteria that cannot survive the antibiotic die off and don't reproduce). We want to understand if their thoughts are based on what we have figured out, background knowledge, or something else. To understand more ask questions about why and how they think the bacteria is changing. Have students explain their using talk moves. At this point it is the student's responsibility to reason this out, and your responsibility to help them make their ideas public and clarify their thinking regardless if their ideas are correct or incorrect.

Formative Assessment Opportunities

D Although students are still uncertain of how antibiotic resistance occurs, we want them to start reflecting on how new

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sample taken from around the zone. The zone of inhibition stayed the same when we plated using bacteria from around the outside of the plate.

➔ Even when you use a higher concentration of antibiotics the zone still got smaller in one of the cultures. This tells me that maybe the concentration might not be as important as we think.

➔ New evidence shows that some zones are getting smaller, but some are not.

evidence might impact their original ideas. By having students adjust their original predictions this could give us insight as to how our students are incorporating new ideas into their thinking. It also allows us to see if they are making those important connections in order to build upon their original ideas.

Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

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Lesson 10: What is different about living in the city vs. the mountains from a bird's perspective?

High School Unit: Why Don't Antibiotics Work Like They Used To?

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Previous Lesson....Where we've been : Students determined that another population of organisms (a kind of bird called a junco) appeared to meet most of the criteria we need in a new comparison case study, but wanted to look a little bit more at reproduction related data in a home-learning assignment to confirm that this candidate case study would be a productive one to follow.

This Lesson....What we are doing now: Students will share discoveries about patterns in reproduction between the populations of mountain vs UCSD juncos from the home-learning assignment and additional criteria that this candidate case study now meets. They will use their ideas about why these differences exist to motivate taking a closer look at how these environments are different (via) Google street view and climate data) and what those differences mean to the juncos from a bird's perspective.

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L10: What is really different about trying to survive in the city vs. the mountains from a bird's perspective? (½ to 1 period) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	Previously recorded data from the video. Climate data for both environments show differences in patterns for temperature but similarities in precipitation patterns throughout the year.. Google street views of both environments show differences in determines of congestion and lushness of vegetation (e.g.) There are many watered lawns in and around the UCSD campus, making little pools of water on a regular basis.	**Obtain, Evaluate, and Communicate Information** by comparing, integrating, and evaluating sources of information presented in different media or formats as well as in words in order to find patterns in the data *that help address the question, What is really different about trying to survive in the city vs. the mountains (environments) from a bird's perspective ?*	From that home-learning we figure out that: • Even though there is some fluctuation in the size of the juncos population on the UCSD campus, it is relatively stable. The matching birth/death rate must be what is leading to a relatively stable population. A small percentage of chicks (12-21%) survive from one year to the next and that apparently matches the annual adult death rate.. *Maybe there is something in the environment that prevents their population from getting any bigger?* • There are about an equal number of males and females in the UCSD population. *Maybe there is something about the breeding that keeps these about the same?* • Juncos on campus reproduce many times in a season because they have a longer breeding season on campus than in the mountains (starts early and lasts longer in the year). *Maybe there is something in the environment that is related to this?* As we compare possible explanations for the patterns in reproduction we saw between the two populations of juncos, it raised some new questions. *What is it about these juncos or their environments that are causing some of them to stay on the UCSD campus all year and others to fly back to the mountains to breed?* We brainstorm some possibilities. Maybe the juncos at UCSD are lazier (takes less effort or energy to remain on campus), maybe city life is less dangerous (in terms of predator),, or now that we think about it maybe it's more dangerous (due to congestion). Maybe food availability is better, or maybe the weather is nicer, or maybe the vegetation is different. The more we brainstorm the more we realize there could be a lot of differences between the environments that might be important for the survival and reproduction of juncos, and we aren't sure what those are. That led us to wonder: *What is different about these environments from a bird's perspective?* We want to compare the environments of the city and mountains using additional sources, because what we noticed in the video suggested some big differences. But big differences to us may or may not be big differences to birds. We want to make sure we take stock of everything that is similar and different from the bird's perspective so we don't overlook anything important in the environment that birds might need. This could help us explain how city life is different than mountain life for birds. After looking at street views in Google Earth of Mt. Laguna vs. UCSD and comparing climate data, we noticed some patterns

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L10: (Continued)			The environment on the UCSD campus is similar to the mountains in some important ways: • Both have fully grown trees that provide potential nesting sites. • There are sticks, leaves, grass, and hair/fur to make nests in both locations. • Summers are warm in both environments. • There is food available in both places. • There is water available in both locations. The environment on the UCSD campus is different from the mountains in some important ways: • The temperature is warmer all year round on the campus. • Precipitation falls mostly in the winter in the mountains, but at different times of the year at UCSD. • There are fewer trees in USCD than the mountains. • The food available at UCSD is found in different places than in the mountains. • There may be more water sources on the UCSD campus than there are in the mountains. • The mountains have fewer people than the UCSD campus and so there is less human-caused noise here. We decided that there really are a lot of important differences between these environments from a bird's perspective, potentially related to food, water, nesting sites, temperature, and interactions with a busy/noisy space filled (or not filled) with people. In a brainstorm, we decide that city juncos might need to be more tolerant of city life, in order to survive there year round, because in order to get enough of the resoruces they need to survive like water and food they have to be move amongst noisy cars and humans. *This led to a new question. What behaviors would a bird need to exhibit that would allow them to be more tolerant of city life?* **Next Steps: We want to know what behaviors make the juncos living in UCSD campus "city birds"?**

Next Lesson....Where we're going: Now that students have identified important differences in the environments of the two populations and birds, and ways they might interact differently with those environments, students will investigate what behaviors the juncos might be exhibiting that could make it well suited to be a city bird.

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Getting Ready: Materials Preparation

Materials For Whole Class

- Project Lesson 10 - Slides. These slides have images and links to
  - An Overview map of UCSD and Mountain region (LaGuna is one the southern end of that region)
  - Links for climate data :
    - **Mt. Laguna**
    - **UCSD**
  - Screen captures of tables and graphs for that climate data.

Materials For Each Group

- Computers with access to Google Earth to explore Street View Maps of UCSD and Mountain Region

Materials For Each Student

- Lesson 10 - Student Activity Sheets (1)

Preparation of Materials (15 min.)

- Make sure that computers/tablets/smartphones (depending on what students have access to) are configured to be able to use the free version of Google Earth

Safety

- School internet safety procedures should be followed

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Getting Ready: Teacher Preparation

Background Knowledge

LS4.B Natural Selection
By the end of grade 8

- There are both genetic and nongenetic variations among individuals in a population.
- A variation that is selected is one that provides an advantage for survival to the point of being able to reproduce.
- Natural selection changes the proportion of individuals with particular traits over time.
- Over time means across successive generations, though the proportion is likely to shift in a relatively continuous manner, since individuals are being born and reproducing at different times.
- The proportion of individuals with a trait goes up over time if it is selected for. Conversely, if we see the proportion of a certain trait going up over time in a population, one possible explanation (among others) is that it is advantageous and thus being selected for.
- The proportion of individuals with a trait goes down over time if it is disadvantageous. Conversely, if we see the proportion of a certain trait going down over time in a population, one possible explanation (among others) is that it is disadvantageous and thus being selected out.

Alternative Student Conceptions

Students may come into this lesson with many different ideas about birds (and other organisms) and how they are adapted to their environments. They also may be thinking that cities and other areas that are densely populated with humans may not be great habitats for organisms to live. It is not commonly known that areas that are densely populated can be very good habitats for a diverse set of organisms that utilize excess resources which are discarded by humans.

Linking Our Understanding to Scientific Terminology

- Populations

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Lesson 10: What is different about living in the city vs. in the mountains from a bird's perspective? (50-55 min)

1. **(10 min) Have students share out the answers to the 2nd to last question from their home-learning assignment. Use the these question from the first page of their student activity sheets for this lesson to guide group discussions.** A

Suggested Prompts:

- ➔ What are some other possible explanations, your group members came up with for the patterns in reproduction you saw in between the two populations of juncos?
- ➔ How are these possible explanations, related to other questions we had about the mountain juncos and those that stay year-round on the University of California at San Diego (UCSD juncos)?
- ➔ What new questions do you now have about these two different environments?

Listen for student responses that refer to what we were are wondering about now and what we were still wondering about at the end of last class, such as:

- ➔ Even though there is some fluctuation in size of the juncos population the UCSD campus, it is relatively stable. The matching death/birth rate must be what is leading to a relatively stable population(A small % of chicks survive from one year to the next (12-21%), but that must match the rate of adult deaths per year). Maybe there is something in the environment that prevents their population from getting any bigger?
- ➔ There are about an equal number of males and females in the UCSD population. Maybe there is something about the breeding and mating that keeps these about the same?
Juncos on campus reproduce more often than Juncos in the mountains.

Teacher Supports & Notes

Additional Guidance

A Have students keep the last page of their home-learning from lesson 9 out in front of them as they respond to this question on their activity sheets for this lesson. This will allow you to do an over the shoulder check of the home-learning if you wish, and emphasizes the importance of using the ideas from our home-learning to advance our thinking in subsequent lessons.

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- ➔ The Juncos have a longer breeding season on campus than in the mountains (starts early and lasts longer in the year). Maybe there is something in the environment that is related to this?
- ➔ The video said that these UCSD juncos are not 'city birds' - what does that mean? Are both groups the same birds but one happens to now live in a city? Is it harder for juncos to live in a city - or harder to live in the mountains? How do some animals end up living in cities and how are these animals different from ones that might not do well living in cities?

2. (5 min) Have a member from each small groups share their ideas with the class in a Sharing Initial Ideas B discussion for students to start connecting their questions together.

Suggested Prompts:

- ➔ Are there some questions that we agree are worth following up with?
- ➔ Which environment do you think would be easier for the birds to live in and reproduce in and why (or similar question students come up with)?
- ➔ What kinds of evidence do we need to collect to answer that question?

Listen for student responses such as:

- ➔ We're interested in finding out which habitat is easier for juncos to live in. We have some intuitive ideas like there is a lot more cement in the city so it probably isn't good for finding food or nest sites. We are always hearing about how building urban areas destroys habitats for animals, so the mountains are probably better. So the more we think about it, it's really weird that some birds would want to stay at UCSD if the mountains are so much better. Are the mountains really better?
- ➔ We need more information about what these two environments are like.
- ➔ We need to figure out what juncos really prefer and what are the mountains and city life like for

Strategies for this Initial Ideas Discussion

B In this discussion, students should lay out the path for the activities they will engage in today. Use the prompts to ensure that students do this heavy lifting to generate ideas.

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a bird.

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3. (10-15 min) Next, show the picture of the two locations (Mt. Laguna and UCSD) in the slides for lesson 10. **Suggested framing:** "Wouldn't it be great to be able to walk around these two locations for ourselves to explore these environments for ourselves? If we can't physically go there, maybe we can virtually go there."

Have students log into Google Earth C **to continue to investigate these two different environments. By using the map view, satellite view, and street view options - have students explore these different environments in small groups. Remind students to use student activity sheet to record their observations.**

Listen for student questions that may come up about using Google Earth as a reputable resource D **for collecting scientific evidence. Agree that being critical of where we get our information from is important.**

Suggest that we should probably gather more information from other sources as well. You have US Climate Data that could be looked at next. Direct students to look at climate data for both locations Mt. Laguna and UCSD by clicking on the hyperlinks and allowing students to explore the data sets or show them the climate data on the slides for Lesson 10.

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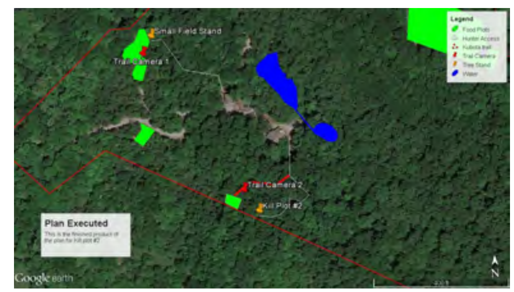
4. (10 min) After students have collected their observations, bring the whole class together for a Building Understandings Discussion E**.**

Suggested Prompts:
- ➔ What kind of evidence of similarities and differences between the mountain environment and the UCSD environment did you find?
- ➔ Are there any differences that may seem small to us - but may be huge for birds?

Support for students in using technology to collect data

C Support for using Google Earth to collect evidence: If students have not yet been introduced to Google Earth then it is helpful to give them a couple minutes to figure out how to navigate. To do this it is common for students to want to find their own house. Use this opportunity to have them learn how to use the features of Google Earth - but set a time limit on this. Through using the map features, as well as the 'street view' feature - a lot of information about any environment can be collected. Remind students that they may be able to move the "person" icon in street view off the actual street in some maps.



Supporting Students in the practice of **Obtaining, evaluating, and communicating information**

D Being a critical consumer of information about science requires the ability to read or view reports of scientific or

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Listen for student responses that share relevant information that they have gathered today. Write a list of a few of these on poster paper or the board as students share them out:

- The environment at UCSD is similar to the mountains in some important ways:
  - There are fully grown trees that provide potential nesting sites
  - There are sticks, leaves, grass, and hair/fur to make nests
  - Summers are warm in both environments
  - There is some food available.
  - There is some water available in both (from precipitation).

- The environment is UCSD is different than the mountains in some important ways:
  - The temperature is warmer for a longer amount of the year in UCSD
  - Precipitation falls mostly in the winter in the mountains, and different times of year at UCSD.
  - There is a smaller number of trees available in UCSD than the mountains.
  - The food available at UCSD is found in different places than in the mountains. Food is usually located near humans because they are dropping things, or near garbages, or stuff growing in backyard gardens.
  - There is a lot of lush areas around UCSD because people are always watering their lawns (which are additional sources of water) F .
  - The mountains are pretty uninhabited, so they are probably quiet most of the time....UCSD is very busy (foot traffic and vehicle traffic) and probably noisy.

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5. (10 min) After students have collected their observations, bring the whole class together for a Building Understandings Discussion.

technological advances or applications (whether found in the press, the Internet, or in a town meeting) and to recognize the salient ideas, identify sources of error and methodological flaws, distinguish observations from inferences, arguments from explanations, and claims from evidence.

Strategies for this Building Understandings Discussion and integrating CCCs

E In order to involve as many students as possible in this discussion, you may want each group member to share out one noticing before the dissection and one noticing after the dissection.

If time is an issue, ask a few volunteers to share with the whole group, and allow the remaining ideas to be shared with an elbow partner.

As students share, draw attention to crosscutting concepts where possible. For example, if students reference that different elements in the two environments may **cause** differences in how the Juncos interact with or utilize that environment - foreground the idea of **cause** and **effect** so that they start thinking using this lens. Also if students share about these environments being **systems** - use talk moves to get them to "say more" about how they define their **system**.

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Highlight the categories that students have identified in these patterns, related to things like nesting sites, food, water, temperature, and how busy/noisy the environment is. One way to do this it to circle these words in the list of things mentioned above.

Have students respond to the Making Sense question on their student activity sheet. Have them share out their ideas or questions related to that prompt.

Suggested Prompts:

➔ What new ideas or questions do you have about how similarities or differences between these two different environments, could be related to the resources that might be good for Juncos:

Listen for student responses :

➔ Birds need a place to nest to have babies.
➔ It probably needs to be warm enough for babies to survive
➔ Food is needed for all living things to survive.
➔ Water is needed for all things to survive.
➔ We are not really sure how noisiness or busy-ness would or wouldn't be something that birds need. Do birds need it to be quiet? Do they care?

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6. (5 min) Then, ask students what steps to take in the next (and future) lessons.

Suggested Prompts:

➔ So we found out that there are key similarities and differences between the two environments, so why would a bird just stop going back to perfectly good mountain habitat and start living here?

➔ Why don't all the birds that migrate from the mountains stay at UCSD all year found?

➔ What does it mean for bird to become "city birds" like the video said?

Helping students connect to prior knowledge

F Some students may already have prior knowledge that parts of California, like San Diego have droughts most of the year. You can connect this background knowledge to the climate data, but then raise the question of why the lawns and trees look so lush in San Diego, to help students connect to the idea people must be using water from other places to water their lawn.

In this unit it is not important for students to know what the water resevoir sources are for this irrigation.

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In your brainstorm - have students start thinking about what their noticings from today's lesson might mean for the ways in which these different groups of juncos might potentially differ in how they would need to interact with their environments:

➔ We're thinking that city juncos might need to be more tolerant of city life, because in order to access the things they need like water and food they have to be close to noisy cars and humans. Wait, what behaviors would a bird exhibit that would allow them to be more tolerant of city life? We want to know, "What exactly makes the juncos living in USCD 'city birds'?"

Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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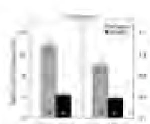
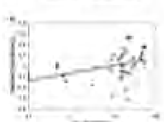
Lesson 11a: What exactly makes these Juncos "city birds"?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been: Students conducted more focussed comparisons between the city and mountain environments the different juncos live in. They determined most of the differences are influenced by humans. They wondered what behaviors would allow them to be more tolerant to city life.

This Lesson....What we are doing now: Students will view a video clip that makes a claim that city juncos are "bolder than their mountain counterparts. They will analyze data sets to determine that one major difference in the behavior can be attributed to how they react to humans that get near them, and how close they let humans get before reacting. They figure out that this reaction time has been changing from one generation to the next, and they will then conduct a thought experiment about one might test whether a behavior like boldness is learned or Inherited.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L11a: What exactly makes these juncos "city birds"? (1-1.5 periods) *Building toward* *NGSS PEs:* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	A portion of a short video clip (from 10:25-12:49) provides information about what people are observing: "bold behavior" in UCSD juncos. Three figures & graphs provide data on reaction vs. proximity responses to humans in both populations of juncos.   	**Argue from evidence** making a claim based on *data of differences in flight initiation distance, as evidence for how such differences in behavior between juncos populations, could give the UCSD juncos a competitive advantage for living in a city environment (cause & effect).* **Plan an investigation** that would produce data to serve as the basis for evidence to *determine if the cause of differences in boldness behavior in juncos is learned or inherited.*	**We are wondering whether city birds are more tolerant of city life than mountain birds. We want to look into how birds interact with their environment in order to see if there is anything that gives us clues about what exactly makes these juncos "city birds."** We look at another video clip and are told that juncos are bolder than the mountain birds and decide that we want to dig more into what that might mean. *What does bold mean for a bird? Boldness feels like a personality trait. Birds can't have different personalities in different environments, can they? What does boldness look like? What drives birds to do the things they do?* The video tells us that juncos found in the city are less afraid of humans. So it seems as if city birds let people get closer to them than mountain birds. *Is that for real? How could you measure that?* **We agree we need some more data on specific actions the birds are doing to see if we can figure out what actions count as "bold" and whether they are actually letting people get closer to them.** We interpret the data from one study and find that UCSD juncos have lower values for flight initiation distances than mountain birds. They let humans get closer to them before taking off. *That is weird, why would one bird react more readily to human presence than another bird? We started thinking-maybe this has something to do with why they decided to settle in the city. Or maybe they learned to be more tolerant of people being around them. Or is something else going on inside the bird that causes it to react in one way vs. another (e.g. that keep its heart from racing vs. makes it race)?* After looking at a second set of data, we find that juncos as a group seem to have become bolder relative to their mountain relatives over generations. (People didn't notice this sort of behavior in these birds until the UCSD campus existed for some time.) *This led us to wonder how the behavior of these UCSD juncos got to be so different from the behavior of the mountain juncos?* We try to try to make some initial explanations as to why this is the case. Maybe the birds need to be braver to get food. This seems to match what we saw in the data about juncos around UCSD being less skittish. They wait until people get relatively close to them before flying away. This seems to make sense to us because if all the birds flew off whenever people were in their line of sight, these juncos would be very stressed. That reaction would not be advantageous in a city

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L11a: (continued)			environment. This is really cool. There are different reactions to stimuli in the environment for these two types of juncos. Perhaps this is what we mean by a difference in "boldness." *But wait, how does personality change from one individual to another? Is it something that is acquired or learned (like training a dog), or is it something that is more of an instinct that you are born with (like the differences between two breeds of dogs)? And in birds, is it the same as in humans or different? We don't have to be like our parents, we can choose to act in different ways. Is personality in birds learned or are they born with it (instinct)?* *Could the environment cause a change in the behavior of juncos over time. In other words, could juncos be learning lessons from various interactions around them? Could the parents be teaching their offspring to be bolder? We bet the birds are just getting used to the traffic and noises of the city. I used to be really shy going to school, but I learned to be more outgoing and now I'm used to going to school. Again, is behavior just learned? Or is it something you are born with? How can we determine if the behavior of individuals in a group is an inherited trait or if it is learned?* We think about ways to test whether or not juncos' boldness is inherited or taught (and is now based on memories). Some of us suggest that if a baby is born to one set of parents but raised by another, that might change their behaviors. Somehow controlling for where a baby is raised might help us isolate whether a behavior is inherited. Some of us may suggest that we switch city and mountain offspring and have them raised in the other environment, or that we could put all the birds in the same place and see if they still act the same way. **(If students struggle to think of ways to test this, do 11b next. Otherwise, skip 11b.)** **Next steps: We've convinced ourselves that we can design a test to figure out if behavior is learned or inherited. Now we really want to see if there is any data about the UCSD juncos to see if their boldness behavior is learned or inherited and if scientists tested it the way we thought they might.**

Next Lesson....Where we're going: Now that your students have an idea of how scientists could investigate an answer to the question, "is boldness in juncos learned or inherited?" they will look at the methodology and research results from scientists who conducted an investigation to try to answer this question.

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Getting Ready: Materials Preparation

Materials For Each Group

- 1 copy each of Figures 11a.1 and 11a.2 Cut this paper in half so that you hand out each figure to the group at different times.

Preparation of Materials (15 min.)

- Load the Juncos video clip. Play between 10:25-12:49. Website: The Junco Project
- Prepare copies of Student Activity Sheet 11a.1
- Prepare copies of Figures 11a.1 and 11a.2
- Prepare to project image of Figure 11a.3
- Prepare a piece of big chart paper titled, "Big Ideas for the Juncos Video"
- Prepare a piece of big chart paper titled, "Lesson 11a - Data Analysis"
- Class Slides

Materials For Each Student

- Lesson 11a - Student Activity Sheets (1)

Safety

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Getting Ready: Teacher Preparation

Background Knowledge

HS-LS4-3 from the FRAMEWORK:
"Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait."

By the end of 8th grade, students were introduced to the following concepts which will be referenced in today's lesson.

- Genetic variations among individuals in a population give some individuals an advantage in surviving and reproducing in their environment. This is known as natural selection.
- It leads to the predominance of certain traits in a population and the suppression of others.

Alternative Student Conceptions

Students may come into this lesson thinking that all behaviors are learned. It is not imperative by the end of this lesson that students understand boldness is inherited, but they should think some behaviors could be inherited and wonder if boldness might be one of those.

Linking Our Understanding to Scientific Terminology

- Novel
- Boldness
- Flight Initiation Distance
- Ornithologist

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Learning Plan: What exactly makes these juncos "city birds"? (90 min)

1. (5 min) As students enter the classroom, ask them to complete the first question on their Student Activity Sheet 11a, "Connecting to the Previous Lesson" Begin with a Consensus Building Discussion A to help students rearticulate the purpose of today's lesson.

Suggested Prompts:

- ➔ What about the UCSD campus makes it a better environment for juncos than the mountains, and what makes it a worse environment in terms of the resources that are good for Juncos?
- ➔ What were we wondering about juncos at the end of last lesson?

Listen for student responses that refer to what we figured out last time, such as:

- ➔ The UCSD environment was very different from the mountain in many ways. It is much warmer all year round, plus there's more food, water and noise because of the humans that live there.
- ➔ UCSD is a better environment for the juncos because there's much more food and water for the juncos to live on. There are also less predators to hunt the juncos in the city. It's just much easier to survive. The city is worse because there aren't as many trees, so less places to nest. And it is much noisier in the city which is probably not good for the birds since they can't communicate.
- ➔ We were wondering whether city birds are more tolerant of city life than mountain birds. We wanted to look into how birds interact with their environment more in order to see if there is anything that gives us clues about what exactly makes these juncos "city birds".

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A The goal of this discussion is to put students in the driver's seat. Use the prompts to help students recall and restate what we as a class figured out in the last lesson and also what this led us to wonder.

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2. (15 min) Next, remind students that even though these environments are different - the birds do not really look different at all. Today, we really need to figure out if the birds are different or if they are just the same birds that happen to be in different places. Direct students to their Student Activity Sheet 11a.1. Also, let students know that you will play the video twice, so if they notice something and want to write it down, they will have a second opportunity to capture their thoughts. B

Now that students are prepared, start the clip of the Juncos Project (www.Juncoproject.org/videos/chapter-6/). Play only from 10:25 to12:49. After students watch the video the 1st time they should fill in the video chart on Student Activity Sheet 11a.1. After the first viewing, remember to pause for 1-2 minutes while students finish recording their thoughts before starting the next viewing.

After students have completed the video chart, gather students back together for a Sharing Initial Ideas Discussion. C **Use the following prompts to help students share their ideas. Collect students’ responses on the “Big Ideas for the Juncos Video” chart paper you prepared earlier.**

Suggested Prompts:
- ➔ How are city juncos different from the mountain juncos? How did the scientist figure this out?
- ➔ Which of these differences do you think is very important with juncos being able to survive in the city?
- ➔ How did they figure out this/these difference(s)?

Listen for student responses that mimic the next step in the story line, such as

- ➔ City juncos are different from mountain juncos because the video said they are more “bold”. They allow humans to get about 3x closer than mountain juncos. But how did they get this

Differentiation Strategies and Alternate Activities

B As you introduce the video portion of this lesson it may be useful to review the previous lesson and emphasize the video shows the differences.

It is up to the students to think of the possible impacts on the juncos’ interactions. While the video is playing students should focus on filling in the left column, leave the right for after the video.

Strategies for this Initial Ideas Discussion

C In this discussion students will share the behavioral and physical differences between the two Juncos populations. Like any other Initial Ideas Discussions, use talk moves to engage in a productive discussion where students are actively sharing their reasoning as well as giving them the

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number? Scientists must have observed a lot of birds and noticed this trend. Did they happen to observe other things as well?

➔ This is really important because a lot of the juncos food comes from humans. They need to be more tolerant of humans so they can eat, because if they weren't, they'd starve. But couldn't being too tolerant be a bad thing? Did they find some sort of "sweet spot"

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3. (15 min) Now that students are wondering about 'boldness' and birds allowing humans to get close to them, it is time to dig into some data already gathered by other researchers. Introduce this data set, by connecting back to the ideas that they raised about how scientists might have figure out these differences saying something like, "OK, well let's dig into the data that scientists collected about the birds that they used to make these claims, and let's see what patterns we notice in it."

Pass out Figure 11a.1 and pair students up. Charge each pair with taking these generalized distances and create a prediction for how these distances (SD, DD, FID, etc.) contrast between mountain and city birds. Add these diagrams to the corresponding question on Student Activity Sheet 11a.1. Circulate and assist as needed, helping students to interpret the initial diagram when necessary.

When all groups have created their predictions, pair up groups (or 3 pairs for 6 students total) so students can present their diagrams to another group(s) to receive feedback and see how they compare. Circulate and observe, if any pairs' model is off, be sure the pair they are with can explain the correct model to the incorrect students. Now that students have agreed on the general idea city birds will have a lower FID than mountain birds, explain that those same researchers wondered the same things and collected data on that as well.

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4. (10 min) Pass out Figure 11a.2 to each large group. Give students about 5 minutes to analyze the graph individually and answer the corresponding questions on the Student Answer Sheets

opportunity where they can argue/agree on the last suggested prompt. Be sure to praise detailed explanations and students who introduce link into previous students ideas, as they introduce their own ideas., ..e.g. "You are doing a really nice job saying how your ideas are related to other people's ideas"

Strategies for this Consensus Building Discussion

D In this discussion it is not important for the students' prediction to be correct, but they do need to reach the consensus that the graph shows the city juncos are 'bolder' (more tolerant, allow humans to get closer) than mountain juncos. If students are having trouble reading the graph it may be useful to project it, and cover half so students only see Foraging Birds or Incubating Females at one time. This should alleviate confusion as students are now looking at only 2 bars.

If students are not familiar with reading graphs it is helpful to start with one bar and do it together as a class. This could be done by saying things like - "What would it mean if the bar was all the way to the top? What if it was all the way at the bottom?" By making the connection to the real world situation that the graph is representing, this will help make the analysis of the graph

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about their noticings from the graphs and if it is similar to their predictions.

After students have analyzed the data and answered all questions gather them back for a Consensus Building Discussion. D **Use the following prompts to help students share their findings. Collect students' responses on the "Data Analysis" chart paper you prepared earlier.**

Suggested Prompts:

- ➔ What do you notice about the differences between city and mountain juncos? How does this compare with your predictions?
- ➔ Why do you think this difference occurred? Has this always been the case?
- ➔ How is this data related to the claims we heard about boldness in birds.

Listen for student responses such as:

- ➔ We saw, from the graph, that city birds allow humans to get much closer to them before they fly away. It's like the video said, more than 3 times closer.
- ➔ We think this happened because the food the birds are eating are around humans, like in trash cans or on the ground. So they needed to be bolder with humans. We think this must have always been the case, otherwise the first birds would have been too scared to eat, but we aren't too sure.
- ➔ Bolder birds would be those that allow humans to get closer to them.

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5. (15 min) Now that students are wondering about how long this behavior has been present, tell them that ornithologists around the world asked that same question and have spent years observing and collecting data about boldness behavior in all kinds of birds. Next, project Figure 11a.3 (Flight Distance over Generations). Allow students 5-7 minutes to interpret the graph either individually or in pairs. Have students also complete the corresponding question on Student Activity Sheet 11a.1. After students have analyzed the data and answered all questions gather them back for a Consensus Building Discussion E **. Use the following prompts to ask**

accessible to **all students.**

Strategies for this Consensus Building Discussion

E In this discussion students need to agree that birds have become bolder over generations, and this trend is probably true for juncos. This discussion could be very difficult for students to even begin if they can not interpret the graph. If this seems to be the case, again, it may be beneficial to help them break it down. As you question them as to what is confusing, it will probably arise that the X-axis scale is not even. Encourage students to come and add their own numbers on the scale (50, 75, etc.). This will make it easier to read. Then, simplify the Y-axis by drawing a straight line from the 0 (you can question students about the important point to elicit this). Now it should be easier to analyze.
Ask students if we are making a general trend from this data, is it important to look at every point? We can really look at the beginning and end of the graph. Almost all birds above generation 50 are above the 0 line. Whereas almost all of the first 10 generations are below the 0 line.

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students to share their thoughts. Collect students' responses on the "Data Analysis" chart paper.

Suggested Prompts:

- ➔ What do you notice from this graph?
- ➔ Because this is data from a variety of kinds of birds, do you find it useful to compare our juncos to it?
- ➔ What are you wondering now you've seen all this data?

Listen for student responses such as:

- ➔ We saw, from the graphs, that there is wide variation in hold bold different birds are.
- ➔ We also can see that birds as a whole population, on average, have become bolder over time generations.
- ➔ We think this data is good for us to use for our juncos. This has so many different kinds of birds and it shows a trend that boldness increases over many generations.
- ➔ We are wondering how did juncos today get so much different from their great grandparents? We know why it was beneficial to be bolder (for food) but did they learn this behavior and teach the next generation? Or was there something else that made them braver?

Suggested Prompts:

- ➔ What do you notice from this graph?
- ➔ Because this is data from a variety of kinds of birds, do you find it useful to compare our juncos to it?
- ➔ What are you wondering now you've seen all this data?

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6. (20 min) Once students bring up the idea of boldness changing over time, use the following prompts to press students to articulate some different ways that boldness might be influenced in an individual:

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Suggested Prompts:

- ➔ But wait, how does boldness change from one generation to the next? Is it something that is acquired or learned (like training a dog), or is it something that is more of an instinct that you are born with (like the differences between two breeds of dogs)?
- ➔ And in birds, is it the same as in humans or different? Like we don't have to be like our parents, we can choose to act different ways. Is personality in birds learned or are they born with it?

- ➔ **Listen for student responses such as:**

- ➔ Maybe their interaction with the environment is changing the behavior of individual juncos over time (by the junco learning a lesson from some sort of bad experience)?
- ➔ Maybe the parents are somehow teaching their offspring to be bolder?
- ➔ I bet the birds are just getting used to the traffic and noises of the city. Like I used to be really shy going to school, but I learned to be more outgoing and now I'm used to going to school.
- ➔ How can you even tell if a trait or not?

Once the question of whether boldness is something that is inherited or learned, emphasize that we should try to figure out a way we could test that question. Arrange students into teams to complete the next portion of their Student Activity Sheets, "Design an Investigation."

Suggested Prompts:

- ➔ Is there a way we can design an investigation to test this question, whether boldness is learned or inherited?

Set students off to work on designing their investigations F. Invite groups that finish to pair up and share their ideas, providing feedback and tweaking their designs accordingly. Circulate and assist to support students in this work.

Differentiation Strategies and Alternate Activities

F Listen for ideas such as :

- Switching city and mountain babies and have them raised in the other environment.
- Tag and shuffle siblings when they are born, and have some raised by Juncos in the mountains and some raised by Juncos in the city.
- Putting all the birds in the same place and see if they still act the same way (do they learn from each other)

.

If you find students struggle to think of ways to test whether boldness is inherited or learned in their groups, skip the rest of this lesson and move to Lesson 11b., telling students something like, "Maybe scientists have come up with ways to test if behavior is learned vs. inherited in other organisms. Let's take a look at some of the research they've done in this area with another organism, and maybe it can give us some ideas we can use for thinking through how we would design an investigation for Juncos related to boldness."

Strategies for this Consensus Building Discussion

G At the end of this lesson it isn't important for the students to have all the

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7. (5 min) Join the group back together once all students have had sufficient time to complete their designs. Engage students in a Consensus Building Discussion G using the following prompts:

Suggested Prompts:

➔ Were you able to come up with a way to investigate whether the boldness in city Juncos is a learned or inherited trait?

➔ Do we agree that it is possible to conduct a scientific investigation to draw conclusions about whether behavioral traits are learned or inherited?

Listen for student responses such as:

➔ Yes! We successfully outlined how an investigation could be done, though we still have to figure out some of the specific details. We want to take baby birds out of their original environment and either switch where they are raised or raise both types together. We agree that it is possible to determine whether a trait is learned or inherited, and we have an idea of how scientists go about determining that.

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8. (5 min) Before concluding the lesson, ask students to consider what should be the focus of the next lesson.

Suggested Prompts:

➔ What should we do in our next class to help us figure out whether the Junco behavior is learned or inherited?

Listen for student responses such as:

➔ We would like to look at more data about Juncos to see if we can draw conclusions about whether their behavior is learned or inherited. We are hoping that scientists may have already

details of the investigation worked out. In the next lesson students will look at an actual study that looks at this 'boldness' inherited question. The purpose of this discussion is that students agree this question could be tested.

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done some studies and whether they look like the investigations we designed today.

Have students complete the Next Steps question on Student Activity Sheets for home-learning.

Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 11b (Optional, if needed): How do scientists tell if a behavioral trait is an inherited or learned?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been: Last time, students learned that juncos that live in the city tend to be bolder in their behavior than birds of the same species in more rural areas. They wondered what could account for this difference in behavior within a species, and wondered whether there was a way to test whether the boldness is inherited or taught.

This Lesson....What we are doing now: Students will examine a study that provides examples of how scientists have conducted investigations to determine if behaviors or traits are inherited or learned. Students will use what they learned from the studies to conduct a thought experiment about how one might test to determine whether the juncos' behaviors are learned or inherited.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L11b: (Optional, if needed): How do scientists tell if a behavioral trait is inherited or learned? (1 period) *Building toward* ↓ *NGSS PEs:* *HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	A journal article describes differences in novelty seeking behavior in bees. Another journal article looking at various familial studies, describes that novelty seeking behavior in humans is mostly inherited.	**Obtain, Evaluate, and Communicate Information.** Evaluate the validity and reliability of methods that appear in scientific journals that attempt to test whether a behavior is learned or inherited in other organisms (bees and humans). **Plan an investigation** that would produce data to serve as the basis for evidence to *determine if the cause of differences in boldness behavior in juncos is learned or inherited.*	After reading two journal articles we figured out that: • Bold bee behavior was linked to the genetic makeup of the individuals, not learned from prior experience or from other nestmates. • Human novelty seeking behavior was also tested with studies to show that is it mostly inherited. • Different methods were used in the two studies, that could be useful for testing heritability vs. learned behaviors in other organisms. *We wondered how we might apply similar methodologies to our juncos?* We created a thought experiment to see how we could test if our urban juncos are learning to be bold or not. We came up with a cross fostering experiment where eggs from the bold birds were placed with the moms of the mountain birds in the mountains and eggs from the mountain birds were raised by the city birds on the UCSD campus. If the behavior was learned, then the offspring should exhibit the behavior of their adoptive parents. However, if the behavior was inherited the birds should retain their boldness or shyness regardless of the environment they were raised in. **Next steps: We've convinced ourselves that we can design a test to figure out if behavior is learned or something that can be inherited. Now we really want to see if there is any data about the UCSD juncos to see if their boldness behavior is learned or inherited and if scientists tested it the way we thought they might.**

Next Lesson....Where we're going: Now that your students have an idea of how scientists investigate to answer their questions, they will look at research methodology and results from scientists who also tried to investigate this.

These materials were developed with funding through a grant from the Gordon and Betty Moore Foundation to Northwestern University and the University of Colorado Boulder.

Getting Ready: Materials Preparation

Materials For Each Group

- Blank Construction paper or chart paper for drafting a model

Preparation of Materials (15 min.)

- Prepare copies of the study, Molecular Determinants of Scouting Behavior in Honey Bees
- Prepare a piece of chart paper titled, "Big Ideas."
- Class Slides

Materials For Each Student

- 1 copy each of Lesson 11b Molecular Determinants of Scouting Behavior in Honey Bees and Lesson11b - Example of Inherited versus Learned Behavior in Baboons
- 1 copy each of Lesson 11b - Sudent Activity Sheets

Safety

- None

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Getting Ready: Teacher Preparation

Background Knowledge

In this lesson, students will need to call upon their close-reading skills and strategies learned in Language Arts and Literacy courses. In order to comprehend the complex language presented in scientific studies, students will benefit from reminders about how to break down complex text and use annotations to keep track of the key ideas in a text.

If you are unsure about the reading skills and levels of your students, this is an excellent opportunity to collaborate with teachers in other departments who can provide guidance as to how much support students will need.

Alternative Student Conceptions

Students may begin the lesson unsure of how an investigation could be designed to test whether or not the city juncos' bold behavior is inherited or learned. They may be under the impression that scientists simply hypothesize but may not be able to actually test their hypothesis. In fact, scientists have developed methodology to test this question, and students will discover that here.

Linking Our Understanding to Scientific Terminology

- Abstract
- Methodology/Experimental Methods
- Scout
- Forager
- Novelty-seeking behavior

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Learning Plan: How do scientists tell if a behavioral trait is inherited or learned? (55 min)

1. (5 min) As students enter the classroom, ask them to complete the first question on Student Activity Sheet 11b.1, "Connecting to the Previous Lesson" Begin with a Consensus Building Discussion A to help students rearticulate the purpose of today's lesson.

Suggested Prompts:

- ➔ What were we wondering about the juncos in our last lesson?
- ➔ What questions did we have about how to design an investigation to answer our questions about the juncos?
- ➔ What could we look at to get some more ideas about how to design this kind of investigation? Do you think other scientists have done something similar in other experiments?
- ➔ How could looking at a similar study help us?

Listen for student responses that refer to what we wondered about last time, such as:

- ➔ We were wondering what causes the boldness in the city juncos compared to birds of the same species outside of the city. We wanted to know if there was a way to test whether the bold behavior was learned in order to survive in the city, or if it was an inherited trait.
- ➔ Our big challenge was that we weren't exactly sure what type of experiment would help us figure out the answer to our question.
- ➔ We wondered, have studies ever been done to test something similar?
- ➔ If we look at a similar study with other animals, then that could give us ideas about what to do with our juncos.

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2. (20 min) Hand out the research article, "Molecular Determinants of Scouting Behavior in Honey Bees", while explaining to students that you found a study that might give us ideas about

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A If you are engaging in this optional lesson, it is probably because your students struggled to come up with a way to design an investigation to help them determine whether the city juncos' behavior was learned or inherited. Therefore, it is critical for students to articulate the purpose of this lesson so that they understand what they will be looking for as they read the studies later.

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how to design an investigation to answer their question about the juncos' behavior.

Before setting students off to read, engage students in a review of reading strategies for a complex scientific text B. Remind students that when we read a scientific text, it is very important to know what our purpose is. In this case, our purpose is to figure out how scientists determine whether a trait is learned or instinct.

Provide students with some basic strategies that will improve their success with this close reading. First, explain that in most scientific studies, there is a lot of extraneous technical information that may or may not contribute to our purpose for reading. Students may need to sift through this information to focus on only the portions of the text that help us answer our question. Next, recommend that students read through the article multiple times, each with a different purpose. The first reading should be for basic comprehension, highlighting portions of the text that were particularly challenging. Subsequent readings should focus on information from the text that helps answer the questions on Student Activity Sheets.

Once students are prepared with the reading strategies, set them off to complete the reading and answer the questions on Student Activity Sheets including the Comprehension Questions and Draw a Model portions. Circulate and assist as needed, checking in to make sure students are drawing out the big ideas of the article B.

After students have completed the reading and answered the questions, gather students back together for a Sharing Initial Ideas Discussion C. Use the following prompts to help students share their ideas. Collect students' responses on the "Big Ideas" chart paper you prepared earlier.

<u>**Suggested Prompts:**</u>

➔ What did you feel were the key ideas from the study?
➔ What did you notice and wonder about the methods the scientists used to investigate the honey bees' behavior?
➔ What was significant about the differences between the "regular foragers" and the "food

Differentiation Strategies and Alternate Activities

B As you introduce the close reading portion of the lesson, you may wish to differentiate the activity based on what you know about your students as readers. A complex scientific text poses unique challenges for students, and some may require additional support as they tackle the text. Consider the options below as a way to differentiate for students who struggle with complex scientific texts:

- Pair students with differing abilities (one strong reader with one weaker reader) to complete the activity together.
- Pull a small group of students and read closely together. Think aloud as you read together to let students in on your comprehension strategies.
- Complete the reading as a large group, reading one section at a time and drawing out the big ideas of the text.

Classroom Artifact

C As a class, you may want to map out the honey bee experiment together if students are struggling to figure out what the big ideas and methods are in the article. Here is an example of the model you might draw with your students. Notice in the model that both scouts and foragers visit the

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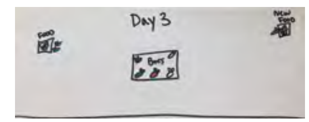
scouts?"

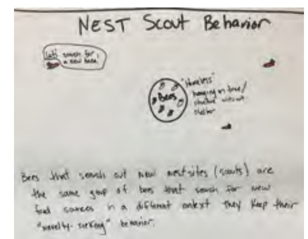
➔ Would mixing the "regular foragers" and "scouts" together help the researchers answer the question, "Is the behavior of scouting learned or inherited? Why or why not?"
➔ What did you include in your models of the steps/methods scientists took to complete the investigation?

Listen for student responses that mimic the next step in the story line, such as

➔ We noticed some key ideas in the article, such as:
  - There are bees who are risk takers, and those that aren't. Even when they are mixed together, some tend to stick with the familiar, while others show more tendency to seek out novel situations.
  - The genetic makeup in these novelty-seeking bees is reflective of similar genetic traits in vertebrates.
➔ The "regular foragers" tended to stick to the familiar, gathering food from sources that were confirmed to be a good resource for food. The "food scouts" kept seeking out new sources of food even when there was enough food for the hive. The "food scouts" took more risks as compared to the "regular foragers."
➔ Answers may vary, but here is what we are going for - Yes, it could help them figure out if the behavior is learned or inherited. The observed the bees behavior side by side to see if the personality of the bees (being bold - risk takers "scouts" or sticking with the familiar "foragers") remained the same in a shared setting. If the behavior was learned - you may find that the all the bees would just stick with the food sources that were good when they had known high quality food available; no bees would scout for new food sources. Or if the environment only had new food sources, you would expect all the bees would learn to be more novelty seeking if the behavior was learned. But since the bees retained their "personality" either "scouts" or " foragers" when put together in the same environment, this indicates that this behavior is inherited. They may also have wanted to know if both the regular foragers and scouts would influence one another to behave differently than they would when separated.
➔ Students will share their models from their Student Activity Sheets D

training dish labeled "food." This is the familiar food that stays out every day. Only scouts abandon the familiar food and visit all three of the new food dishes. The scout bees show the novelty-seeking behavior in different contexts - looking for food and looking for a new home. Students will find out in the next lesson that this is similar to the juncos (bold juncos from the city retain their bold behavior when raised together with non-bold mountain birds in a chamber when they are held by people).





Strategies for this Initial Ideas Discussion

D In this discussion, students will share what they found to be the most important

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3. (10 min) Use another case to show another example of how to untangle if a behavior is more E **learned or inherited. Have students read the article and sketch out as a group what happened in the baboon experiment. See example** F

Suggested Prompts:

- ➔ What was this experiment testing?
- ➔ What were the results? How could you tell what the results were?
- ➔ What would you expect to see if the behavior was more inherited?

Listen for student responses such as:

- ➔ They were testing if the behavior of staying with the group or running away was more learned or inherited by the female baboons.
- ➔ The female baboons from both troops changed their behavior really quickly when they were in a different environment. This is evidence that the behavior is more learned than inherited.
- ➔ If the behavior was inherited, we would expect to see the female baboons from the Savanna to keep running away from the male when they were placed in the Hamadryas, and the baboons from the Hamadryas should keep going back to the male in the Savanna.

(20 min) Charge students with the task of taking what they learned from both studies and apply it to our work with junco behavior. Arrange students into teams to complete the next portion of Student Activity Sheet 11b.1, "Design an Investigation." Review the purpose of the lesson with students by asking:

Suggested Prompts:

- ➔ How could we use the honey bee or the baboon study to help us design an investigation for the juncos?

Listen for student responses such as:

information from the article. Just as in any other Initial Ideas Discussion, it is important to allow students to use the talk moves to engage in a productive discussion with occasional argument about their ideas. As always, praise risk-taking when students go public with their ideas.

Additional Guidance

E If time allows, give students the opportunity to critique one another's' models. Students could share their work in a gallery walk, or with another partner or group to give and receive feedback. This is not a critical step in the lesson, but would provide students would good practice with constructing and refining models.

Additional Guidance

E We now understand in science that a behavior can never be only learned or only inherited. So the argument of "nature vs. nurture" doesn't really exist. The answer is always, both! Although these common garden experiments are helpful to investigate if certain traits might be moreso influenced by genes or the environment. It might be useful to share that with students.

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- ➔ Both studies investigated behaviors to determine whether they were learned or inherited. We can use the methods from those studies to guide the design of our investigation of whether or not junco behavior is inherited.

Set students off to work on designing their investigations. Invite groups that finish to pair up and share their ideas, providing feedback and tweaking their designs accordingly. Circulate and assist to support students in this work.

---

4. (5 min) Join the group back together once all students have had sufficient time to complete their designs. Engage students in a Consensus Building Discussion E **using the following prompts**

Suggested Prompts:

- ➔ Were you able to come up with a way to investigate whether the boldness in city Juncos is a learned or inherited trait?
- ➔ Do we agree that it is possible to conduct a scientific investigation to draw conclusions about whether behavioral traits are learned or inherited?

Listen for student responses such as:

- ➔ Yes! We successfully outlined how an investigation could be done, though we still have to figure out some of the specific details. We agree that it is possible to determine whether a trait is learned or inherited, and we have an idea of how scientists go about determining that.

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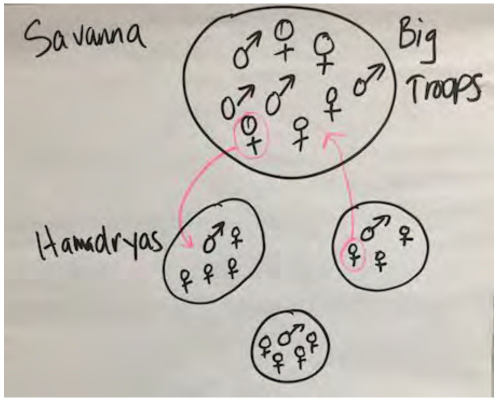
5. (5 min) Before concluding the lesson, ask students to consider what should be the focus of the next lesson F**.**

Suggested Prompts:

Classroom Artifact

F**:** As a class, map out what happened in the baboon experiment to help the students visualize the methods.



Strategies for this Consensus Building Discussion

F The purpose of this optional lesson is to help students see that there are ways to investigate whether a behavior is learned or inherited. Therefore, it's not important for students to have all of the details of the investigation worked out perfectly. In the next lesson, students will look at a study that was actually conducted with juncos regarding this question of inherited "boldness." In this Consensus Building Discussion, the goal is for students to agree

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- ➔ What should we do in our next class to help us figure out whether the junco behavior is learned or inherited?
- ➔ What could we look for to help us learn more about junco behavior?

Listen for student responses such as:

- ➔ We would like to look at more data about juncos to see if we can draw conclusions about whether their behavior is learned or inherited. We are hoping that scientists may have already done some studies and whether they look like the investigations we designed today.
- ➔ We might be able to find an investigation that has already been conducted, much like we found for the honey bees.

Students can complete the final two questions on Student Activity Sheet 11b.1 as a homework assignment.

that there is, in fact, a way to test for this.

Strategies for this Consensus Building Discussion

F Before the lesson concludes, we want to give students a chance to consider what would be most helpful as a next step in their investigations. The link between the honey bee study and the work students have been doing with juncos may not be perfectly clear to all students. If students are having difficulty seeing the connection, remind them that scientists have already conducted studies about insects that demonstrate unique behaviors, and that it may be the case that we can search for something similar with juncos, as we know they have unique behaviors as well.

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Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Building Toward Common Core Standard(s)

- CCSS.ELA-LITERACY.RST.9-10.1
  Cite specific textual evidence to support analysis of science and technical texts, attending to the precise details of explanations or descriptions.

- CCSS.ELA-LITERACY.RST.9-10.2
  Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

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Lesson 12: Do the juncos just learn to be bolder or is their behavior something they inherited?

High School Unit: Why Don't Antibiotics Work Like They Used To?

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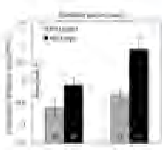
Previous Lesson....Where we've been In the last lesson, students developed an idea of how scientists could investigate to answer their questions, they will look at research from scientists who did answer this question to see if their thought experiment was correct

This Lesson....What we are doing now: Students will figure out what the researchers did to test whether the behavioral differences in the two populations of juncos were due to inheritance or learning in their respective environments by applying sound scientific processes to define the controls and constants in a common garden experiment. Students will analyze and interpret data from the study to determine that city juncos have inherited behavioral traits from their parents.

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions and* **Next Steps**
L12: Do the juncos just learn to be bolder or is their behavior something they inherited? (1 period) *Building toward* ↓ *NGSS PEs:* *HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	Modified excerpts from a primary source provide information about mountain and city birds that were raised together from a young age and showed different levels of exploratory behaviors.. 	**Obtain, Evaluate, and Communicate Information.** Evaluate the validity and reliability of methods that appear in *text (and visually) from a* scientific journal which attempted to test *whether an exploratory behavior is learned or inherited in juncos*. Determine the central ideas or conclusions to summarize *patterns in* complex evidence presented in the text by paraphrasing them in simpler but still accurate terms.	We evaluate the methodology that scientists used to determine whether observed behavioral differences in boldness in juncos are a product of genetic inheritance or learned within their different environments. From this we determine that: • Scientists designed a "common garden" experiment to test whether birds born in the city behaved differently from birds born in the mountains. • Birds from the two populations tested were raised in the same greenhouse from a young age. • Any differences among the birds could be assumed to be genetic since the environment is the same for all of the birds. • If birds from one population behave differently from the other birds, it would tell us that the behavior is inherited rather than learned. After analyzing the results from the scientists' experiments, we notice patterns in the data: • City birds have higher exploratory behavior than mountain birds when raised together in the same environment. • High exploratory behavior includes earlier initial movement, visiting more floor quadrants, trying more dishes for food, and making more total movements as compared to birds that demonstrate low exploratory behavior. We argued from evidence, that • exploratory behavior in novel settings is another way to measure boldness; • males tended to explore more than females; • UCSD juncos explore more than mountain ones; • Differences in exploratory behavior can't be learned because both groups of birds are in the same new environment; and • there must be a genetic difference in exploratory behavior because the differences we read about were based on gender and type (USCD juncos vs. mountain juncos). This raised some questions. *How can this really be? How can a tendency toward a certain kind of behavior really be something you are born with?* We know what you are born with your genes, and we know you get your genes from your mom and dad (who get theirs from their moms and dad). *So somehow the genes of these birds must be influencing their behavior, right? But how would that work?* This leads us take stock of what we already know about genes and traits: • We've only heard about genes (alleles) influence physical traits like hair/feather color, height, body shape, etc. • We also know that these alleles provide your cells with instructions regarding what substances to produce (or not

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L12: (continued)			• produce) and how much of those substances to produce (e.g. pigments, growth hormones). • We have no idea how a substance can actually influence behavior. This raised the question, *How can producing vs. not producing a substance influence the behavior of an organism?* We brainstormed different possibilities: • *Perhaps there is some sort of difference related to what substances are produced inside the birds that would influence how skittish or bold they are when reacting to external stimuli* • *We know in humans that the production or release of substances like adrenaline change in our body when we are scared. And we know that some people are born with bodies that produce more or less of certain growth hormones. Maybe there is something like this we can measure that is different in the birds which could be related to their behavior.* **Next Steps: We want to know how these birds are making substances inside their bodies that are related to them exhibiting different behaviors.**

Previous Lesson....Where we've been Now that students know that there is a genetic connection to boldness, students will look into whether it is some sort of substance that is produced in the bodies of juncos that could be the result of having certain alleles. that could lead them to exhibit these different Boldness behaviors.

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Getting Ready: Materials Preparation

Materials For Each Group

- None

Preparation of Materials (15 min.)

- Create a set of copies for each student.
- Teacher should pre-read the text to identify appropriate literacy and extension strategies for their students.

Materials For Each Student

- Lesson 12 - Student Activity Sheets (1)

Safety

- There are no specific safety concerns.

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Getting Ready: Teacher Preparation

Background Knowledge

HS-LS4-2 from the FRAMEWORK:
"Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait."

In middle school and in previous lessons,, students were exposed to concepts of inheritance through DNA.

- There are both genetic and nongenetic variations among individuals in a population.
- Variations relevant to understanding natural selection are those that are genetic, meaning here that the variations are inherited.
- A variation that is selected is one that provides an advantage for survival to the point of being able to reproduce.
- DNA carries the information of inheritance (we don't know how yet)
- Different versions of a gene are referred to as "alleles."

Alternative Student Conceptions

Students may feel that any bird in the city behaves the same just because they were raised in the city--learned behaviors. At the end of the data analysis, students should reason that, since the different behaviors were still present when birds were raised in the same environment, behaviors can be inherited from parents. They really do not yet know that proteins, as the product of genes, do the actual work that results in certain behavioral differences.

Linking Our Understanding to Scientific Terminology

- Heritable
- Environment
- Behavior
- Protein
- Allele
- Gene

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Learning Plan: Do the juncos just learn to be bolder or is their behavior something they inherited? (45 min)

1. (5 min) Begin with students answering the opening question on the Student Activity Sheet 12.1 to direct attention to the day's activity. Lead a Consensus Building Discussion [A] to bring the class to a common starting point at the beginning of this lesson.

Suggested Prompts:

➔ What behavioral differences did we notice between the mountain and city juncos?

➔ Predict: Are these differences in behavior between the populations inherited or learned? Explain.

➔ What could researchers do to see if the two populations are different due to inherited traits or just environmental differences between the two locations?

Listen for student responses that refer to what we figured out last time, such as:

➔ Behaviors were notably different between the mountain juncos and the city juncos with respect to their boldness of behavior. We saw that mountain juncos took flight much quicker than city juncos as shown by differences in Flight Initiation Distances. We decided that we need to know if these differences are the result of learning in the different environments or inherited from parents.

➔ Predictions of either case are acceptable with good reasoning. We think boldness could be a genetic thing that is inherited or that it could be a learned behavior due to different influences between the mountain and city habitats.

➔ We could take birds from one habitat to another and see if they change. Birds from both locations could be collected and raised in an environment that is neutral to both.

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2. (8-10 min) Remind students that even we though we have thought through some different methods for designing a fair comparison to investigate these questions, scientists who try to investigate similar questions might not always design a method that makes for a fair

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A The goal of this discussion is to get students all on the same page. Use the prompts to help students recall and restate what we as a class figured out in the last lesson. Their ideas should motivate what we are going to need to do next, in this lesson. This could also help if students were absent last class - to help bring them up to speed on where the class is.

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comparison.

Tell students that their goal in reading excerpts 1 and 2 from the original research on the next page to see how the scientists investigated this question. And as they read, evaluate the methodology the scientists used.

Tell students to read the excerpts and answer the Making Sense Questions for Part 1 on the following next pages.

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3. (5 min) Next, shift to a Building Understanding Discussion to help students converge on what the experiment will try to measure and how it proposes to do that in a fair comparison for the question we have related to whether behavior is inherited or learned.

Suggested Prompts:

- ➔ What steps in the methods these scientists used, seem to provide for a fair comparison of the two junco populations in the common garden experiment?
- ➔ To flip it around - what might be an example of a **bad experiment** that would not be a fair comparison of these two populations of juncos?

Listen for student responses that mimic the next step in the story line, such as

- ➔ The experiment removes the differences due to environment for birds collected in the two different locations. This allows the comparison of the two populations without the influences of the city or the mountains altering behavior.
- ➔ Juveniles were captured from two different habitats, raised in identical conditions, and then tested for behaviors related to their willingness to explore a new situation.
- ➔ Researchers went to great lengths to see that conditions for and handling of the juncos were the same regardless of where the individuals were collected. Constants and controls include species, age, number, identical capture methods, identical housing conditions, identical exposure to humans, and testing of exploratory behavior.

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4. (8 min) Now that students have examined the methods used to make the common garden experiment, they need to look at the results to see if there is evidence to support claims of either inheritance of behaviors or learning of behaviors in different environments. Students begin by analyzing and comparing the graphs from the field studies and the common garden experiments. Motivate this next step by saying something like, "Since we agree the methodology these scientists planned to use will help answer the question of whether behavior is learned or inherited in these different populations of Juncos, let's take a look at the results of their study alongside the data from the Flight Initiation Distance measurements we looked at earlier."

Have students analyze the graphs and answer the questions in Making Sense of Part 2.

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4. (10 min) Have student volunteers describe patterns they notices in the data, and what the new evidence tells us. B **Students should articulate the evidence, from this class or previously, for any claims they make.**

Suggested Prompts:

- ➔ What patterns do you notice between the two populations in these two experiments?
  - ➔ What does the new evidence from the common garden experiments support in addition to the earlier field studies?
  - ➔ How do males and females compare to each other?
  - ➔ Are there differences between city and mountain juncos with respect to exploration?
- ➔ What is the relationship between how close a bird will let a person get to them before flying away and their exploratory behavior?

Listen for student responses such as:

- ➔ The common garden experiment shows that city juncos are braver and show more exploratory behavior than mountain juncos even when they are raised in identical conditions.
- ➔ Exploratory behavior in novel settings is another way to measure boldness.
- ➔ Males tended to explore more than females.
- ➔ UCSD juncos explore more than mountain ones
- ➔ These differences in behavior can't be learned because it's the same new environment for both.

Supporting students in using cross-cutting concepts

B Different students may see different **patterns** in the data. Some classes may not mention all the patterns listed below.

Encourage students to keep sharing out a different patterns they noticed, or other ways to describe the patterns that others have mentioned, to encourage more students to contribute to this discussion.

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It must be a genetic difference because the differences between groups was bases who their parents were or whether they were a male or female.

- ➔ Flight Initiation and exploratory behaviors give us an indication of how adventurous and bold birds are from the two different populations. Birds that let people get close to hem also are the ones that explore more in common garden experiments.
- ➔ Those that aren't as brave than those who are fly away when human approach them from further off and less likely to explore.

Suggested Prompts:

- ➔ What do the results tell us about whether boldness in Juncos was inherited or learned? C

- ➔ The results of the common garden experiment suggest that the environment doesn't directly affect whether a Junco learns to be more or less exploratory. We can conclude therefore, that this boldness behavior is somehow inherited.
- ➔ And since there seems to be a correlation between boldness for exploration and boldness for letting humans get close, we can conclude that boldness in flight initiation distance is also somehow inherited.

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5. (5 min) Raise the question about how something like behavior can be inherited. Take stock of examples of physical traits that can be inherited in people first to review what it is we already know about how heritable physical traits are connected to alleles whose differences in instructions results in difference in what substances the cells of the organism produce. D

Suggested Prompts:

- ➔ How can this really be? How can a tendency toward a certain kind behavior really be something you are born with?
- ➔ We know what you are born with is your genes. So somehow the genes of these birds must be influencing their behavior, right?
- ➔ How might that be similar or different than how genes influence physical traits?

Listen for student responses such as:

- ➔ We've only ever seen genes (alleles) influence physical traits like hair/eye/skin/feather color, height, body shape, etc.

Strategies for this Consensus Building Discussion

C This is a key question and punchline to focus the conversation on. The results seem to indicate that boldness in Juncos is inherited.

Strategies for this Consensus Building Discussion

D This is an opportunity to review and rearticulate the big ideas related to genetics that students have learned in prior units of study. Ask questions that help students articulate examples of physical traits we know are inherited in humans or other animals. Then help students connect these examples to the following chain of reasoning: a) which alleles are in that organism's cells → provide instruction for which proteins are produced or not → affect which variation the organism shows for that physical trait.

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- ➔ And we also know that these alleles provide your cells instructions regarding what substances to produce (or not produce) or how much of those substances to produce (e.g. pigments, growth hormones).
- ➔ We have no idea how a substance can actually influence behavior.

- ➔ would influence how skittish or anxious it is, ….how quickly it reacts to external stimuli (e.g. heart racing) like adrenaline?
- ➔ Maybe there is some sort of hormone we can detect?
- ➔ We know in humans that the production or release substances like adrenaline change in our body when we are scared. F And we know that some people are born with bodies that produce more or less of certain growth hormones. Maybe there is something like this we can measure that is different in the birds? **Develop a brief list of some of what your class has already investigated (in previous units of study) or learned in prior grades about the alleles and physical traits. Keep a record of the list you make together posted in the room. Such a list might include:**

- **Genes (alleles)can influence physical traits like hair/eye/skin/feather color, height, body shape, etc.**

- **Alleles provide your cells instructions regarding what substances to produce (or not produce) or how much of those substances to produce (e.g. some examples include pigments, growth hormones).**

Then foreground this question, by writing it below the list of what we know:

- How can producing (vs. not producing) a substance influence the behavior of an organism?

Have students turn to a partner to discuss their ideas related to the last question on their student activity sheets: What kind of things might we want to try to detect or measure inside of these birds to investigate this question further? E

After brainstorming with a partner have students share out some ideas.

Listen for student responses such as:

- ➔ We've only ever seen genes (alleles) influence physical traits like hair/eye/skin/feather

Alternate Activities

E Space is also provided on the student activity sheets to have students write their response to the question, "What kind of things might we want to try to detect or measure inside of these birds (or any organism - e.g. people) to investigate this question further?" if you want to have students think independently first before turning and talking with a partner.

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color, height, body shape, etc.

- ➔ Maybe there some sort of difference like this also inside the bird that is related to them behaving differently that we could detect or measure?
- ➔ Maybe we can see what alleles the birds have that are bolder vs. less bold?
- ➔ Maybe there is some sort of difference related to what substances are produced inside the bird like a hormone or something. F

Before dismissing students, emphasize that it sounds like we have a wealth of possible things that might be useful to investigate next time to help answer our new question.

Additional Guidance

F If students don't bring up the example of hormones or adrenaline, you might ask "What type of substances do we know of that when they are in people's bodies affect how those people act/react?" Students may give examples of drugs. Another questions to ask, is "Are there differences in the substances we might detect in a person's body that might account for why they would behave one way vs. another in a stressful situation?" Accept all responses.

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Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Building Toward Common Core Standard(s)

- CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

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Lesson 5d: What's happening with our antibiotic experiment?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Previous Lesson....Where we've been: Now that your students have decided that juncos have changed along with an environmental shift, we want to start making connections between the change in the juncos and the change in our bacteria by comparing the results of our investigation to the junco data.

This Lesson....What we are doing now: Students will continue to carry out their bacteria investigation, making observations and recording their data about the bacteria population exposed to another round of antibiotics. Students continue to look for trends in the data and refine their ideas about what might be happening. As students see the zone of inhibition continue to decrease for one line of descendant bacteria, they will use this pattern to revise their explanations about why antibiotics are not working in Addie and will repeat another round of antibiotic dosing.

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L5d: What's happening with our antibiotic experiment? (25 min.) *Building toward* *NGSS PEs: HS-LS4-2, HS-LS4-3, & HS-LS4-4*	Results from previous experiment set up in lesson 5c.	**Carry out investigations** to produce data to serve as the basis for evidence to help explain why *some lines of descendants of a population of E.coli bacteria growing in different parts (different environments) of a Petri dish appear to be growing further and further into a zone of higher concentrations of antibiotics after each additional dose (patterns) of antibiotics.*	We take a picture of our Petri dishes and measure the inhibition zone in centimeters. The additional data from this replating is showing an even clearer pattern than before: • The inhibition zone is getting smaller each time for the bacteria that we collected and replated from close to the edge of the inhibition zone. • The inhibition zone is not changing in size for the bacteria that we collected far away from that zone.. We know that all these bacteria are descendants from the same original population of bacteria in the same environment (they all came from the same original container). It seems like one population of bacteria is changing in some way and one is not. And if one population is changing, why isn't the other one? We know that the antibiotics and where the bacteria are in the environment have something to do with explaining this. **Next steps: We want to continue comparing bacteria close to the inhibition zone to the bacteria far away from this zone. We select bacteria close to this zone and re-plate them in a new Petri dish with fresh antibiotic at the same concentration used previously. Then we also select bacteria far away from the inhibition zone and follow the same procedure as noted with the bacteria close to the zone.**

Next Lesson....Where we're going After we return to look at the results from this last round of replating, student will start to make connections between how environmental changes, interactions with those environments, and individuals with trait variations in the population lead to changes in both populations. This will be done by comparing the results of our bacteria investigations to the junco comparison study data.

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Getting Ready: Materials Preparation

Materials For Each Group

- Agar plates from 5c
- Agar Petri dishes (6)
- Cotton Swabs (6)
- Filter paper (1)
- Hole puncher (1)
- Tweezers (1)
- Masking Tape (1)
- Sharpie (1)

Materials For Each Student

- Return to record data in partially filled out copies of Lesson 5a - Student Activity
- Pair of gloves for each student (1)
- Student Activity Sheet

Preparation of Materials (15 min.)

- New Agar Petri Dishes - to be prepared and stored ahead of time
- Incubating Agar plates from lesson 5b - take a look to see if there are any groups with colonies growing inside the zone of inhibition. This will be an observation we want to make sure students pull out. If there are none yet, that is fine.
- Ampicillin mixture of 1mg ampicillin mixed with 10ml water
- Ampicillin mixture of 3mg ampicillin mixed with 10ml water
- Ampicillin mixture of 5 mg ampicillin mixed with 10ml water
- Post Student Investigation Sheets (Safety Guidelines) on lab tables
- Class Slides

Safety

- Lab safety is everyone's responsibility. Take precautions especially when working with live bacteria samples. When we work with these samples keep them contained and that we are not exposing them to ourselves or the environment. Remember that we are looking for answers as to how bacteria become antibiotic resistant so we do not want to introduce one of these bacteria into the environment by accident.
- Don't even think about having food or drink in the lab space
- Clear your lab space and wipe it with disinfectant; put on gloves and safety goggles
- Leave everything at your desk, you don't want to risk getting our sample on your pens, pencils, or anything else
- If you should have an accident please get your teacher right away
- When you are finished you will need to put your tweezer in the disinfectant and dispose of your swabs and any other paper product you may have used in the BIOHAZARD bag
- Spray your table with disinfectant and wipe it down; remove your goggles and put them in the cabinet to be disinfected
- properly take off your gloves properly and dispose of them in the BIOHAZARD bag.

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Getting Ready: Teacher Preparation

Background Knowledge

LS4.C from the FRAMEWORK: "Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions."

- Our investigation of bacteria that are resistant to antibiotics is the entry point for students into the concept of adaptation by natural selection. Those bacteria that are resistant to antibiotics are killed, while those that are resistant can reproduce and further the species. When antibiotics are overprescribed the environmental conditions change, and bacteria adapt to the new environment by becoming pan-resistant.
- By introducing the Juncos we have brought up the idea of environment. Students can see how the environment affects the birds, but could environment affect our bacteria. Although our bacteria is growing in a small contained space we need to consider that there are different environments within the Petri dish. In this respect our original environment would be the Petri dish with only E.Coli and our new environment would be the introduction of the antibiotic.
- What students are seeing is natural selection in action, they might not recognize it yet but they can relate to the fact that something is changing - the environment has changed in both examples and the organisms are changing also.

Alternative Student Conceptions

With the introductions of Junco's students have begun to examine environment and how environment might affect an organism. When we examine the birds it is easier to spot the differences in both location and the different factors within each environment, but students might not notice how the Petri dish also contains different environments. The environment around the outside of the dish is different than the environment around the zone of inhibition. Once this difference has been identified, you will want your students to start thinking about how these places are different from each other. It is important to ask students to explain their ideas and not just identify the differences. This can be done by asking students to clarify their thinking and by asking others if they agree or disagree with this idea.

Linking Our Understanding to Scientific Terminology

- Antibiotic resistant

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Learning Plan: What's happening with our antibiotic experiment? (25 min)

Teacher Supports & Notes

1. (5 min) Re-engage students in our bacteria/antibiotic investigation: "In our last lesson we determined that Juncos are behaving differently depending on their environment; however, we do not yet know why, but it might have something to do with a chemical that is produced within them. We need to reexamine our bacteria investigation and see if the data we have about Juncos helps us to figure out what is going on with our bacteria or vice versa. It has been a few days since we replated our investigation so we need to take some time and see if this gives us any new data. Let's remember what we were interested in figuring out. "

Suggested Prompts:

- ➔ What were the reasons we decided to replate the bacteria last class?
- ➔ What are we looking for in this investigation, and what do we think we will see?

Listen for student responses such as:

- ➔ We wanted to figure out if the zones of inhibition would continue to get smaller in our different concentrations of antibiotics or if they would stay the same size as the previous replating.
- ➔ When we looked at our investigation the last time we noticed that the inhibition zone only got smaller in size when we took the bacteria sample from the bacteria growing from around the zone. When we looked that the sample that we took from around the outside of the petri dish the zone of inhibition was the same size as the first investigation . We think the same thing might happen when we check our Petri dishes today.

Give students an opportunity to document and record their bacteria/antibiotic investigation on the data table they created on student activity sheet 5a.1. This should include pictures as well as measurements of the zone of inhibition.

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Students should notice that the samples cultured from the different place's are different from each other. The cultures grown from the outside ring should result in similar zone of inhibition as the second trial. The cultures grown from around the ring of the zone of inhibition from Lesson 5c should result in a decrease in zone size. There also might be a difference between the three concentrations of antibiotics. The lower concentrations of antibiotics should have a larger decrease in size of the ZOI.

2. (10 min) Begin with a Building Understandings Discussion A: Students should notice some consistent patterns in their data. These patterns should lead students to discover some cause/effect relationships between the bacterial growth and the antibiotic. By the end of this discussion the student will come to the conclusion that there is indeed something going on with the bacteria that is growing around the zone. This conclusion will lead them into determining that they should replate the bacteria again to see if the current trend in data continues.

Suggested Prompts:

- What kind of a trend are you seeing across your three data points? Do you see this same data trend within each concentration?
- What ideas do you have about why you see these trends?
- Is the **distance** the antibiotic spread out onto the agar, the same for all concentrations of antibiotics? Why or why not?
- What do we think is happening to the bacteria where the zone is getting smaller?
- Now that we see a trend do we have enough data to get a clear understanding of what is happening in our investigation? Do we need more data?

Listen for student responses that refer to what we see in the investigation, such as:

- We see that bacteria grew in some places in the dish, but not others. There still seems to be a ring around the antibiotic drop where no bacteria is growing, but the size of the ring is smaller than the last time from the sample we took from around the zone of inhibition. The size of the ring is still bigger with the higher concentrations of antibiotic, but these are a still smaller than

Strategies for this Building Understandings Discussion

A In this discussion students should start seeing some clear data trends and will probably start coming to the conclusion that the bacteria growing around the zone of inhibition is starting to become antibiotic resistant. Looking at the patterns logically leads students to realize these are cause/effects relationships. However, if they don't see this on there own, see if they can relate their data back to Addie's condition - can we make some connections between what we are seeing in our investigation and what we know about Addie's case. It is important for students to come up with this conclusion on their own in order to make the decision to replate one more time.

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in the first trial at least with the zone culture.

- ➔ The size of the zone of inhibition that we plated using a sample from the outside rim of the Petri dish (away from where the antibiotic were dropped) are still almost the same size as the original plates. So those are really not changing
- ➔ We still think the antibiotic is spreading out like we thought (concentration becomes less as it moves away from the disc) just like the concentration become less as it travels through our bodies, because it seem to be working the same in the samples that we took from around the outside of the Petri dish.
- ➔ Maybe the bacteria that is growing around the zone is becoming resistant to the antibiotics? We think this because we know the antibiotics should be seeping onto the plate the same distance between all three concentrations. And since the ZOI is smaller with the low concentrations of antibiotics, we are convinced that there are areas where the bacteria are growing in the same place with the antibiotics. We know for sure that something is going on with these bacteria because when we use samples from around the zone the zone on the next replate is always smaller.
- ➔ We think we need to do this investigation another time to see if our data trends continue. If we have more data, and see consistent trends we could better understand what is going on.

This discussion should lead into the class deciding to replate again, however the discussion should lead to the idea that we will only need to replate from the three cultures (one from each antibiotic concentration) where the zone of inhibition is getting smaller.

We currently have 6 dishes 1.) 1mg zone of Inhibition (ZOI) - 2.)1mg away from ZOI 3.) 3mg ZOI 4.) 3mg away from ZOI 5.) 5mg ZOI 6.) 5mg away from ZOI

When we go to replate we will only take samples from the three samples that were grown from the ZOI (dishes 1, 3, and 5) From these three plates the students will again grow bacteria cultures from around the outside of the Petri dish and from around the zone of inhibition

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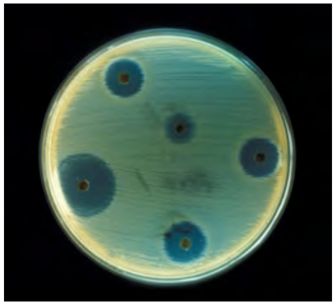
(making six new plates total). B

Inessence students should really be focused on two different noticings:

- **When cultures are taken from around the outside of the petri dish (away from the zone of inhibition) the antibiotics (no matter what concentration) still seem to work the same. The measurements of the inhibition zones tend to measure almost the same**
- **When cultures are taken from bacteria growing from around the zone of inhibition the data show that the zones of inhibition are decreasing in size (all concentrations are showing a decrease in the inhibitions zone, however the lower concentrations should show the most dramatic results).**
  - **Other noticings might include bacteria actually going within the zone, however this usually does not manifest unit the next replate. On the picture, see this occurring where there are little white dots inside the ZOI.**



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3. (5 min) Carrying out an investigation: Have students prepare the new plates in their groups. The procedure should be the same as in Lesson 5a, except the bacteria will come from the plates with the bacteria selected close to the ZOI. Again we want to plate samples from around the zone and from around the outside in order to try to figure out if the bacteria is indeed changing.

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4. (5 min or homework piece) Reflection C **Before dismissing students, ask student to predict what will happen with the ongoing re-plating experiment. Then have them answer the following prompts either on an additional sheet or in their science notebooks.**

Suggested Prompts:

Differentiation Strategies and Alternate Activities

B Depending on space and materials you may choose to continue this investigation in several different ways, some other ideas include:

- To replate from the zone of inhibition and the outside of each plate and continue to record data from each plate
- Have each lab group only replate one or two of the antibiotic concentrations and then share their data with the rest of the class *note that the most dramatic results will come from replating the lower concentrations
- If you have multiple classes, have each class work with a different concentration and share data across all the classes.

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➔ What do you want to adjust or add to your predictions and/or models about what's happening based on our new evidence?
➔ Is the ZOI getting smaller in all concentrations of antibiotics? Why or why not do you think this is occurring?
➔ What do you think is going on with the samples taken far away from the ZOI? Do you have any evidence to support your ideas?

Look for student written responses to refer to what we see in the investigation, such as:

➔ New evidence shows that the zone of inhibition seems to be decreasing in size when we replated using a bacteria sample taken from around the zone. The zone of inhibition stayed the same when we plated using bacteria from around the outside of the plate. Students may also predict that the zone will get even smaller on the next replate.

➔ Recent evidence should also result in a more drastic decrease in the inhibition zone in the low (1mg) concentration.

➔ Even when you use a higher concentration of antibiotics the zone still got smaller in one of the cultures. This tells me that maybe the concentration might not be as important as we think.

➔ For some reason the cultures plated from around the outside of the plate are almost the same size as the first investigation, we think something is changing in the bacteria growing around the zone, but not in the bacteria around the outside.

Formative Assessment Opportunities

C Looking at student responses to these questions and adjustment they have made to their models is a good way to gain insight to student understanding of the three dimensions of the NGSS. Some key connections that you should look for at this point include:

- Are students using the evidence (cross- cutting concepts) they have gathered from their investigation to adjust their model (scientific practices) ?
- Are they using that model to make predictions and/or help explain what is going on with Addie's illness (disciplinary core idea)?

By looking at these pieces you can determine if students are making the critical connections in order to build understanding and problem solving skills.

Alignment With Standards

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Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

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Lesson 13: Are there differences inside the birds that would explain why they behave differently in response to things happening around them?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been: Students analyzed and interpreted data from a common garden research study to determine that city juncos have inherited behavioral traits related to boldness and exploratory behavior from their parents. This raised the question, how can inheriting different alleles lead to differences in behavior?

This Lesson....What we are doing now: Students will investigate primary sources using text and graphs to figure out that elevated corticosterone (CORT) levels in birds correspond to how easily birds get stressed which in turn is correlated to boldness levels. Students then develop out a model that accounts for how differences in heritable alleles can lead to differences in CORT response to stress, which is related to how the birds behave (bold vs. skittish). Together, the class then builds a consensus model to explain how UCSD juncos became bolder over time as compared to their mountain ancestors.

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L13: Are there differences inside the birds that would explain why they behave differently in response to things happening around them? (2 periods) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	Human took captured birds from their native environments, held them, then measured their CORT levels. These levels were higher for mountain birds when they are held in a stressful situation.  	**Argue from evidence** Construct a written argument based on data and evidence from a primary source research article *to explain how differences in the amount of CORT produced/released in juncos could provide a mechanism linking how differences in alleles in juncos could result in differences in their behavior.*	The left side of Fig. 2 tells us that when scientists would capture and hold a mountain bird and measure the chemicals in its blood, they noticed a difference in the amount of a particular substance referred to as CORT (corticosterone). This is somehow related to the stress hormone cortisol. We saw some patterns in the data: • When a mountain birds or a UCSD birds is stressed, its CORT levels go up in response to the stressor. • Mountain birds produced/released more corticosterone than UCSD birds. So this means that when mountain birds are stressed, they also have higher CORT levels compared to city birds. When the birds are not stressed, there doesn't seem to be much difference in the CORT levels. We think that maybe it's a difference between the type of birds and something they are born with, or maybe it's something that is different because of where they were captured. So to make sure that it's not the environment (and that it really is from differences within the bodies of the birds), we use more data related to CORT levels. We see the same patterns as well as a difference between females and males. This convinces us that the amount of CORT released into the blood is something that is connected to the alleles these juncos are born with. Since we think CORT may be a stress-induced hormone and there are differences between individuals in both populations, we want to see if there is a relationship between boldness and CORT levels. We have determined from the data graphed in Fig. 4 that the birds that produced more CORT also tended to display fewer exploratory behaviors, regardless of whether they are mountain or UCSD juncos. *How are boldness, CORT, and genetic information connected?* We remember from middle school that alleles cause cells to produce proteins and other substances, which leads to the expression of physical traits. So different alleles produce substances that influence how much or how quickly corticosterone is produced or released, which is related to a bird acting bolder or more skittish.

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L13: (continued)			*So how does this additional data play out with our model regarding how a population could change over time?* We map out a cause and effect model as a class to explain what's going on with the UCSD juncos: • Birds from the mountains migrate down to the coast for the winter. • A city campus gets developed which has some very different environmental features for birds: more water, access to nest sites, more food year round, few predators, but also lots of noises and people. • For some reason, some birds stay there instead of going back to the mountains. • The birds that do the best in the city are the bolder birds because they can tolerate being around people. Boldness personality gives these birds a competitive advantage in this environment. • The shy birds don't survive as well in the city (get less food). There birds might not live long enough to pass on their genetic information (dead birds don't have babies) • Over several generations, the bold birds in the city are reproducing more because they are able to get more food (survive easier), stay in their nest sites longer, etc. • We know boldness is caused by some allele differences. • Because boldness is determined by an allele, we should see the number of alleles in associated with boldness increase in the population and the frequency of alleles associated with shyness decrease. **Next steps: Now that we've figured out that juncos have changed along with an environmental change, we want to compare what we've learned about juncos to what's happening with our bacteria.**

Next Lesson....Where we're going: Now that students have developed a natural selection explanation for juncos, they will take what they learned about juncos and compare it to bacteria to compare both systems, in an attempt to generalize the natural selection model across both populations.

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Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 13 - Student Activity Sheets (1)

Safety

- None

Getting Ready: Teacher Preparation

Background Knowledge

- **Corticosterone (CORT) is** a corticosteroid, C21H30O4, that is secreted into the bloodstream by the adrenal cortex. Students will figure out in this lesson that the substance is a stress related hormone, similar to adrenaline that affects how organisms respond to stressors in their environment. The will also figure out that the amount of CORT that an organism releases into their bloodstream when stressed is correlated to how bold they act, which in turn, students already know is heritable trait.

Alternative Student Conceptions

Linking Our Understanding to Scientific Terminology

- Corticosterone (CORT)
- Urbanization
- Correlated
- Adrenaline
- Testosterone
- Allele

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Learning Plan: Are there differences inside the birds that would explain why they behave differently in response to things happening around them? (one 45 min, and one 60 min. period)

1. (10 min) Begin with students answering the opening question on the Student Activity Sheet 13.1 to direct attention to the day's activity. Lead a Consensus Building Discussion A **to bring the class to a common starting point at the beginning of this lesson.**

Suggested Prompts:

➔ What did we figure out last class about what is causing the differences in boldness between the UCSD juncos (city birds) and the mountain birds?
➔ What questions do we still have about what is causing these different behaviors in the two populations of juncos?

Listen for student responses that refer to what we figured out last time, such as:

➔ Exploratory behavior in novel settings is another way to measure boldness.
➔ These differences in behavior can't be learned because it's the same new environment for both.
➔ It must be a genetic difference because the differences between groups was bases who their parents were or whether they were a male or female.
➔ If the birds are raised in the same environment and then if the boldness was something they learned by their parents or by getting used to the environment, then the birds should show the same amount of boldness behavior. But, if the the birds are raised in the same environment and the mountain birds act less bold and the city birds still act more bold, then that would tell us that the boldness behavior must be something they are born with because they are not learning it from their environment.
➔ How can differences in genes/alleles can result in differences in behavior?

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A The goal of this discussion is to get students all on the same page. Use the prompts to help students recall and restate what we as a class figured out in the last lesson. Their ideas should motivate what we are going to need to do next, in this lesson. This could also help if students were absent last class - to help bring them up to speed on where the class is.

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2. (10 min) Have students work on part A of the Student Activity Sheets . Tell students that we are going to look at a real scientific study that collected some data that might help us with the questions we still have.

Explain to students that they will use a thinking routine in groups to engage with the abstract they read today. This routine is called "Connect, Extend, Question" and is designed to help students connect what they read or observe to prior knowledge, extend their thinking, and generate and collect additional questions about the particular study. Instruct students to use the thinking routine you read the abstract from a study titled "Boldness behavior and stress physiology in a novel urban environment suggest rapid correlated evolutionary adaptation" led by Jonathan Atwell in Part A of Student Activity Sheet 13.1. As they do, students should record their thinking on the activity sheet. Remind students that this is from an article published in the peer-reviewed journal Behavioral Ecology in 2012. They will notice it was not written to be easily understood by any and all readers. As students "Connect, Extend, Question" they will be looking for the following in the abstract.

Suggested Prompts:

➔ What was this study asking?
➔ What were they trying to figure out?
➔ What kinds of data were they collecting?
➔ Can we tell just based on this what the scientists were actually DOING in their experiment(s)?
➔ What did you learn that was new or unexpected?
➔ What new questions did you come away with?

As students share, collect ideas in a common place or ask students to take notes. Listen for and write down questions from students such as:

➔ The study was asking, what are the differences in behavioral (flight initiation distance) and physiological (CORT) traits for San Diego juncos and Mountain juncos.
➔ They tried to figure out the different CORT levels for birds in different environments.

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- ➔ The collected flight initiation data, CORT data, and environment data for each population of juncos. They collected data in the wild and in a common garden experiment.
- ➔ I learned we can measure physiological data and compare it to a physical trait.
- ➔ I learned that boldness behavior can be inherited.
- ➔ What about the environment might be important to juncos surviving in San Diego?
- ➔ What is the relationship between CORT and flight initiation distance?

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3. (10 min) Have students work in small groups on part B of the Student Activity Sheets. After 5 min, have a building understandings discussion about the patterns students are seeing in the data.

Suggested Prompts:

- ➔ What patterns did you see in the data?
- ➔ Why did the scientists need to do both a field study and a common garden study?
- ➔ Why do you think measuring CORT was important for figuring out why the juncos can survive in San Diego?
- ➔ What do you think CORT is?

As students share, check off which questions this first piece of data answered and listen for a write down additional questions students' ideas bring up. Listen for responses such as:

- ➔ Right at capture, the birds had about the same amount of CORT but 15 and 30 minutes after capture, the Mt Laguna juncos had higher levels of CORT.
- ➔ In the common garden study, the patterns in the data are similar but females had lower CORT overall than males.
- ➔ We think CORT is a reaction to stress. We wonder what is happening in the body when this is released?
- ➔ In the field study, the San Diego juncos were captured in San Diego and the mountain juncos were captured in the mountains. In the common garden study, they were captured in the same environment. Maybe scientists did this study to see if the environment was a factor in the CORT

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measurements.

- ➔ But we see the same patterns in the field study and the common garden study, so if it's not environment that is causing these differences? What is causing these differences?
- ➔ We think it must be something that the birds were born with. We think their CORT levels in response to stress are something they are born with - so juncos from San Diego are born with lower CORT levels that juncos from the mountains.
- ➔ I remember that boldness can be inherited, what is the relationship between the patterns we see in this data and the boldness of the birds?
- ➔ I think CORT is a stress-induced hormone because when the birds were stressed, it increased.

---

4. (10 min) Have students work in small groups on part C of the Student Activity Sheets and making sense and next steps. After 4 min, have a building understanding discussion about the relationship between boldness, CORT, and genetics.

Suggested Prompts:

- ➔ What patterns did you see in the data?
- ➔ What is the relationship between boldness and CORT?
- ➔ We figured out the CORT is something that is inherited, what does inherited mean to you?
- ➔ If CORT is inherited, what is the relationship between boldness, CORT, and genetics/inheritance?
- ➔ In humans the adrenal cortex secretes hormones like adrenaline and testosterone as well as other substances into the bloodstream. If different Juncos were born with differences in how the cells in their adrenal cortex function related to the production and/or release of CORT, how could that help explain why they behave differently in response to things happening around them?

As students share, listen for responses such as:

- ➔ The more boldness behavior, the less CORT released - this is for all birds regardless of San Diego

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or mountain population.

- San Diego birds were more bold overall.
- There seems to be a steeper relationship between boldness and CORT in San Diego male birds, we wonder why this might be?
- Inherited means it came from their parents. This has something to do with genetics.
- In middle school we learned about different alleles of genes that produce different proteins. And this can lead to different physical traits. We think this might also lead to different behaviors.
- Thinking about the genetics of CORT, maybe the birds in San Diego have different alleles than the mountain juncos which influence how much or how quickly CORT (corticosterone) is produced or released.
- The data shows that the more CORT that is released the less bold the bird behaves. So San Diego juncos must be bolder than mountain juncos because they release (or make) less CORT.
- If more or less CORT is released, then that might be a cause or effect of acting more or less stressed out in response to changes in the environment.

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5. (5 min) Wrap up by asking student to write their ideas down for the questions in the Next Steps section of their Student Activity Sheets. Then have students share out some of their ideas in the last few minutes. B

Suggested Prompts:

- What does this new data add to your thinking about how populations change over time?
- What questions do you still have?

Start preparing for a class model by making a visible list of students thoughts about populations changing over time, in the next class you'll make a class model of the San Diego juncos population changing over time. Listen for student responses such as:

- Bold birds have a competitive advantage.
- Shy birds do not survive as well and therefore don't reproduce as successfully as bold birds.
- Bold birds are better in the city because it's easier for them to get food. They survive more often

Alternate Activities

B If time is limited, you can assign the Next Steps section of their Student Activity Sheets as home-learning and follow-up with it in the first part of the period the next time you meet. This lesson continues into a 2nd day, so a natural way to launch the 2nd day of this lesson is to have students share out the ideas from their Next Steps section, to start building a list of thoughts about how the juncos population might be changing over time (as outlined in the rest of this step).

Alternatively if you have additional time left at the end of the period on the first day, you can start the 1st step of Day 2 (step 6).

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than birds that are not bold, when they reproduce, their babies have a CORT allele that makes them bold too. Over time, there are bolder birds in the population of San Diego juncos.

- We know CORT and therefore the bold behavior is caused by an allele, we should see more boldness alleles in the population over time while the alleles associated with shyness decrease.

Day 2

6. (10 min) As students come into class, have them list all the components they think should go in a model that explains how the San Diego juncos population changed over time.

Suggested Prompts:

- What did we figure out yesterday?
- What are all the things (or components) that we need to explain how the San Diego juncos changed over time?

Ask students to share out and add to your list from the previous day. Listen for student responses such as:

- Boldness
- CORT levels
- Genetics, alleles
- Competitive advantage
- Food, the city, the mountains - the environment in both places
- San Diego juncos and mountain juncos

Ask students what they think we should do with all these components to help link it back to Addie's case and understanding how the bacteria were changing over time?

Suggested Prompts:

- How do we connect all these components to explain how the populations of juncos in San Diego changed when their environment changed?

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Ask students to share out and write next to the list of components. Listen for student responses such as:

- ➔ We need to show the environment changing.
- ➔ We need to show which birds survived in San Diego and which birds didn't
- ➔ We need to show that birds who survive reproduce
- ➔ We need to show that boldness (CORT) is inherited
- ➔ We need to show multiple generations

---

7. (15-20 min) In pairs ask students to draw a model of how the population of San Diego juncos changed over time to become bolder than the population of mountain juncos using the components, interactions and mechanisms the class came up with?

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8. (10 min) Have pairs post their models around the room and do a gallery walk where students notice what is common across the models and what is different across the models.

Suggested Prompt:

- ➔ What is common across the models and what is different across the models you drew?

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9. (15 min) Have student share what the noticed in the models and start creating a class model together on chart paper or on the board. Have a building consensus discussion where you start adding things to the class model that the models all had in common and then ask students to share ideas and discuss what was different across models and what we agree the class model should have.

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As you listen to students discuss, your consensus model should be building toward a model that shows the following components, interactions, and mechanisms:

- ➔ The birds that do the best in the city are the bolder birds because they can tolerate being around people. Bold responses gives these birds a competitive advantage in this environment.
- ➔ The shy birds don't survive as well in the city (get less food). With less food, they are at a competitive disadvantage for surviving as well as the bold birds. So dead birds don't have babies
- ➔ And shy birds who did still survive and do have babies, don't reproduce as successfully in the city (don't stay in their nest as long)
- ➔ We know boldness is caused by some allele difference since city and mountain birds raised in the same environment retain their bold personality, regardless of the shared environment
- ➔ Because boldness is caused by an allele, we should see the number of alleles in associated with boldness increase in the population and the frequency of alleles associated with shyness decrease.
- ➔ Over several generations, the bold birds in the city are reproducing more often because they are able to get more food (survive easier), stay in their nest sites longer) etc. , which leads to a population, which on average is bolder than their mountain ancestors/cousins.

7. (5 min) Ask students to write individually their reflections on how the class model of juncos might help them to explain how Addie got so sick.

Suggested Prompts:

- ➔ How does our class model of the San Diego juncos help us to explain how Addie got so sick?
- ➔ What do the changes that have happened in the juncos populations and bacteria populations have in common?

Look for student responses such as:

- ➔ The environments that both populations are changing over time - for the juncos it is the

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urbanization of the city and for Addie it is the addition of antibiotics to her body.

- ➔ Some juncos are better suited to survive in the city and some bacteria are better suited to survive when Addie is treated with antibiotics.
- ➔ The organisms that survive in the environment can reproduce.
- ➔ Over time, there are more bold birds in San Diego and over time, there are more antibiotic resistant bacteria in Addie.

Alignment With Standards

Building Toward Target NGSS PE

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

Building Toward Common Core Standard(s)

- CCSS.ELA-LITERACY.RST.9-10.2: Determine the central ideas or conclusions of a text; trace the text's explanation or depiction of a complex process, phenomenon, or concept; provide an accurate summary of the text.

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Lesson 5e: What's happening with our antibiotic experiment?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been: In the previous lesson students started to build a consensus model to explain why the UCSD birds are becoming more bold over time, taking into account the new data about CORT levels in birds. This specific case model should have been generalizable elements to our developing model for evolution. In lesson 5d, students completed the last plating of their bacteria experiments They have been following trends in the data where they are seeing decreased zones of inhibition in some of the treatments. We were replating to confirm this pattern in the data, and perhaps some students are connecting the patterns in the data to a generalized model for evolution.

This Lesson....What we are doing now: Students will collect their final data from the bacteria selection experiment. They will find that the inhibition zone continues to decrease in the treatments with antibiotics collected from the zone of inhibition, but not in the treatments with antibiotics collected from far away from the zone of inhibition. They analyzed these trends and came up with potential mechanisms to explain the trends. As a class, we will also relate this information back to Addie's case in order to see if we can determine what is going on with her treatment and why it is not working.

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), *New Questions* and **Next Steps**
L5e: What's happening with our antibiotic experiment? (1 period) *Building toward* *NGSS PEs: HS-LS4-2, HS-LS4-3, & HS-LS4-4*	Results from previous experiment 5b, 5c, and 5d, located in activity sheets from lesson 5a	**Construct an explanation** based on evidence obtained from *our bacteria experiment*, applying scientific ideas *that we developed in lesson 9,* to answer why *some lines of descendants of a population of E.coli bacteria growing in different parts (different environments) of a Petri dish appear to be growing further and further into a zone of higher concentrations of antibiotics after each additional dose (patterns) of antibiotics.*	We take a picture of our Petri dishes and measure the inhibition zone in centimeters. When we look across the four measurements from experiments L5b, L5c, and L5d, the inhibition zone is definitely getting smaller in the dishes where bacteria were collected close to the inhibition zone. We do not see the zone decreasing in the second petri dish with the bacteria collected far away from the zone. We've also noticed that sometimes we will see a little colony of bacteria growing inside the inhibition zone. *What's going on? Why are we seeing this difference?* We have ideas about what might be going on with the bacteria from our juncos experience too. Here are some of our ideas to explain what's going on with our bacteria experiment: • We think the bacteria popping up inside the inhibition zone must be resistant to antibiotics. We've done some experiments testing how the antibiotics must be moving out of the filter paper evenly, so we don't think that antibiotics are just not hitting the areas where we see the small bacterial colonies growing in the inhibition zone. • *Why is the inhibition zone decreasing in the dishes with the replating of bacteria close to the zone?* There must be some bacteria in the original sample that are naturally resistant and some that are not resistant to this antibiotic. When the bacteria that are resistant to the antibiotic come in contact with it, they continue to grow and reproduce, whereas the non-resistant bacteria die. When we take a swab from the edge of the zone of inhibition where the concentration of the antibiotic is presumably lower than in the center of that zone, we are picking up a bacterial population that has a greater percentage of resistant bacteria and a smaller percentage of non-resistant bacteria. With each successive experiment, the more numerous resistant bacteria continue reproducing. Most of the non-resistant bacteria in this next round are killed by the antibiotic. A small number of them might survive around the edge of the zone of inhibition and are picked up in the next swab. Even more of the survivors, however, are resistant bacteria in the next round and the zone of inhibition gets smaller. • *Why is the inhibition zone not changing in the dishes when we replating with the bacteria far away from the zone?* This is a little more challenging to explain: – We've done some experiments testing how the antibiotics must be moving out of from the locations where we dropped it, decreasing in concentration quickly as we get away from the filter paper, so we don't think that there are any antibiotics particles getting to the areas far away from the inhibition zone. – Bacteria that are far away from the zone of inhibition do not come in contact with the antibiotic. Therefore, this area of the Petri dish has different environmental conditions than the area closer to the location where the antibiotic was added. Both antibiotic resistant bacteria and non-resistant bacteria live and die at the same rate.

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L5e: (continued)			◦ The region in the Petri dish that is far away from the zone of inhibition likely contains both resistant and non-resistant bacteria. All of these bacteria are living and dying at a "normal" rate because they are not coming in contact with the antibiotic. When a random sample of bacteria far away from the zone of inhibition is taken, the proportion of both variations of bacteria does not change when the bacteria are re-plated because there is no competitive advantage for one trait variation over the other. All the bacteria are competing with each other for space and food. The antibiotic resistance trait offers no advantage under these circumstances and so the size of the zone of inhibition doesn't change from one experiment to the next. Next steps: We have to communicate what we've figured out with the community! We spend some time going back to our mission and add things we want to include in our infographics. We should spend some time designing our first draft of our infographics to incorporate what happens with antibiotics and bacteria resistance.

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Next Lesson....Where we're going Students will take what they have learned about resistant bacteria and juncos to compare both systems in order to generate a natural selection model across both populations.

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Getting Ready: Materials Preparation

Materials For Each Group

- Agar plates from 5d

Preparation of Materials (1 min.)

- Student Investigation Sheets (Safety Guidelines) should be posted on the lab tables
- [Class Slides]

Materials For Each Student

- Already filled out Lesson 5a Student Activity Sheet which have all the student data recorded in them.

Safety

- Lab safety is everyone's responsibility and we must take precautions especially when working with live bacteria samples. We need to make sure that when we work with these samples that we keep them contained and that we are not exposing them to ourselves or the environment. You need to remember that we are looking for answers as to how bacteria become antibiotic resistant so we do not want to introduce one of these bacteria into the environment by accident.
- Don't even think about having food or drink in the lab space
- Clear your lab space and wipe it with disinfectant
- Put on gloves and safety goggles
- Leave everything at your desk, you don't want to risk getting our sample on your pens, pencils, or anything else
- If you should have an accident please get your teacher right away
- When you are finished you will need to put your tweezer in the disinfectant and dispose of your swabs and any other paper product you may have used in the BIOHAZARD bag
- Spray your table with disinfectant and wipe it down
- Remove your goggles and put them in the cabinet to be disinfected
- properly take off your gloves properly and dispose of them in the BIOHAZARD bag.

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Getting Ready: Teacher Preparation

Background Knowledge

LS4.C from the FRAMEWORK: "Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions."

- Our investigation of bacteria resistant to antibiotics is the entry point for students into the concept of adaptation by natural selection. The bacteria that are resistant to antibiotics are killed; those that are resistant can reproduce.
- By introducing the Juncos we have brought up the idea of environmental changes. Students can see how the environment affects the birds, but could environment affect our bacteria. Although our bacteria is growing in a small contained space we need to consider that there are different environments within the Petri dish. Our original environment would be the Petri dish w/only E.Coli and our new environment would be the addition of the antibiotic.
- What students are seeing is natural selection in action, The environment has changed in both example; population changes are occurring over time in both environments too.
- In this unit, we do not go into horizontal gene transfer as part of the explanation because this goes beyond the scope of the HS DCIs. Basically, resistance in bacteria is spread even faster, because not only can bacteria pass on alleles to offspring, but they can also share resistant alleles through a process called horizontal gene transfer. This is when bacteria can swap genetic information with neighboring, unrelated bacteria.
- We know that the Juncos live in different environments, and we can see the differences in both their environment and in their behaviors. In general, environmental factors allow some traits to have a competitive advantage over other traits. Organisms with the traits that give a competitive advantage are more likely to survive and reproduce, so they would pass on the alleles that correspond to the traits with the competitive advantage. In this case, it wouldn't really matter if the organisms reproduce sexually or asexually. Both types of reproduction would result in change of allele frequency. With limited resources, the more advantageous alleles in a certain environment would increase in the population.

Alternative Student Conceptions

Now that we know that the Petri dish does contain different environments, we need to compare how these different environment relate to bacterial change. Some students may think that maybe some of the bacteria in the very first investigation that we plated (5a) contained bacteria that was already antibiotic resistant. This is a common misconception, and will take some questioning in order to get students to use the data to determine that the bacteria is actually changing slightly around the zone of inhibition with each replate. Students must look at the patterns in the data and then relate that data to cause and effect relationships.

It's important for students to understand that the bacteria is indeed evolving to become antibiotic resistant and that there were not antibiotic resistant bacteria already within the original sample.

Linking Our Understanding to Scientific Terminology

- **Natural Selection**

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Learning Plan: What's happening with our antibiotic experiment? (45 min)

1. (10 min) Re-engage students in our bacteria/antibiotic investigation: "In our last lesson we determined that environmental factors play a role in how organisms change, however we do not yet know if the behaviors we are seeing in the Junco's is the same as we see in our bacterial growth. We need to reexamine our bacteria investigation one last time and see if our new information on Juncos helps us to figure out what is going on with our bacteria or vice versa. It has been a few days since we replated our investigation so we need to take some time and see if this gives us any new data. Take a few minutes to think about what we were trying to figure out."

Suggested Prompts: A

- What were the reasons we decided to replate this investigation?
- Draw a set up of one of our plates (put one arrow at bacteria on the zone of inhibition and one arrow near the edge of the plate). These bacteria are on the same plate. Are bacteria at these two arrows in different environments like the juncos are in different environments (mountains vs. city)? Why or why not? Describe what's actually different between the two locations.
- What are we looking for in this investigation, and what do we think we will see?

Listen for student responses such as:

- We wanted to figure out if the zones of inhibition would continue to get smaller in our different concentrations of antibiotics or if they would stay the same size as the previous replating. We also think that since the zones of inhibition are getting smaller that maybe they will disappear all together.
- So some of us think it's not exactly like the Juncos because the environments are so close together - more like having different environments inside one room or inside one house. We think they are different environments because the bacteria close to the zone of inhibition actually get a little bit of antibiotic in their space, but the bacteria far away from the zone don't

Teacher Supports & Notes

Additional Guidance

A You may need to take some time here to review how different organisms reproduce. Reproduction is one way that new genetic material can be introduced into a population. You could also use this as an opportunity to talk about mutations, and how these can affect a population as well. Mutations can happen at random or can be caused by environmental factors.

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set any antibiotics on them.

➔ When we looked at our investigation the last time we noticed that the inhibition zone only got smaller in size when we took the bacteria sample from the bacteria growing from around the zone. We think that our Petri dishes contain two different environments (the one around the outside rim of the dish has NO antibiotics and the one right next to the zone of inhibition has some antibiotics), and we wanted more data to see if our current trend continued. We think this time we will see the zone getting even smaller or maybe it will have disappeared altogether. When we looked that the sample that we took from around the outside of the petri dish the zone of inhibition was the same size as the first investigation. We think the same thing might happen when we check our Petri dishes today.

Give students an opportunity to document and record their bacteria/antibiotic investigation on the data table they created on student activity sheet 5a.1. B **This should include pictures as well as measurements of the zone of inhibition. When students are done have them place their Petri dishes in a designated area so they can be properly handled and disposed of, always remind students that they are working with hazardous materials and need to take proper precautions.**

Students should notice that the samples cultured from the different environments from within the Petri dish are very different from each other. The cultures grown from the outside ring should result in similar zone of inhibition as the previous trials. The cultures grown from around the ring of the zone of inhibition from Lesson 5d should result in a decrease in zone size, by this time some bacteria should also be growing in the zone of inhibition as well.

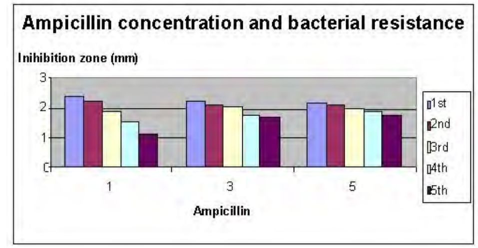
2. (10 min) Begin with a small group Building Initial Ideas Discussion: C **Analyzing and Interpreting Data - Students should continue to notice some consistent patterns in their data, but should also identify a new piece, as colonies of bacteria start to grow within the zone of inhibition.[3] These patterns should lead students to notice some very distinct cause/effect relationships between the bacterial growth and the antibiotic. In this section we would like students to start brainstorming about why they think they are getting the results they see. "Now**

Classroom Artifact

B Here is a sample of what your student's data might look like.

Ampicillin concentration	The diameter if inhibition zone in Petri dish (mm)				
	1st generation	2nd generation	3rd generation	4th generation	5th generation
1mg	24	22.5	19	15.5	11.5
3mg	22.5	21	20.5	18	16.5
5mg	21.5	21	20	19	18

Use the below graph to plot the results in the above table.



Strategies for this Initial Ideas Discussion

C It is important that you give your students time to analyze their data and give them an opportunity to come up with some reasons as to why they are seeing the results they recorded. This allows for ownership of the material and encourages them to be active learners.

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that we have several points of data, start to brainstorm in your groups about what the data is telling us. Why are we seeing these patterns? Take about 5 minutes and brainstorm ideas with your group, record your ideas on a piece of scratch paper and be prepared to share out your ideas"

Possible student brainstorming ideas: D

- ➔ The zone of inhibition has always gotten smaller when we have grown the bacteria with a sample from around the previous zone of inhibition. We think this is happening because the bacteria is becoming immune to the antibiotics (like when we become immune to different things like chicken pox), or maybe like when we do conditioning for sports. At the beginning our muscles are really sore but as we keep working out we get stronger and our muscles don't hurt as much.
- ➔ We think that maybe the bacteria that is growing around the zone is becoming resistant to the antibiotics, but we are not sure how that is happening. Bacteria reproduces by binary fission (it splits in two) so we are not sure how it is changing, but our data suggests that is has to be because our zone of inhibition is getting smaller. We need to figure out how or if bacteria changes to get new genetic material.
- ➔ We think that there were some antibiotic resistant bacteria already living in the original sample so when the bacteria started to grow in the Petri dish the bacteria that was already antibiotic resistant grew and made more. The bacteria that was already antibiotic resistant reproduced more, and the bacteria that wasn't died. So the proportion of bacteria with antibiotic resistance increased in proportion which made us able to detect it as we replated our experiments.
- ➔ We think that there is different bacteria growing within the Petri dish because when we grow bacteria for samples taken from around the outside of the dish the zone has measured about the same as the previous plate, but in our other samples the zone always gets smaller. We think the bacterias are different because if they were the same the zone would always measure the same and they don't.

When time is up and groups have recorded their ideas, and prepare for whole group discussion.

Formative Assessment Opportunities

D This is a good opportunity for you to walk around the room and listen to the different ideas that the groups are coming up with. You can gauge what groups are on the right track, and where you might need to address misconceptions.

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3. (20 min) Building Understandings Discussion: E **The goal at this point is to get the students ideas public and then have them engage in argument based on the current evidence. They will also need to relate this evidence to the evidence we have from the Juncos in subsequent lessons. First have the students share their ideas about what they think is happening with the bacteria. As students share their ideas record them on chart paper or the board. Doing this validates their ideas, but also helps identify partial understandings.**

As you guide students through this discussion make sure to ask them to explain their reasoning and allow other students to ask probing questions. It is not enough just to tell a group that what they are thinking is wrong, they have to come that conclusion themselves based on evidence and class discussion.

Suggested Prompts:
- ➔ Let's look at our data tables, what does the evidence tell us about where the bacteria is growing?
- ➔ What are the similarities and differences between our data sets? What are we seeing in the samples grown from the outside rim of the Petri dish verses from bacteria grown from around the zone of inhibition?
- ➔ If there was antibiotic resistant bacteria in the sample from the beginning wouldn't we see colonies growing in the zone from the beginning?

Listen for student responses such as:
- ➔ According to our data we know that bacteria is growing everywhere except in the zone of inhibition. Some of our zones of inhibition decreased in size as we continued to replate and some replates stayed the same.
- ➔ The zone of inhibition decreased with each trial when we took our bacteria sample from around the zone of inhibition. The zone of inhibition decreased across all the concentrations, but it decreased that most in the lower concentration. When we replated from a sample from around the outside of the Petri dish (away from the zone of the inhibition) our zones of inhibition measured the same for each of the replates. However, our zones of inhibition were

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smaller in the lower concentration and got larger as the antibiotic concentration got stronger but still all about the same. Bacteria grew in all of our investigations, but it didn't always grow the same.

➔ There were some bacteria that were randomly resistant in the beginning growing close to the zone of inhibition (ZOI), but we couldn't detect them because they were such a small proportion of the original population. Everytime we swabbed at the ZOI we selected for the bacteria that were resistant naturally, so they became a larger and larger proportion of the population until we could distinctly detect their effect on the ZOI getting smaller. The non-resistant bacteria close to the ZOI can't survive and don't reproduce - their proportion in the population get smaller and smaller. When we swab far away from the ZOI, there is no selection pressure on those bacteria so the proportion of resistant and non-resistant remains the same, so no difference in the ZOI is detected every time we replate E .

By the end of this discussion student will come to the conclusion that there are two separate environments within the Petri dish. One environment is around the outside edge of the dish. Bacteria that grows here has not come into contact with the antibiotic, and when it is replated has a zone of inhibition that have almost identical measurements across all the trials. The second environment in the Petri dish is the bacteria from around the zone of inhibition, this is the bacteria that seems to be evolving. This is the bacteria that is becoming more antibiotic resistant with every replate. Each time we replate from this environment the zones of inhibition measure smaller. We will also address what is happening with the other trails - the trails from around the outside. Students will come to the consensus that the number of bacteria that have the antibiotic resistant trait is showing up more and more causing that population to grow in number. The bacteria that do not show for the antibiotic resistant trait will continue to die off. This is similar to what we saw in the computer simulation activity.

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4. (5 min or homework piece) Reflection and next steps: Before dismissing students, ask student to reflect on what our investigation revealed to us about how bacteria survive and

Strategies for this Building Understandings Discussion

E By taking the role of discussion facilitator you are really letting the students make the important connections they need to make in order to understand what is going on the the bacteria and how antibiotic resistance increases in the population over time. Students must not just share their thought at this point but also need to asked the reason behind those ideas. Make sure you are asking students to explain and clarify their ideas. Also, ask if other groups have come up with similar ideas, or if some groups have a completely different ideas of what is happening. Depending on ideas, this discussion could lead to having students argue from evidence in order to get to what is really going on with the bacteria.

Formative Assessment Opportunities

F These reflection pieces can be utilized in part or in whole to gather valuable insight in students' thinking. This allows you to gather information in order to make informed decisions about your next steps as a teacher.

As you are looking through these answers or talking with your students about their thoughts continue to ask yourself; are my

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reproduce. What does this data tell us about how bacteria can change over time. Also, think about how this information relates to what we are seeing in the Junco population. Lastly, how does this new information help us to understand what is going on with Addie's case? Why did this investigation give us some key insight to how and why her body is reacting the way it is. Students can answer the following prompts either on an additional sheet or in their science notebooks F

- ➔ **Why is it important for us to understand what is going on within the different environments of the Petri dish? What is the data telling us?**
- ➔ **Why would it be important to communicate this data to others? Is this information something we should add to our Mission board? Why or Why not?**
- ➔ **Why is this new evidence important in helping us determine what is going on with Addie's case?**

Look for student written responses to refer to what we see in the investigation, such as:

- ➔ The data we collected from this investigation is important because it has helped us understand several things about how bacteria works. We learned that there can be more than one environment within a single Petri dish and the bacteria growing in each environment is different. The bacteria that is growing around the outer edge seems to be unchanged but the bacteria growing around the zone of inhibition seems to be changing, becoming more antibiotic resistant.
- ➔ The information from both the bacteria investigation and the Juncos both have to do with a change in the environment. When organisms change their environment or when the environment changes around them it can cause the organisms that live there to change too, even if we can not always see it.
- ➔ I think it is important to communicate this information on our mission board because it is important for people to know that bacteria can become antibiotic resistant because of things that we do (or don't do). When we choose not to take all of our antibiotics we learned that we are giving bacteria the chance to evolve because we are not killing them all. We learned that

students on the path to understanding or are their ideas based on misconceptions? Are they making the connections necessary to gain conceptual understanding? Do they understand how the cross-cutting concepts of patterns and cause and effect drive our need for discussion, analysis, and possible argument about the evidence they have gathered about the content.

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bacteria can grow and reproduce really fast so we really need to make sure we are taking our antibiotics the right way when we are sick.

➔ This information relates back to Addie's case because her body is not responding to any antibiotics. Maybe some of the bacteria she picked up already had resistant traits, but they weren't visible at first - which is why the antibiotics seemed to help kill off some non-resistant bacteria at first. But as the resistant bacteria reproduced, the antibiotics became less and less effective until eventually her body was only populated with resistant bacteria. We think in order to make her better we have to give her a new antibiotic or maybe an antibiotic that her body has never seen before, and may that would help. We also no longer think that we need to give her a stronger dose of an antibiotic that they have already tried, we don't think that would work anymore.

Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

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- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

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Lesson 14: How do the changes that happened to the Juncos populations compare to our bacteria populations?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been Students figured out how differences in heritable alleles in juncos can lead to differences in CORT responses to stress, which is related to how the birds behave (bold vs. skittish). They applied their natural selection model to this trait to explain how the UCSD population birds became bolder than their mountain ancestors over time.

This Lesson....What we are doing now: Students will take what they learned about juncos and compare it to bacteria to compare both systems, in an attempt to generalize the natural selection model across both populations.

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L14: How do the changes that happened to the juncos populations compare to our bacteria populations? (1 period) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2,* *HS-LS4-3* *HS-LS4-4,* *HS-LS4-5,* *& HS-LS4-1*	All phenomena related to the juncos case and the bacteria and antibiotic Petri dish experiments	**Develop and Use a Model** revising it to account for common elements and interactions across two systems and revise it again to provide a mechanistic account for how all populations on Earth might be changing over time (adaptation from natural selection). **Ask questions** based on potential limitations in this model, related to migration, reproduction, mating, and changes in populations over longer periods of time.	We compared what is similar and different between the juncos and bacteria in our Petri dishes and found lots of similarities. We organized these similarities in a system comparison chart to try to generalize the common mechanisms, interactions and outcomes between both systems. After doing this we settled on a general set of mechanisms and outcomes that appear to be at work across both: • There was one initial ancestor population that had trait variations in it. • There were differences in the environmental conditions in different places at different periods of times. • Individuals with some variations survived more often than others because a trait they had granted a competitive advantage (better chance) for survival over others in different environmental conditions. • Surviving individuals can reproduce, passing on the alleles for their trait variations; dead individuals can't pass on their alleles for those trait variations. • This leads to traits (and the alleles responsible for those) that help individuals survive and reproduce (pass the related alleles on) so that they become more common in a population over time (from one generation to the next). We recalled that these mechanisms and outcomes looked really similar to what we discovered about bacteria in the NetLogo simulation and Addie's world before, and seems to confirm that these mechanisms and outcomes are not population/system specific. We revised our mechanisms and outcomes to represent what type of changes might be occurring in **all** population of organisms over time. We referred to the outcomes as adaptations and the mechanisms/principles as natural selection, but realized this shorthand way of referring to our system models masks a deeper understanding of the "how and why" behind what is happening related to things we see (and want to change) like the growing prevalence of cases of antibiotic resistance. We argued that we didn't want to fall into that trap when making an effective infographic for our Mission Board. We want to use these general principles in our infographic. We want to show people how partial exposure to antibiotics can actually select for bacteria that are harder to kill and lead to more resistant bacteria each time we use antibiotics incorrectly. We want to kill all the bacteria in the host and not leave any behind to become more resistant. We need to update our info graphic (2nd draft). But even if we feel we might be ready to start our infographic, we realized that we still have some pieces of our model that seem incomplete and that we are not sure about. We think we have some limitations to our model that we still need to figure out in order to really understand what is going on with Addie, bacteria, and the juncos. Until we do that, we won't be able to apply that model to explaining changes for all life on Earth

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Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L14: (continued)			As part of our home-learning to pick up on in lesson 16, we brainstormed new questions: • *How could moving/transferring/migrating organisms back and forth between different environments affect the population over time (either in the juncos and bacteria or in other populations)?* • *How could differences in reproduction between bacteria and juncos might be affecting population changes over time (either in the juncos and bacteria or in other populations)?* • *What type of population changes could we see over a longer period of time (either in the juncos and bacteria or in other populations)?*

Next Lesson....Where we are going Students have worked out a solid natural selection model, that they will apply to their infographics in the next lesson. But they also have just started poking potential holes in it by raising new questions from the cases they investigated that they will want to answer. These new questions, related to migration, mating, and longer periods of time will setup the motivation for a future lesson that start their journey into the final bend of this unit, where they will uncover additional mechanisms of evolution that account for the emergence of new species of organisms, by continuing to follow the juncos case study further.

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Getting Ready: Materials Preparation

Materials For Partners

- None

Preparation of Materials (5 min.)

- Prepare a space (dry erase board, chart paper, etc.) to compile student responses about conclusions drawn from …...
- Prepare a chart paper or word processing document (to be projected) to collect student responses for the class discussion in the Similar/Different Activity

Materials For Each Student

- Lesson 14 - Student Activity Sheets (1) (the home learning assignments - part A and part B are included in these activity sheets)

Materials shared between classes.

- Clip magnets to hold papers to board and to move them around (if necessary)
- Roll of tape (if necessary)

Safety

- None

Materials per class

- Blank poster papers (3)

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Getting Ready: Teacher Preparation

Background Knowledge

From the FRAMEWORK:

LS4.C: Adaptation by natural selection is ongoing. For example it is seen in the emergence of antibiotic-resistant bacteria.

Cause and Effect: Mechanisms and Prediction Today infectious diseases are well understood as being transmitted by the passing of microscopic organisms (bacteria or viruses) between an infected person and another. A major activity of science is to uncover such causal connections, often with the hope that understanding the mechanisms will enable predictions and, in the case of infectious diseases, the design of preventive measures, treatments, and cures. It is also useful to look for similar patterns in different species of organisms for evidence to confirm or revise an explanatory model of a process that occurs in the natural world.

Other information:

Models of all kinds have limitations in how they function to explain a phenomenon. It is both important and valuable to recognize those limitations as it necessitates pursuing additional questions and probing deeper into evidence that may support the development or revision of a model.

Alternative Student Conceptions

Students will come into this lesson having investigated a simulated environment in which they were able to manipulate various conditions and collect data on how the bacterial population changed in differing conditions.

In this lesson, students will be challenged to identify components of a system and utilize that in order to (1) identify gaps in current understanding and (2) demonstrate a need to pursue studying another organism (Juncos).

Students may be unfamiliar with what a "system" is and components of systems. Discussion prompts and teacher supports include guidance on how to scaffold a discussion about systems and use it to pursue other questions.

Linking Our Understanding to Scientific Terminology

- Systems
- Natural selection
- Adaptations

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Learning Plan: How do the changes that happened to the juncos populations compare to our bacteria populations? (50 min)

1. (10 minutes) As students enter the classroom, ask them to complete the first section on Student Activity Sheets "14.1- Connecting to the Previous Lesson" individually (5 min). Then bring the class together for a Consensus Building Discussion to help students compare these similarities and differences. (5 minutes).

Suggested Prompts (these mirror the questions in section 8.1 of the student activity sheets):

- ➔ Summarize how the juncos traits we observed being passed on are different then the trait(s) we considered in the bacteria.
- ➔ Summarize how the bacterial traits we observed being passed on is similar to the trait(s) we observed in juncos.
- ➔ How do differences in trait variations between individuals within both populations contribute to how these populations changed over time?
- ➔ How do changes in the environment contribute to how these populations changed over time?

Listen for student responses that refer to what we have figured out and what we still wondered about last time, such as: A

- ➔ One differences was that the trait was a physical one in bacteria and a behavioral one in juncos.
- ➔ Another difference was that bacteria reproduce asexually and Juncos reproduce sexually. B
- ➔ Both traits were heritable. This means they both are due to differences in the alleles in individuals.
- ➔ There were variations in both traits in both populations.
- ➔ Some variations in bacteria helped them survive chemical exposure, some variations in Juncos helped them gather more resources in environments when exposed to lots of people/stimuli.

Teacher Supports & Notes

Strategies for this Building Understanding Discussion

A The point of this connection is to (1) revisit living things reproduce and pass traits on to offspring, (2) bacteria are similar to juncos in the sense that the trait we are observing is connected to an allele, and (3) they are different in that they are different types of adaptations. Being different types of adaptations is critical to point out because it excludes the explanation that this pattern in what we are seeing over time is specific to the organism or the type of adaptation.

This discussion will lay the groundwork for establishing consensus (in the next part of the lesson) on the general mechanisms that both systems share in common in the next section of the lesson.

Shifting to a generalizable mechanism (natural selection) is what we are after. By the end of the lesson, students will argue that this mechanism is not exclusive to certain organisms or traits. It is a uniform

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➔ Both traits influenced who survived more often and therefore who reproduced more often.

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2. (10 min) 14.2 -Activity "Comparing Bacteria in our Petri Dishes and Juncos". Frame the goal of this investigation, by reading the text at the start of the activity , We have observed four different populations changing over time: (1) bacteria in Addie's world, (2) our NetLogo simulation, (3)Juncos, and (4) our bacteria in the Petri dish investigations. And that we have compared the NetLogo simulation to Addie's world already in Lesson 8. Let's use what we figured out in lesson 8, to compare it the other things we have learned since then from the juncos and the Petri dish investigations. This comparison across systems, will help us refine our model of why antibiotics weren't working to kill the bacteria inside of Addie and prepare our infographic.

Have students work in small groups, make a summary chart of columns A and B regarding the key conditions and outcomes that we know were important parts of both the bacteria and juncos. Each cell that has "…" in it needs to be completed. Remind students to wait to fill out column C, as we will decide as a class how we want to summarize that column. C

Examples of student responses are shown below:

	Petri Dish Bacteria (System #1)	Juncos (System #2)
What "Types" (trait variations) were in the initial population?	1. There was one initial ancestor population that had trait variations in it for antibiotic resistance, that we swabbed onto the first Petri dish with.	1. There was one initial ancestor population that... had trait variations in it for boldness that migrated from the mountain to the UCSD and back each year.

explanation across all of science that describes an important mechanism for how living things change over time.

Additional Guidance

B Draw out this difference and make note of it on the board. It will be an important one to come back to later in the lesson. This difference will ultimately be used to motivate the start of bend 3 (two lessons from now) to investigate how differences in mating in combination with natural selection may affect the type of changes we see happening in populations over time.

Differentiation Strategies

C Seek out small groups with members who may not have shared their ideas publicly yet and join in their conversations as they complete a row of the table. Select students you haven't heard from to help prime them for being willing to go public in the next Consensus Building discussion (in the next part of the lesson) by:

1. asking different group members to articulate what is similar between Addies World and the NetLogo simulation (this will help students practice articulating their first draft

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What type of changes are occurring in the environment?	2. The environment conditions of the Petri dish were different based on where in the dish and based on the concentration used in the drop from the bottle.	2. ......The environmental conditions of the mountain vs. UCSD are different. There are more resources (food & water & warm temperatures for longer periods of time) available for juncos in the city than in the mountains. But there are also more people in the city and stimuli to react to.
How did the environmental change affect which individuals tended to survive?	3. Some of the bacteria died near the antibiotic, we also observed that…. ...not all bacteria died in the ring of inhibition, that led us to think that those individuals that survived there must have had a trait variation that made them more resistant to being destroyed by bacteria.	3. ....Bolder juncos survive more easily in the city because they get more resources they need for survive, and therefore reproduce more often. ...Less bold juncos survive more easily in the mountains, because they might survive better if they flee startling stimuli (e.g predators)
Which type of individual reproduced more? Why?	4. The bacteria that reproduced more often near the antibiotic were the ones that…. were antibiotic resistant because they had some structural differences (on the surface of their cells or inside their cells) that allowed them survive exposure to these chemicals for longer. Near the edge of the plate there was no type of individual that reproduced more often than another (as a far as we can tell).	4. The juncos that reproduced more were ... ...the city juncos because…....they demonstrated traits (boldness) that made them more likely to survive. If they were surviving, they were having more babies.

ideas they have on that question)

2. Following up with reinforcement like, "that is a really cool noticing. Would you be willing to share that in a little bit with the rest of our class when we talk about what we want to put in column C as a whole class?"

This process can help students try out their ideas in a smaller group setting, get positive feedback on the value of the idea, and have time to get themselves ready to go public to the whole class with that idea.

An additional strategy that may be useful is to have students share what their PARTNER told them, not what they wrote on their papers. This assists in facilitating discussion because students know they will be held accountable for the ideas their partner shared with them. In turn, they will be more engaged listeners and more active classroom discussion participants. This type of discussion also lends itself nicely to talk moves such as "Do you agree with what he/she said? Why or why not?" or clarifying questions such as "Is there anything you misunderstand about what he/she said?"

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What is happening to the population over time?	**5.** ..The population that is replated from near the antibiotic disk is…. growing further and further into the zone of inhibition with each replating, because that population is becoming more antibiotic resistant over time. This is because the ones that survived each dose of antibiotic are the ones with trait variations that allowed them to survive some level of antibiotic longer than others, which allowed them to reproduce more offspring like them, which led to a shift in the distribution of traits in the population towards a greater proportion of bacteria that have trait variations that give them antibiotic resistant.	**5.** …. Bolder juncos became more common in the city whereas this type of juncos did not become more common in the mountains over the last 60 years.

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4. (10 min) After students have worked in pairs or small groups to fill in their graphic organizer for column A and B, call everyone's together for class discussion. Direct students to look at column heading C. D

Suggested Prompts:

➔ Just like in an earlier lesson, you'll notice your graphic organizer uses the term "system"(referring to the column C of your graphic organizer).

Remind students of the idea that systems have multiple parts working together, and the way these parts work together produce certain outcomes. Emphasize that thinking of any process, or thing, or a set of things like as a system, often allows us to see how parts in other systems might

Supporting Students in the Crosscutting Concepts

D Similar to what students did in lesson 8, the objective of the similar/different activity, is to identify commonalities between the two systems. In identifying things that are similar among the systems, students will be identifying components of a system and interactions between those components.

Additional Guidance & Possible Student Responses

E The ultimate goal of this discussion is to develop a way of describing what is in common between these two systems, that could also work for predicting and explaining what we think might be at work for any population of living organisms is interacting with a changing environment over time. That is where we are headed in the next step.

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work together in similar ways. Ask students for what is common between the two systems (their Petri dish experiments and the juncos). Record column C together publicly on a projected word-processing document, chart paper or overhead that is identical to the organizer in their handout. Listen for and summarize student responses such as: E

C. Conditions or Outcome Common to both Systems
1…. There was one initial ancestor population that had trait variation in it.
2….here are differences in the environmental conditions in different places at different periods of times. .
3. ...Some variations survived more often than others because a trait they had granted a competitive advantage (better chance) for surviving over others in different environmental conditions.
4…. Survivors can reproduce, passing on their trait variations to their offspring if they have the resources they need (space, food, nesting sites, water, temp). Dead individuals can't pass on their trait variations.
5…. Traits that help individuals survive and reproduce (pass these traits on) become more common in a population overtime.

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5. (5 min) Point out to students that our list of what is similar, seems a lot like what we came up with in lesson 8. Encourage students to look back at lesson 8 to compare to it. Emphasize the idea, that when scientists keep seeing the same mechanisms at work today in multiple systems for long periods of time, they assume those mechanisms operated that way in the past and will continue to do so in the future. F

Pose the question from section 8.4, "Generalizing Our Model" What, if anything, would we need to

Supporting Students in the Crosscutting Concepts

F A cross-cutting concept connect emphasized in the Framework for is **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** The particular phrase "Scientific knowledge is based on the assumption that natural laws operate today as they did in the past and they will continue to do so in the future." is called out in the foundation boxes for the performance expectations this unit targets. In this step we suggested the phrase "mechanisms" rather than "natural laws" be used to make this point. Another student friendly alternative could be "scientific principles".

Supporting Students in using scientific terminology

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change in the wording of column C, in order to make it a general model for explaining and predicting the mechanisms and outcomes we would expect to see at work in all populations of all organisms over time?

Give students a couple of minutes to write their responses individually. Then have students share out their responses. Fold in responses that help generalize the language of column C to make it applicable to any population of organisms.

Once the class is satisfied with this general model, summarize their findings by saying, something like, "scientists refer to this mechanism for how populations change over time as "natural selection" and refer to the outcomes of natural selection as "adaptations". G

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5. (5 min) Emphasize that these seem like we have figured out some really important ideas that could help us explain to other people what is happening in our infographic. Post a representation of column C on the mission board.

Ask students to talk with a partner about the following, If we just go around referring to what is happening to the bacteria to make them more resistant to antibiotic over time as "adaptation through natural selection," why might most people still not really understand what that means? What aspects of the how/why will have to make sure they understand?

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6. (5 min) Return to the Mission Board, and ask students to consider what other challenges will we have to consider in applying what we figured out to creating an effective infographic. Have students share their ideas with the whole group and/or respond individually. H

Listen for student responses:

➔ Accept all responses.

G Now that students have built the idea of natural selection and adaptations, it makes sense to start connecting these words to this idea, as a shorthand for the complexity of what they figured out.

Formative Assessment Opportunity

H An exit slip on this question can help you gather additional information about what you will need to emphasize at the start of lesson 15, before students start creating their infographic, so that they consider all the dimensions in the rubric that the class uses/builds for this next end of bend 2 assessment.

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6. (10 min) Then assign the students the home-learning 14-part A by reading the top of the directions to it, You have lots of potential sources of evidence to use in your infographic. If you use it all of it, it be an overwhelming amount of information for a reader to make sense of. For home-learning, consider the sources of evidence we have and how they might be useful for helping other people understand what they need to know in the infographic we are making by filling out the table below. In the next lesson we will use your evaluation in the table below to make choices about what, if any evidence, you want to actually reuse or repurpose for use in your infographic.

Tell students that we will use part A in our next lesson, so bring it completed to class next time.

Then motivate where we might want/need to go in future lessons, even if we think we have a pretty strong model to use for our infographic. Problematize by saying something similar to the following, But even if we feel we might be ready to start our infographic, we still should be skeptical as scientists about possible limitations or gaps in our model of natural selection. Let's go through a brief list of some of the things that may or may not be limitations in our model.

Suggested Prompt: (these mirror the questions in section 8.1 of the student activity sheets):
- ➔ We know Addie got bacteria from two different environments (the hospital and the playground). And we know that bacteria can be transferred from one environment to another. So does our model really account for everything that might be happening in such cases?

Listen for student responses:
- ➔ Changes in the environment over time are part of out model, but explaining how moving, migrating, a population to new environments isn't really spelled out in much detail.

Suggested Prompt: (these mirror the questions in section 8.1 of the student activity sheets):
- ➔ We have reproduction as a mechanisms in our model for both bacteria and birds. But are there some important differences in the way these organisms reproduce that we may have oversimplified?

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Listen for student responses:

- ➔ Bacteria don't mate, juncos do.
- ➔ The different outcomes from sexual vs. asexual reproduction isn't really part of our model
- ➔ Something led the first group of UCSD birds that to change their mating behavior from their ancestors, but we don't know what.

Suggested Prompt: (these mirror the questions in section 8.1 of the student activity sheets):

- ➔ Though we can use our model to explain the growth of antibiotic resistant cases since 1944, and the changes in the Juncos population since the UCSD campus was built, would its predictions be different over much longer periods of time? What would we see happening over thousands or millions of years?

Listen for student responses:

- ➔ It seems like natural selection would still be happening, but it is kind of hard to predict the type of changes we would see over much longer periods of time.

Then tell that another part of their home-learning, will be to start trying to identify new questions that these possible limitations raise that we would want to explore further in a future lesson after we work on the infographics. Have students to turn to Lesson 14 - Home-learning - part B to where this assignment is. Ask students to complete this part B of the home-learning by the time the class is ready to start lesson 16 (the first lesson in bend 3 of our unit). [K]

Additional Guidance

K The home-learning is split into two parts, because we need one of these for building coherence into the next lesson (part A), and we need the other for building coherence into the subsequent lesson (part B)

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.

- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.

- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

...And, are just starting to set-up for building toward:

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.

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Lesson 15: How Can We Share What We've Learned with Our Community?

High School Unit: Why Don't Antibiotics Work Like They Used To?

T

Previous Lesson....Where we've been : In lesson 5e we think we've figured out why the zone of inhibition is decreasing in some plates and not others. We also related this information back to Addie's case to see if we can determine what is going on with her treatment and why it is not working. In lesson 14 students took what they learned about juncos and compared it to bacteria in order to create a generalized natural selection model across both populations.

This Lesson....What we are doing now: This is where students will be taking their generalized natural selection model and knowledge gained about how resistant bacteria spread throughout a person and a community and create a simplified version of those explanations to share with their community in an infographic or other public message.

S

Lesson Question	Phenomena	Lesson Performance Expectation	What We Figure Out: (CCCs & DCIs), New Questions and Next Steps
L15: How can we share what we've learned with our community? (1 period) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2* *HS-LS-4-3* *& HS-LS4-4*	Results from all previous experiments (and model 1) Home-learning from Lesson 14-part A Student Activity Sheet from Lesson 6 Chart from Lesson 14	**Obtaining, evaluating, and communicating information** Integrate sources of information to solve a problem (people not following CDC recommendations regarding antibiotic use) by communicating scientific information and ideas *about natural selection that help explain the cause for why antibiotic resistance infections are (effect) becoming increasingly common.*	There is so much we've figured out about what's happening with resistant bacteria. Let's go public to our community!

T

Next Lesson....Where we're going: Now that students are confident with their natural selection model, a question will be raised that cannot be easily explained with our current understandings. If the mountain birds continue to come back to UCSD every winter, why don't the city UCSD birds and mountain birds continue to mate with one another? Why are they considered two different populations? This question will motivate ongoing investigations to continue into bend 3 of the storyline which will help students build and apply additional mechanisms of evolution.

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Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 15 - Student Activity Sheets
- Copies of previously filled out:
  - Chart from Lesson 6 - Student Activity Sheets
  - model 1 from end of Lesson 8 Student activity sheets
  - Results from all previous experiments (5a-5e)
  - Chart from Lesson 14
  - Optional: Chart from Lesson 9

Preparation of Materials (15 min.)

- Make copies (digital or paper) of the Infographic Assignment Prompts and Rubrics for each student.
- Make copies of the CDC Recommendations, first introduced in Lesson 4 of Bacteria.
- Post any relevant posters or class charts that might help students build their infographic, particularly from Lessons 4, 7, and 14.
- Check that the link to the YouTube video,"Getting Started" works on your internet connection.

Getting Ready: Teacher Preparation

Alternative Student Conceptions

There will be a temptation for students to focus their energy on developing an infographic that is visually pleasing, but light on compelling data and explanations of the science they have worked with over the last few weeks. As such, it is important to monitor students and probe their thinking to be sure they are considering how to synthesize the relevant science and communicate it in a way that is accessible for the general public. These infographics should be **more compelling** than the CDC recommendations **because they help explain how things work to convince people <u>why</u>** they should engage in (or change) certain behaviors.

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Learning Plan: How can we share what we've learned with our community? (4 x 50 min)

1. (10 min) Have students individually reflect on the following question in their Student Activity Sheet 15.a. to help students take stock of all they've figured out in this unit to help motivate the culminating project. Use the following prompts to help students reflect. Then, transition to a Consensus Building Discussion. [A]

Suggested Prompts:

➔ Think back to all you've done to learn about the evolution of bacteria and the spread of antibiotic-resistant bacteria in this unit. From what you've learned, what are your biggest takeaways?

Listen for student responses [B] **that refer to what they found interesting or shocking throughout the unit, such as:**

➔ We have to be so much more vigilant about how we take care of ourselves, particularly when it comes to behaviors like proper hand washing. We also know now that we need to make sure to follow our doctor's instructions, even when we get sick.

➔ We learned that despite the fact that the CDC has clear instructions about how to prevent the spread of antibiotic-resistant bacteria, people are ignoring them. Knowing what we do about Addie's situation, this is baffling.

➔ I always thought if the bacteria weren't being killed or got stronger it meant that it mutated and all of a sudden started to have new characteristics and just developed the strength, but I never knew how. It surprised me to learn that the "strength" was always there in the population. Bacteria with that special strength were able to out-compete and pass on their genetic information more than the weaker bacteria who died out.

➔ I was also surprised to find out how fast bacteria reproduce when we did those exponential curves.

➔ I was surprised to see the interaction of antibiotics and bacteria - we just saw the antibiotics popping the bacteria like a balloon.

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

[A] As this is the final lesson for this bend of the unit, you may want to share with students that they can think more broadly, drawing from all of their learning over the many lessons to add to the discussion.

Strategies for this Consensus Building Discussion

[B] Any answers relevant to the topic are acceptable. If needed, ask students some additional probing questions to motivate the activity in this lesson, creating the infographic with recommendations for behaviors in which people must engage in order to prevent the spread of antibiotic-resistant bacteria. You may consider adding the following questions:

- What did you find disturbing about the spread of antibiotic-resistant bacteria?
- What will you be sure to do now that you wouldn't have done before?
- What, if anything, have you already shared with friends and family about this unit?

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➔ I couldn't believe that 1/3 of us have resistant bacteria on ourselves right now!

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2. (10 min) Next, shift to a Sharing Initial Ideas Discussion C. Use the following prompts to guide students to re-articulate what they've already determined in previous lessons about needing to spread the word in a more effective manner. You may want to refer to the "Mission Board" started in Lesson 4.

Suggested Prompts:

➔ We know that the CDC's guidelines that suggest what people should and should not do are not effective. What have we discussed about disseminating the information we've learned in our investigations with the public?

➔ What do people need to know in order to truly influence their behavior?

Listen for student responses that mimic the next step in the story line, such as

➔ We need to share information with the public that will truly compel them to follow the guidelines in the CDC, but we need to do it in a more effective way. People need to understand the science behind why these behaviors actually prevent the spread of bacteria, but they also need to understand what can happen if they do NOT follow the guidelines.

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3. (30 min) Hand out the Infographic Assignment Prompts and Rubric packet. Turn students' attention to the first page, reminding students of the good news about a collaboration we have with a local clinic in which they will share Infographics with the general public that share the CDC recommendations and explain why they are critical.

Give students a moment to read through the assignment description. After all students have had sufficient time, pause to answer any questions that may arise about the nature of the

- What surprised you about the effectiveness of the guidelines put out from the CDC?

Strategies for this Initial Ideas Discussion

C Leading up to this lesson, students have agreed several times that information about the spread of antibiotic-resistant bacteria must be made available to the general public. Refer back to these moments if students don't offer ideas about how critical it is to share this information.

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assignment.

Infographics, while they may be a familiar medium for students, may not be something students have created before. In order to familiarize themselves with the elements of infographics that they will need to consider when designing their own, students will complete some reading about what makes great scientific infographics in jigsaw groups. Begin the jigsaw activity to learn about and share information about high quality infographics D**.**

Check in with groups by using the following prompts:

Suggested Prompts:

- ➔ What are the most important things you learned about high-quality infographics?
- ➔ What will you be sure to include in your infographics?
- ➔ Will infographics be a useful tool for spreading the message we want to send to the community? How will you make sure?

Listen for student responses such as:

- ➔ We can't neglect the science in our infographic. Instead it needs to be front and center as we make an emotional or personal appeal to the community.
- ➔ We need to include our sources and cite specific, relevant data to back up our claims.
- ➔ The data must be presented in such a way that is visually pleasing and clear. Any visual aids we include should contribute information rather than distracting from information. Everything should have a clear purpose of spreading our intended message.

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4. (50 min) With a solid understanding of what scientific infographics should look like, students can now engage in additional research to determine the criteria upon which they will be graded when they design their own infographics.

Share with students that because they have been the drivers of this unit up until this point, it is

Additional Guidance - Jigsaw Activity

D Split students into four groups, assigning each group one of the resources from the Infographic Assignment:

- Make It Matter
- Find Credibility and Give Credit
- Show What You Mean
- How Can I Make My Infographic Visual

Students can read through the material they are assigned, sharing out the key points with their group members to ensure they are taking away the most important information. Then, re-format the groups so that each person in the new group has read a different article. Students should share out what they learned from their article so that all of the students have a common understanding of the key information from all four articles.

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only right for them to be partners in determining the grading criteria for the final infographic. Invite students to turn to the page in their packets titled, "Defining Shared Criteria for a Good Infographic." Give students a moment to read through the information and pause to answer any questions. Divide students back into their Jigsaw groups from Step 3. Assign an article to each group, guiding them to use Student Activity Sheet 15.1 to take notes.

Once students have read their assigned articles, reassemble the groups so that there is one student from each of the letter groups (A,B,C,D) E**. Instruct students to share what they learned and to come up with a list of 6-7 criteria that they want to propose to the large group. Remind students that they need to be prepared to justify their proposals with reasons that they think the criteria are important to include.**

Once groups are ready to make their proposals, give students the opportunity to share their criteria with the class, capturing each group's criteria in a shared space (whiteboard or chart paper.) Once the class has completed its list of criteria and explained it, ask the group if any can be combined, and do so. Once they are combined, see if there is a class consensus on the list, or if anyone disagrees with one that is proposed on the list. Continue to develop consensus until there are between 8-10 criteria on the list.

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5. (50 min) Pose a rhetorical question to students to get them thinking about the effectiveness of the existing CDC Documents and how they might improve upon these documents. Once the question is posed, send students off to work on drafting out a list of the information and data they will definitely include in their infographics.

Suggested Prompts:

➔ The CDC has already put out guidelines for people, but they weren't effective. What specific information will you include to ensure that the community adheres to these guidelines?

Differentiation Strategies and Alternate Activities

E Students who struggle with reading could be assigned to group C "Partner Needs" for a shorter, more straight-forward reading assignment.

Differentiation Strategies and Alternate Activities

F Any students with special needs may benefit from an infographic template ready to help their organization. You could also assign one or two sections at a time and check for understanding as they go to keep them on track.

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Send students off to work on their drafts F. Circulate and assist, probing students as necessary to ensure that they are considering the guidelines for what types of information to include. Take care to notice whether or not students are including scientific information from their investigations to back up their recommendations and explain their importance.

When students have completed a draft, pair them up with another student to get feedback using the rubric you created out of the shared criteria from Step 4. In their initial reading of the work of their peers, instruct students to examine the infographic without providing any feedback. Then, ask them to review it a second time, this time using the rubric to give specific feedback. Students may want to seek feedback from multiple partners, applying the feedback they are given after each meeting.

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6. (50 min) When students appear ready to begin creating their infographics, gather the group to examine the instructions for using the Venngage tool to design their infographic. Play the Getting Started YouTube video and guide students to the Support page if they need additional instructions about how to use the tool.

When students have completed their first draft of their infographics, give them a chance to seek feedback from a trusted peer in a similar manner to their work in Step 5. Remind students to use the rubric to give specific feedback to their peers.

When students have completed their infographics and applied peer feedback, each student should share out his or her infographic to the class. Preferably, they would also be able to share this with a representative from the partnering clinic or other healthcare professional.

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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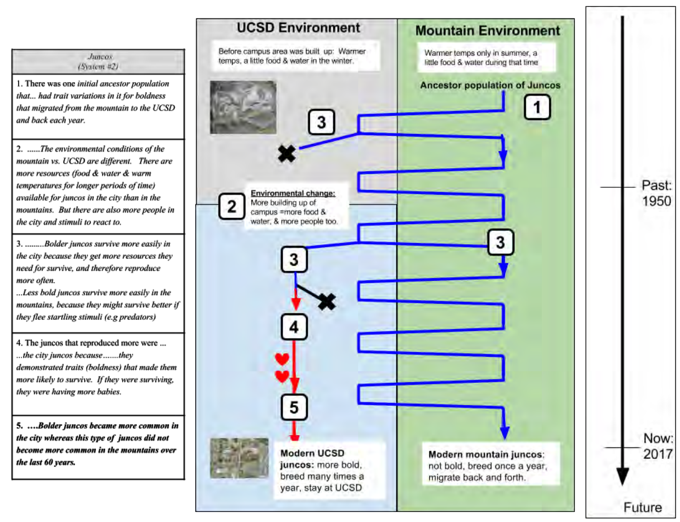
Lesson 16: Where did these two different populations of juncos come from (and how do we know to which population a bird belongs)?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students developed infographics of what they figured out from juncos (natural selection) and how it could be applied to the growing prevalence of antibiotic resistant bacteria. They went public with their infographics to their health care community, to help inform and change personal healthy care choices when it comes to the (mis)use/overuse of antibiotics.

T	**This Lesson...What we are doing now:** You will help the class build a consensus model to represent a line of common ancestry for the mountain and UCSD juncos, and use to raise new questions related to gaps in the model, that will motivate future investigations across this last bend of the unit. In this lesson, you will foreground questions about whether each population really is its own group, or whether individuals intermix between groups. Students will analyze data that will suggest that there is very little immigration between the two populations (though there is some), which will motivate wondering whether they (the immigrants or the visitors) are interbreeding during the time they are together on campus.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L16: Where did these two different populations of juncos come from (and how do we know to which population a bird belongs)? (60 min.) S *Building toward* ⬇ *NGSS PEs:* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	Aerial photographs of the UCSD campus site, before and after it was built provide patterns in urban development of the area over that time. The methodology used and some of the results from Pamela Yeh's paper on *"Rapid Evolution of a Sexually Selected Trait Following Population Establishment in a Novel Habitat"* provides banding data on the Juncos to help establish if there is migration.	**Develop a model** based on evidence to illustrate the relationships between systems *(the UCSD environment and mountain environment, the populations of juncos in each, the changes to those populations over time and mechanisms of natural selection at work on both populations).*	We took stock of our explanation of the juncos from L14 and constructed a consensus model to represent what we know. In doing so we identified some lingering questions from L14, as well as new questions we realized that the model raises: • Why are there two different populations anyway, particularly when they keep visiting the same environment at the same time of year? • Why don't the current UCSD juncos, or the parents, or grandparents of these UCSD juncos decide to go back to the mountains? • Why don't new ones that visit from the mountains decide to stay?  This led us to realize we don't know the answer to these questions because we don't know what, if anything, might be keeping the two populations apart, particularly since they overlap in some of the time they are in the same environment. We brainstorm wayt they might be affecting each other's populations when they are together during that time period. Maybe they • learn some behaviors (those that aren't inherited) from each other when they are together; • migrate from one group to another; and/or • have babies together. All of these seem like they would affect the outcomes of natural selection because if they are influencing each other in one of these ways, maybe one population is making the other one more like it, or maybe both are becoming more like each other. This possibility is something we neglected in our natural selection model (influx of individuals or alleles from outside populations).

		Gather & Communicate Information by critically reading scientific literature adapted for classroom use to summarize the *methodology* (how scientist keep track of juncos in the UCSD population) and evidence *from this study (to determine the relative proportion of immigrants detected in the population from one year to the next).*	This raised some questions related to gaps in the evidence we have for any of these ideas: ● *We don't actually know if either there is immigration --- do mountain juncos decide to stay?* ● *Do they ever mate with each other during their time together, so that the offspring are hybrids of both populations, in which case they might be a little like both parents?* These questions led us to identify an even bigger problem: We don't actually know if the current UCSD juncos are natives born to UCSD parents or whether they are recent immigrants or who their parents are. *This foregrounded a more immediate question we need to answer, how do they even know which bird is which, for sure? If they do go back and forth or mate, then what does it really mean to be a UCSD or a mountain bird*? In fact at some point this would be a real problem in history, because what would classify the first immigrants -- are they UCSD or mountain birds -- *when does it count that they are a separate group, population, or some scientists might even call these different species?* **We decided we need to look more closely at which bird is born to whom (who are their parents) and do they stay where they are born. We brainstormed possible ways that scientists might keep track of that, and decided we needed data like this to answer our questions.** We look at a section of methodology use and some of results (from Pamela Yeh that describes how they keep track of the birds. From the summary we discover: ● Scientists band the UCSD birds after they are born; a band is a unique identifier bracelet the bird wears on its leg. ● Only a few unbanded (banded ones are UCSD) juncos are found in the resident UCSD population each year. (There actually are some migrants (a small percentage ~ 5%). ● Also, there are some other populations of juncos, with different trait variations in them across North America. We argue from evidence that this tells us: ● Most moms in the UCSD population tend to stay in that population (most UCSD birds descend from other UCSD birds -- see lesson 9 data in student activity sheet) and so the population is stable. If some adults left, the population wouldn't be that stable. ● It doesn't look like both populations have overlapping ranges where they breed, even though there is some overlapping time where they are in the same place and COULD interbreed during that window. BUT we still don't know if the UCSD juncos and the visiting mountain birds or the new immigrants interbreed with the native UCSD birds during that window (winter on the UCSD campus). We need more data on that sort of thing -- who bred with whom. That led us to wonder, *is there some way that we could know for certain whether a child is an offspring of one dad vs. another?* **Next steps: We have some ideas. We have heard paternity tests related to DNA can be used to figure out who is the dad of a baby and want to look into that further to figure out if birds are the offspring of one parent versus another.**

Next Lesson….Where we're going: Students will look into how DNA testing works through a short reading. The class will use a karyotype to elicit their ideas about how chromosomes are passed on from parents to offspring (ideas developed in middle school). You help students extend the model to show how gene locations (loci) and corresponding alleles could be used to infer who the biological dad of an offspring is, if you knew each of the alleles in the mom, the offspring, and in all the potential fathers. Students will extend the model of simple inheritance (50% of the genetic information from each parent) through a home-learning reading to make discoveries about mutation rates, mitochondrial DNA and differences between X and Y chromosomes.

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Getting Ready: Materials Preparation

Materials For Whole Class

- Poster paper or butcher paper in 4 colors (example: gray, green, blue, white)
- Colored marker
- 10 Index cards & blank white paper
- Scotch tape, magnet clips, and/or push pins depending on how you want to mount the strips of paper to the board you will build in this lesson
- Pictures of the the UCSD area before and after the campus was built

Additional materials needed for **option 2** (see preparation of materials to the right):

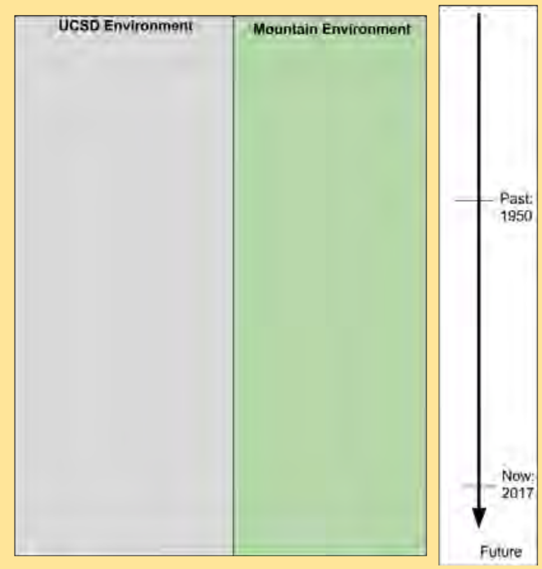
- 3M Painters Masking Tape, 60 yd. x 1/8", Blue, 5 mil - 2090 or cut dozens of ⅛" strips of blue paper in 2" and 1 ft. sections
- ⅛" strips of red paper (3 - one ft. sections)
- ⅛" strips of black paper 3 - one ft. sections)
- 3 heart shapes cut out of red paper

Materials For Students

- Lesson 16 - Student Activity Sheets (1)
- Lesson 16 - Campus aerial photos (1 for each pair of students or one projected for class)

Preparation of Materials for making a Common Ancestry Board (15 min.)

- Hang three big sheets of butcher paper already side by side on a wall or cork board (e.g. gray for representing an older campus environment next to a green for the mountain one). Include a representation of the timeline to the right as well on white butcher paper.
- Print Lesson 16 - Campus aerial photos for students. Print one color copy for you to use on the poster.
- **Option 1:** Make one of these for every class you have, and draw on it using markers when you add lines of common ancestry.
- **Option 2:** Make one of these to share between classes. In this case, you will want to tape and tack diagrams to the board with each class the first time they build the board, and take them down between classes. If you do option 2, then additional material prep is as follows:



- Cut 10 heart shapes out of red paper to tape on later (Option 1: use a red marker instead).
- Cut the strips of paper needed (see materials for whole class). If you use painter tape instead for the blue line on the board, then you may want to pull strips of painter tape that will make up segments of the blue line shown below on the poster and put them to the side.

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Getting Ready: Teacher Preparation

Background Knowledge

Alternative Student Conceptions

Linking Our Understanding to Scientific Terminology

Natural selection

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Learning Plan: Why are there two different populations of juncos (and how do we know to which population a bird belongs)? (45 min)

1. (5 min) Facilitate a Consensus Building Discussion around the question, "where did these two populations of juncos come from?" Have students refer to lesson 14 system #2 to review the information they have already discovered about the juncos. A Have students discuss in their table groups what they discovered and what questions they still have about juncos. Next have each group share out one thing they reviewed from lesson 14 system #2 and one question that they still have about the juncos.

Listen for *student responses* such as:

We know that juncos lived in the mountains and migrated during the winter months to a milder climate near the UCSD campus.

We know that sometime in the 1980s some juncos stayed on the UCSD campus and never went back to the mountains when the winter was over.

The juncos that live on campus are bolder than the mountain juncos and that was tested and proved through blood tests.

UCSD juncos reproduced more than the mountain juncos.

We think that the mountain juncos still visited the campus during the winter and then went back to the mountains, but the juncos that made their home on the UCSD campus did not travel back and forth.

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A The purpose of this discussion is to take stock of what students already figured out in lesson 14 so that these ideas can be reused in this lesson to make a class model of the split in the mountain vs. UCSD juncos populations that occurred sometime before 1983.

This lesson does not have a separate student activity sheet for it. Instead, have students look back at lesson 14, system #2 through this lesson to draw ideas from it as the class co-constructs this model.

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Listen for *student questions* such as:

Did something happen that made the juncos want to stay on the UCSD campus?

Do the mountain juncos ever mate with the UCSD juncos?

Do other mountain juncos ever decide to stay in the city?

Do UCSD juncos ever go back and live in the mountains?

Why did some birds stay at UCSD and others keep migrating?

Motivate the need to capture our shared ideas and shared questions in a public representation to represent what we know about this case.

Suggested Prompts:

➔ In order to determine what it is we want to figure out and what we all agree is known about this case, it may be useful to build a model of a juncos case that shows what we know is happening to the two populations now, and what we think happened to them in the past.

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2. (5 min more) Have students bring their Lesson 14, system 2 summaries with them and gather around the poster paper you already have hanging side by side (e.g. gray for representing an older campus environment, and green for the mountain one), that is already labeled "UCSD environment" on the gray paper and "Mountain environment" on the green paper. Tack or tape an index card on the top of the Mountain side of each section of the paper (this is one on the right side. Add a post-it note or index card with a #1 on it tho the spot that represents the initial ancestral population of juncos. B

Additional guidance

B When wall space is limited in your room, it may make the most sense to build the poster following the guidelines for option 2 in **Getting Ready: Material Preparation.** The rest of this lesson will outline the steps needed to follow option 2.

Attach an index cards with tape (or push pins if on corkboard). Either option allows you to remove all these from the poster at the end of this class, so that it is ready to co-construct anew with the next class you teach using option 2.

Build a key next to the poster adding a piece of paper representing step 1:

Juncos explanation thus far (from L14) *(System #2)*
1. There was one *initial ancestor population that... had trait variations in it for boldness that migrated from the mountain to the UCSD and back each year.*

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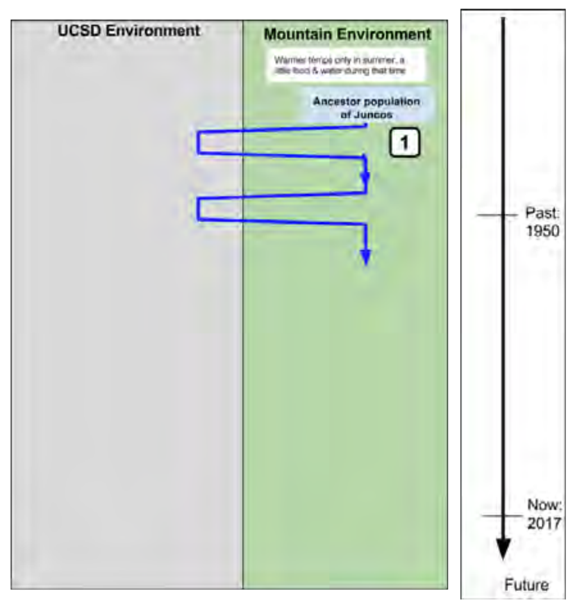
Point to the the timeline added to the right side of the poster. C

Make sure to address the migration patterns if the students don't bring this up, you may need to prompt them.

Suggested Prompts:

- ➔ Look back at system #2, in Lesson 14. What do we know about where the mountain juncos live? When do they live there?
- ➔ Do they remain in that one environment year round?
- ➔ We know that in the past the mountain juncos migrated back and forth from the mountain region to the coastal region every year, for years without any of them staying and surviving right? How might this be an important piece to this puzzle?
- ➔ If we started mountain population of juncos, up here in the green in the past, how might we show this back and forth migration each year?



Add the line as it is shown in the the example (more blue line in the mountain region to indicate this is where they spend more time). It is recommended you use yarn for this line. Only do a few zigzags to represent migration in the past. D

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3. (7 min) Next, ask students, "What is it we know about the mountain environment?"

Additional guidance

C To support the interactive nature of the co-constructed modeling building, this lesson will provide more teacher direction details than are typical in other lessons.

Additional Guidance

D Using yarn instead of marker, allows you to quickly remove the yarn from one class to the next. Attach tape, magnetic clips or push pins to the yarn at each corner of the zig-zag in the blue line shown.

Any labels you add should be on white copy paper or index cards that you can add and remove easily.

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Add a brief description of student responses to the top of the green butcher paper using a piece of white copy paper.

Ask students, "We have a good start to our model to help us represent our understanding of the patterns of migration from the mountains to the coast. But what else do we know from lesson 14 that we should include about how the UCSD environment has changed since the campus was built?"

Students should recognize that this model has not addressed the fact that the coastal landscape has changed dramatically over time. And they should articulate the need to represent this environmental change in the model.

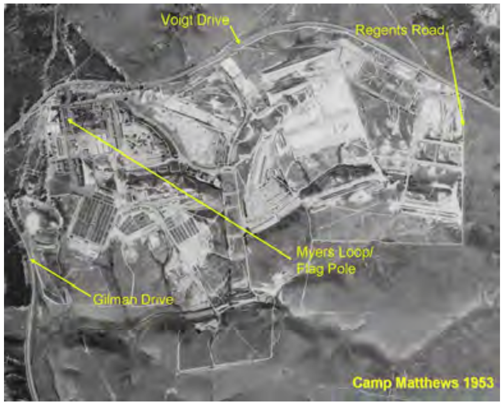
Then say, "We need some way to briefly summarize the environmental changes that have occurred at the UCSD site, since campus was built. And we need to show what it was like in the past (point to the left top side of the model) and what it is like now (point to the left bottom side of the model). Let's briefly look at some photographs of the UCSD environment -- one from before the campus was built and one from today."

Pass out a copy of [Lesson 16 - Campus aerial photos] to each pair of students and project a color image of these from the computer. E Summarize that the aerial photograph in the top photo is the site of Camp Matthews, a military base, that was active for a bit after WWII, but was eventually closed, and the land given to UCSD to build their campus at that site in 1960.

Have a quick whole group discussion about the major environmental changes that came with building up the campus. This should be similar to what they wrote in step 2 of system 2, in Lesson 14.

Classroom Artifact

E Example:



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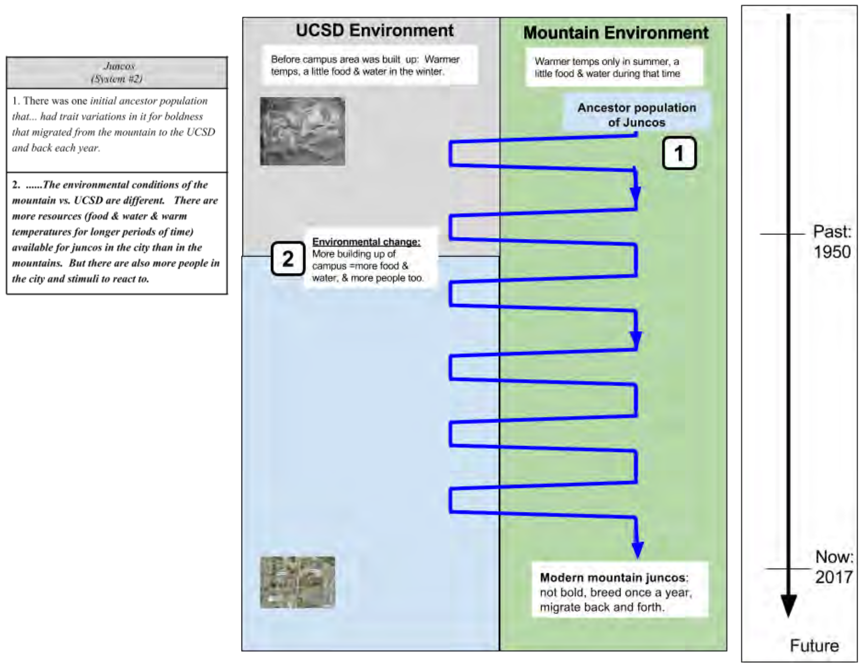
To represent this environmental shift cover up a part of the gray background for the UCSD environment with a different color butcher paper to represent the more recent environment at UCSD that started occurring after campus was built (late 1950s) After adding the blue butcher paper background, place an index card with a #2 on it at this location, and add another piece of white paper that is a key for #2.



Add a piece of white paper that describes the environmental change that occurred over time at the UCSD location right between the gray and blue sections on the left. F

Add the zig-zagging blue line all the way back and forth into the blue "changed" UCSD environment. F

Additional Guidance

F Keep students involved in the co-construction by having them help write up the index cards and paper that go on the poster.

Ask students questions about how to draw things that are in each piece of the explanation, or where the annotations should go.

Suggested Prompts

- "Should the environmental change go above the blue, below it or right between the gray and the blue? Why?"
- "What should we do with this blue line now? How should we show that they migrated back and forth as time went on?

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4. (8 min) Have students refer to lesson 14, system #2 explanation to continue to add what we know to the model. Students should be able to recognize and restate the third part of the explanation.

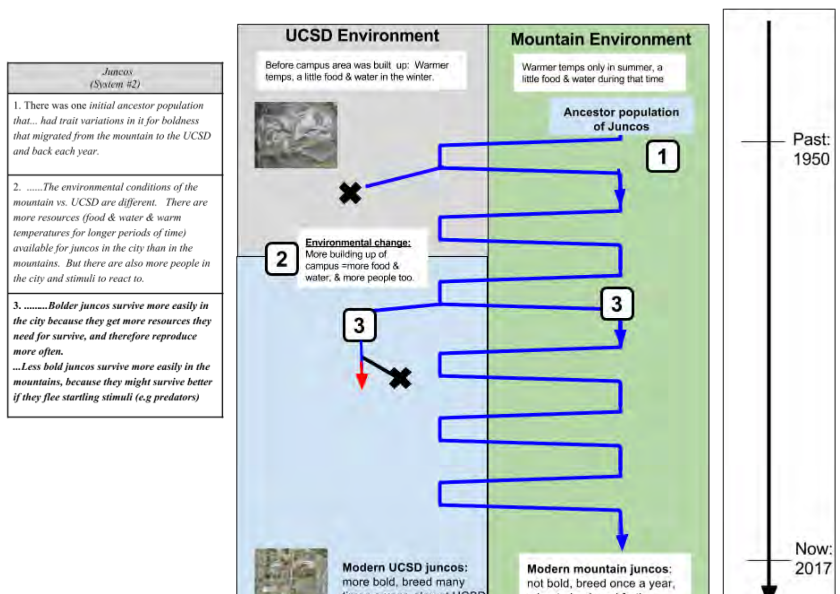
Listen for *student responses* such as:

At some point (1983 or before) some juncos never returned to the mountains. They stayed on campus and started breeding there.

Quickly review what we know about the competitive advantage for juncos with certain trait variations over others in the UCSD environment -- that juncos that have the boldness trait stayed on the campus and made it their home.

Add a blue line of yarn showing a branch of descendants that settled on the campus 30 some years ago.

Have a whole group discussion to address the idea that only certain variations of the juncos (bolder ones) survive better on the UCSD campus than others (based on their boldness). Add a representation of some not surviving and some surviving like the red arrow and "X" shown to the right. Add a #3 index card to summarize this representation, also add a "3"



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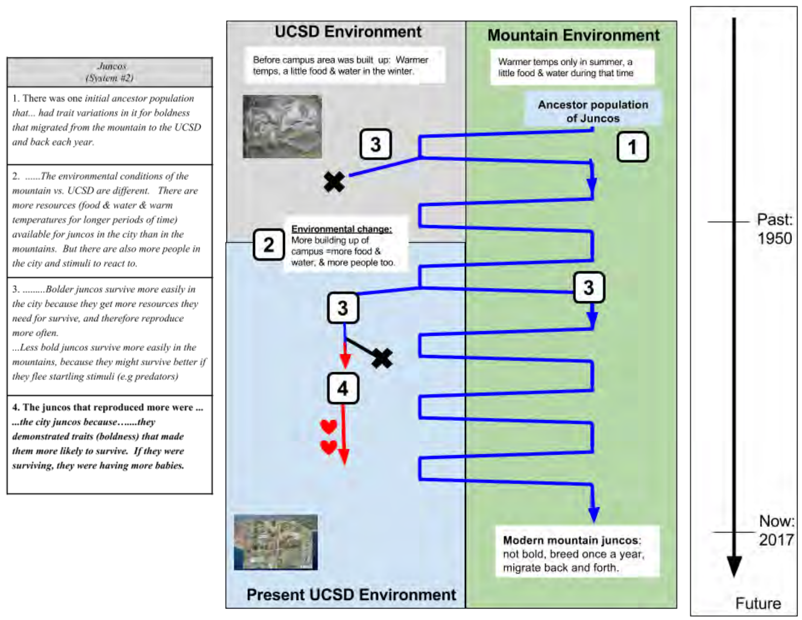
to the mountain side, and reconstruct a summary with students of the logic behind whether bolder or less bold juncos have a competitive advantage in the mountain and include a paper in the key to summarize this.

Ask students, "Is there any evidence that juncos might have stayed in the past? If so do you think they would have survived? Why?"

Add a branching blue line in the past ending in an X to represent we don't think they would have survived if they did migrate. If students argue that whether the "staying on the coast" happened in the past, then add a question mark to this branch.



Next, have students brainstorm with a shoulder partner or small group (2 min) what they think the competitive advantages are within the two groups: "Why do mountain juncos survive in the mountains and UCSD juncos survive on the UCSD campus and not vice versa?" Have students share out one idea from each group, record students' ideas on the board in order to build on their ideas later in the lesson. The model has now grown to include the different groups of juncos and the competitive advantage of each group.

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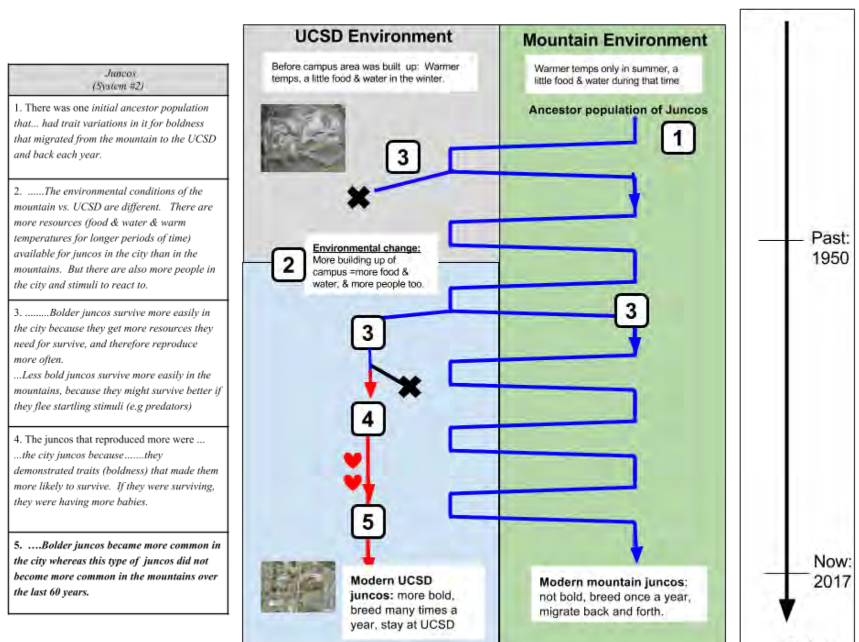
5. (5 min) Now ask students if they feel their model represents everything from their explanation in Lesson 14 for this system. At this point students should recognize the need to add something to the model indicating that the birds that stayed this time and reproduced. G

Add a couple heart representations (icons) to the red arrow as you extend it downward to represent having more babies over time. Students should also keep in mind the reproduction rate. The two populations of juncos did not reproduce at the same rate. How could we represent that on our model? Use at least two hearts to represent the higher rate of reproduction in the UCSD juncos compared to the mountain population and one heart to represent the lower rate of reproduction in the mountain population. Add an index card with a 4 on it to the poster. And add an annotation to the key.

6. (5 min) Now ask students , "How did this lead to a change in the distribution of traits in the UCSD population? " H

To indicate this shift add a #5 to an index card to represent how the juncos population that made their home on the UCSD campus changed over time (more bold, breed more) and a piece of white paper that summarizes this



Strategies for this Consensus Building Discussion

G If they are struggling to connect in the next piece of the puzzle from their prior explanations, have students refer to lesson 14, system #2 explanation and read part four of the explanation -- what we know about which juncos have offspring (those that survived).

Strategies for this Consensus Building Discussion

H If they are struggling to connect in next piece of the puzzle from their prior explanations, have students refer to lesson 14, system #2 explanation and read part five of the explanation.

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population change.

Ask students "When we look at points 3--5 on our model, we see an ongoing process. Does this process have a name?" By now students should have heard the term natural selection, but take some time to have a whole group discussion on the process specifically related to the juncos. They need to understand the idea of natural selection in order to make predictions and ask relevant questions in the next section. Label the steps 3--5 as natural selection.

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7. (5 min) Say, "We have a model to refer to that we all agree represents what we know about these two populations. It shows us

- **how they became different from one another;**
- **that both populations came from one ancestor population; and**
- **that both populations still visit the same environment for part of the year.**

What questions do we have that are still unanswered? Let's look back at the questions we came up with at the beginning of this lesson and also take a minute in your small groups to add any other questions you may have about these two different junco populations and their ancestor population to the board."

Listen for *student questions* such as:

Did something happen that made some of the ancestor juncos want to stay on the UCSD campus?

Do the mountain juncos ever mate with the UCSD juncos?

Do other mountain juncos ever decide to stay on campus?

Do UCSD juncos ever go back and live in the mountains?

Strategies for this Building Understandings Discussion

If students don't raise questions about migration or mating, then use additional prompts to generate more student questions

Suggested Prompts:

➔ They visit the same environment during the same portion of the year. Do you think they might interact with each other during that time? What ways might they interact with each other or influence each other? Does being in the same place at the same time cause them to influence or interact with one another? In what ways might they influence or interact with each other?

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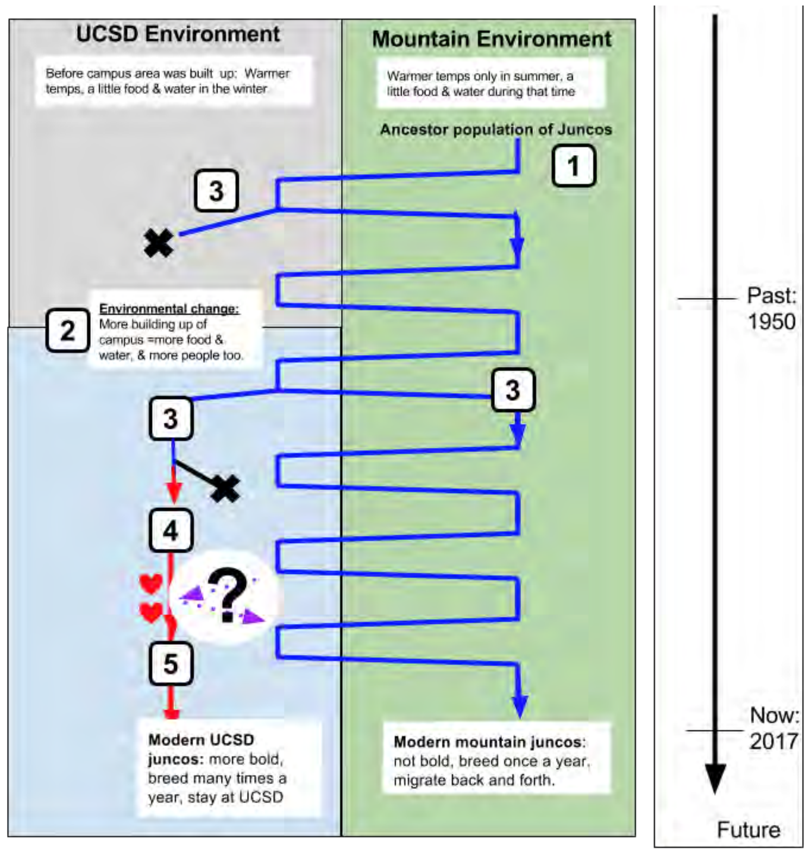
Are there other things that have changed in the birds?

Does this happen in other places, where one ancestor population becomes two different populations?

Summarize by pointing out that many of the questions that students have raised are around ancestors, migration, and breeding. Emphasize the need to show which parts of our model we have some big questions about.



Add dotted lines and questions marks to any parts of the model students are wondering about, but make sure to emphasize that one big question area is around trying to figure out things like, "How do we know whether a bird is part of one population or another? Or whether they immigrate or mate? And how would we know for certain which birds come from which population?" J

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7. (8 min) Give each student a copy the Lesson 16 Student Text. In order to take a closer look at the

Strategies for this Building Understandings Discussion

J This issue was brought up in earlier lessons. However you want to revisit the question here, to either recall what we learned earlier (that birds were banded), or to brainstorm ways to keep track of which bird is which.

Once the idea of banding birds is re-raised, use it to motivate the need to look more closely at the banding related data to see if we can use it to answer some of our questions.

Questions around this part of the model are what students will be investigating over the next few lessons, and will eventually lead them to deciding that these two populations are no longer interbreeding and/or that they aren't producing offspring that survive in the UCSD environment. At that time, students will co-construct a definition of species to represent this idea.

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data, have them read it individually and note the information they feel would be important to figure out how one population of mountain juncos came to be two. Ask them to make annotations and underline passages in a close reading of the text. Remind students to look for any evidence that will help us in figuring out our next set of questions (these should be posted somewhere in the classroom in order for the students to reference). Give students 7 minutes to complete this task. When they have finished have students discuss the reading in their small groups.

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8. (12 min) Have each group document the data from the reading that they think will help them answer the next set of questions and why. Groups may use a sheet of paper or you may provide them chart paper if you prefer. K

Lastly, have a whole group discussion about the data that was presented in the reading.

Suggested Prompts:

- ➔ What data can be used to answer some of our new questions?
- ➔ Does this data answer any of our new questions completely or just support what we think might have happened to the junco population?
- ➔ Do any of these data points raise more questions?

Listen for *student ideas* such as:

Most of the juncos in the UCSD population appear to be banded; therefore we know they descended from a UCSD mom (because mom's are also banded and observed incubating the egg they lay).

There are very few migrants into the UCSD population (under 5%) each year.

There are some other populations of juncos besides the mountain ones and UCSD populations,

Additional Guidance

K If time permits, when groups are finished give each group a set of stickers (markers, post-its) and have them go look at the other groups' work. Have them put a sticker next to the data points they agree with on the other papers.

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with different trait variations in them across North America. These could also have been sources of where the ancestors of the UCSD population came from.

Suggested Prompts:

➔ Did the article tell us anything about who mates with whom? Do we know who the UCSD moms mate with -- a UCSD dad or a mountain dad?

Listen for *student ideas* such as:

We still don't know if the UCSD birds and visiting mountain birds or the new immigrants interbreed with the native UCSD birds during that window (winter on UCSD campus).

Nobody is "banded for that"; that is probably hard to catch happening without cameras on the birds all the time.

Ask students how we might be able to figure out whether a bird is the offspring of a dad from one population vs. a different dad from another.

Suggested Prompts:

➔ Is there some way that we know for certain whether a child is an offspring of one dad vs. another?
➔ Are there any ways that people can figure that out who is the dad of a given offspring?

Give students a couple minutes to brainstorm ideas and have them share out their ideas.

Listen for *student ideas* such as:

We have heard paternity tests related to DNA can be used for figuring out who is the dad of a given baby.

Maybe you can use DNA testing to figure out if birds are the offspring of one parent versus another.

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Summarize the students ideas as the next steps we should pursue next time, looking into how DNA testing works and how it could be used to figure out who the dad is of a baby, in order to see if we can use similar methods with the juncos.

Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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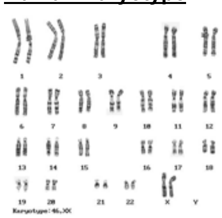
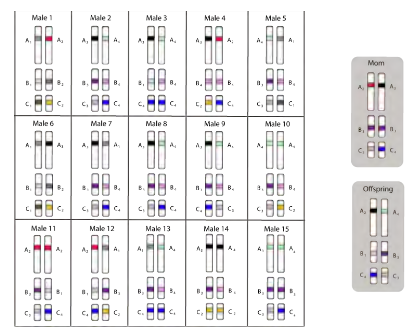
Lesson 17a: How can you tell for certain if someone is the biological father of a child?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students built a consensus model to represent a line of common ancestry for the mountain and UCSD juncos and used it to raise questions about whether each population really is its own group, or whether individuals intermix between groups. They determined that there are some migrants between group each year, which further motivated wondering whether they are interbreeding.

This Lesson...What we are doing now: Students gather information about how much DNA is unique between different people and apply what they figure out to a karyotype-based model for patterns of inheritance between offspring and parents that could help identify who the dad of a child is.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L17a: How can you tell for certain if someone is the biological father of a child? (50-55 min) I *Building toward* ⬇ *NGSS PEs:* *HS-LS4-1,* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	**Article #1:** (http://www.bbc.co.uk/science/0/20205874) provides an overview of DNA testing works. **Human Karyotype** 	**Develop and use a model** based on evidence *(a human karyotype)* to illustrate the relationships between structures chromosomes, genes, alleles, and loci, and their function; use the model to predict the percentage and number of chromosomes passed on from one human parent to their offspring. **Gather and communicate information** integrating qualitative and quantitative scientific information in written text along with visual displays to determine additional structures *(mtDNA, Y vs. X chromosomes) and mechanisms (mutations) that would cause a child to end up inheriting genetic*	Based on our wondering, *Were mountain birds that were visitors to UCSD or the new immigrants (that 5%) interbreeding with the native UCSD birds?,"* we came up with the idea for doing a paternity test thing -- something with DNA that we could check. We read a bit about how similar the alleles of DNA are between people (article #1) and how DNA testing compares the segments of DNA that are unique between individuals (e.g. the ones responsible for trait differences between individuals).  We tried to represent this idea of DNA that is unique between individuals vs. the DNA that is the same using a karyotype (showing the 23 pairs of chromosomes that all humans have in common). And we marked small locations (loci) on chromosomes that would represent those genes that have alleles that vary between individuals. (We agree that for some genes there are more than two alleles.) Then using the karyotype representation, we realized that all the DNA that an offspring inherits (both the DNA that is similar between all humans and the stuff that is unique) all comes from mom and dad (50% from each -- one allele for each gene from each parent in the chromosome pairs). We applied this model to an example population of possible dads (that carry different combinations of alleles for three genes) and compared known DNA for a mom and her child (see image to the right). We were able to use our ideas (and the idea that there is also a 50/50 chance which allele of each gene on each chromosome pair is passed on to an offspring) to identify who the dad would be. We argued from our model that we just need a way to measure/detect if the children have the same alleles that their parents had. We think there should be a complete match in half their DNA to each parent. So if an offspring doesn't have one of the alleles that a parent has then that wouldn't be the parent…that will help narrow down who their parents are. And we think that the more alleles we check, the more likely it would be that we could identify the likely parent. **We think we can use this method to determine if a bird has a parent that's from one population vs. another.** But since our model was based on the assumption that 50% of the DNA you get comes from your mom and 50% comes from dad, and that your DNA would match 50% of each of their DNA exactly, this raised another question, *Do you ever inherit*

		information that is different than what the parents had (50% + 50% ≠ 100%)?	*instructions that don't match your parents' DNA exactly? Is it ever possible that a child can end up inheriting genetic information that is different from what the parent's had (50% + 50% ≠ 100%)?* **Next steps: We have heard about mutations and we decided we wanted to investigate this question a bit more about what that is -- and prepare to look into that via a home-learning assignment (data packets).**

Next Lesson....Where we're going: Lesson 17b will follow up on the home-learning assignment. Student discoveries from this will help them realize that no 50% of genetic information is inherited from each parent, due to such factors as rare mutations, mitochondrial DNA, and X vs. Y chromosomes. These three factors will be used to develop another model for establishing common ancestry in lesson 17b. In lesson 18 students will use the karyotype model of inheritance they developed in this lesson and analyze data about the frequency and diversity of alleles found in the mountain vs campus junco populations to argue that it is very unlikely that male birds from the mountains are interbreeding with female birds from UCSD and/or if they are, their offspring aren't surviving.

Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 17a - Student Activity Sheets (1)
- Lesson 17a - Student Article (1)
- Lesson 17a - Home Learning (1)

Materials For Whole Class

- Projector to display the following on a white board:
  - Lesson 17a - PI#1 - Human Karyotype
  - Lesson 17a - PI#2 - Allele Matching Diagram
- White board markers

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Getting Ready: Teacher Preparation

Background Knowledge

The karyotype model developed in this lesson and the related home-learning assignment build off prior knowledge that students would have developed in middle school:

LS3.A: Inheritance of Traits

- Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits. (MS-LS3-1)
- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. (MS-LS3-2)

LS3.B: Variation of Traits

- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. (MS-LS3-2)
- In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. (MS-LS3-1)

Linking Our Understanding to Scientific Terminology

- Karyotype
- Gene
- Allele
- Loci
- Body cell/Somatic cell
- Sex cell/Gamete
- Optional: Gene pool

Introduced in the reading:
- Mitochondrial DNA (mtDNA)
- Mutation
- Mutation rates

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Learning Plan: How can you tell for certain if someone is the biological father of a child? (50-55 min)

1. (5 min) Ask students to read the lesson question and make a prediction on the first page of their Student Activity sheets in response to it: Based on what you have heard about outside of class, summarize some of the ways that you think people can tell for certain if someone is the biological father of a child. After a couple of minutes, have a few students share out their predictions.

Listen for *student responses* such as:

We think there is a paternity test thing -- something with genetics that we could test.

Could we do a DNA test?

Maybe a child would share more DNA in common with their father than with someone who is not their father.

---

2. (15 min). After establishing consensus [A] of why the idea of comparing DNA could help us figure this out, ask students to summarize some of the important ideas behind how DNA testing works to determine who is related to whom by annotating an article for main ideas related to what we predicted. Tell students to take 5 minutes to read and then 5 minutes to answer the questions on the rest of page one of their student activity sheets.

Then have students share out their ideas to the last two questions on the student activity sheet.

Suggested Prompts (same as student activity sheet prompts):

Teacher Supports & Notes

Additional Guidance

A Though the word DNA hasn't been introduced yet in this unit, the idea of alleles have. If that connection hasn't been brought up by students yet, help students connect the idea now that alleles are sections of a DNA molecule that provide genetic instructions to all the cells of the organism.

Since most students will have heard about paternity tests related to people or DNA fingerprinting, a time efficient way to establish consensus around this idea is as follows:
1) After the first student brings up this idea, you can ask students how many of them wrote something similar.
2) Then ask for a few of them to share how they phrased this idea.
3) Then ask how many students have heard of something similar.
4) Then ask why would comparing DNA of a child and a group of people help us figure out which person is the biological father of a child.

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➔ What did you say for the second question (Q2)? (The article claims that only about 0.1% of the DNA (genetic information) is different between different people. What might be some of the traits that these differences would influence?)

➔ What ideas did you have for the third question (Q3)? (If all people have over 99.9% of their DNA in common, what are some of the traits that all people share in common that this DNA would be responsible for producing?)

Listen for *student responses* such as:

The trait differences related to the 0.1% of DNA that is different could be for things like eye color, hair color, skin color, height, blood type.

The trait differences related to the 99.9% of DNA that people have in common could be for things like how to make cells, tissues, and all the substances that the human body needs in order to function.

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3. (10 min) Ask students to turn to the second page of their student activity sheets and project [Lesson 17a - PI#1 - Human Karyotype] on a white board. Tell students, "This is a karyotype. It is a series of photographs taken using a microscope of the chromosomes that are found in the nucleus of every human body cell (somatic cell)." B The photographs were rearranged so we could compare patterns in what we notice about these chromosomes. Let's also use this karyotype to summarize what we know about how DNA is passed on from parents to offspring and how all this is connected to genes and alleles."

Ask students questions about what patterns they notice in the chromosomes and what else they recall as you co-construct C a diagram like the one shown on the next page. Have students make a copy of the annotated diagram on their student activity sheets.

Additional Guidance

B The exception to this is red blood cells. Whether you mention the exception or not is up to your judgement. The main idea of this discussion is to convey that cells that make up the human body all have the same DNA in them.

Strategies for this Consensus Building Discussion

C If this unit is being taught after a genetics unit, this will be a quick review. If this unit is being taught before a genetics unit then some of these ideas will be new and others should be ones they worked with in middle school. In the latter case, go slower through the co-construction of the annotated model to gauge which ideas are most familiar to the group and which are novel.

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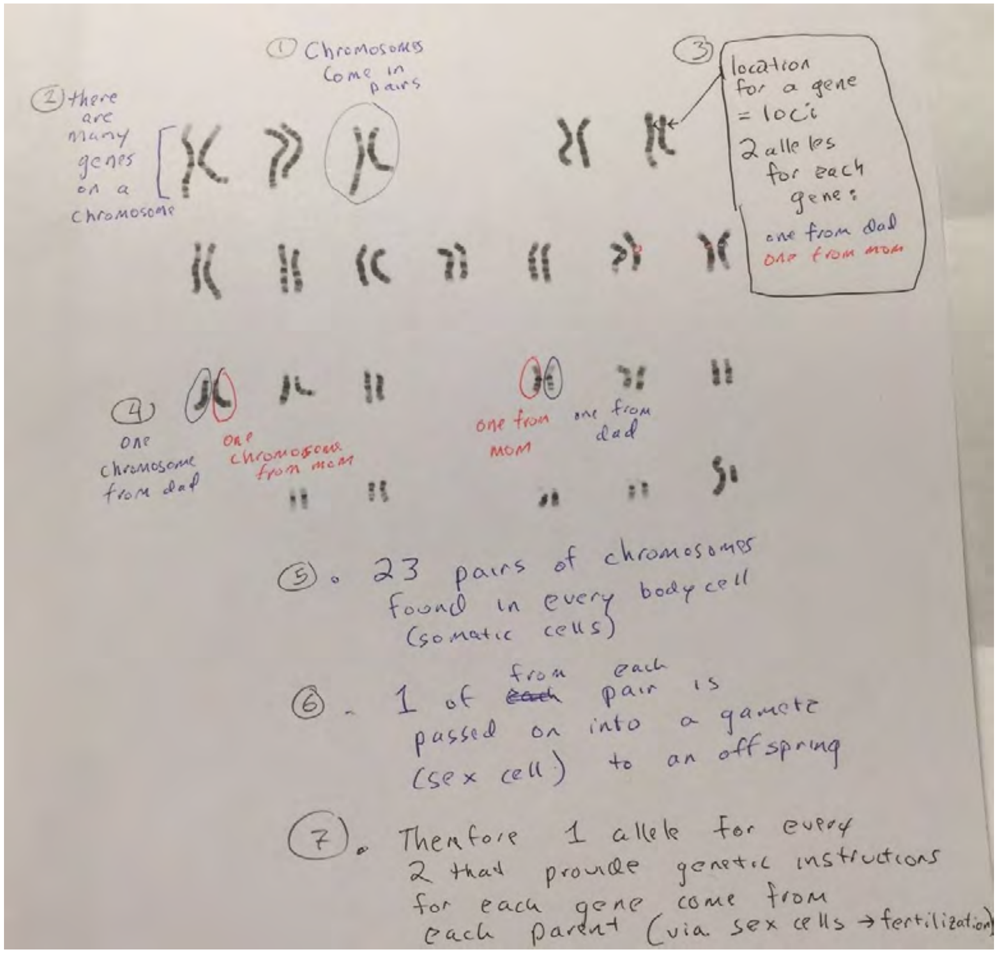

Once the diagram is annotated, have students complete question 4 (Q4) on the bottom of their students activity sheet. D

Formative Assessment Opportunities

D Walk around to check student responses to see if they say "50% of the chromosomes" and provide reasons connected to one of the ideas outlined in the diagram above or to previously covered mechanisms of inheritance (e.g. one chromosome of every pair is randomly sorted into sex cells, through the process of meiosis).

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4. (10 min). Tell students that we are going to try out this idea to see if we can use it to answer our original question in this lesson -- determining who a dad might be. Have students turn to the next page. Project [Lesson 17a - PI#2 - Allele Matching Diagram]() so that students can refer to the color banding for each type of allele. E

Read through the directions together. Emphasize that this model is showing allele variation for the 0.1% of the DNA that varies between individuals. Have students work with partners to answer questions 5 and 6 (Q5 and Q6).

Listen for *student responses* F **such as:**

answer for Q5: dad #3

answer for Q6: The first population is not missing any alleles, the second population is missing allele A2, the third population is missing allele B2 and C1.

---

5. (8-13 min.) Discuss questions 7 through 9 (Q7, Q8, Q9) as a class. Brainstorm ideas in this discussion for how this might all apply to the two populations of juncos, figuring out whether a baby bird has a parent that comes from one population vs. another, and whether there might be some things in this 50%-50% inheritance model we overlooked. G

Listen for *student responses* such as:

Some people are born with mutations.

Mutations are when there are random changes to the genetic instructions.

Maybe something goes wrong during meiosis or fertilization and a child doesn't end up with the

Additional Guidance

E If student activity sheets are printed in black and white, they won't have this color cue for the alleles at each loci. They will only have letters and subscripts. Showing the color version of the projected image is a nice supplement for finding patterns, and can be used a reference point for a quick check in if necessary on questions Q5 and Q6 (see F).

Formative Assessment Opportunities

F Try pulling up a chair to different tables where partners are talking through their ideas. Gauge student responses. To determine if this optional step is needed: Have a student go to the whiteboard and use markers and Lesson 17 - PI Allele Matching Diagram to explain their answers.

Alternate Activities

G The goal of this discussion is to brainstorm ideas that we will investigate in future lessons and in the next home-learning. The space provided on the student activity sheets for this question is to support the option to have small groups of students talk about this idea and have one person in the group write down ideas the

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right number of chromosomes or alleles.

We would need to see data on actual DNA in parents and offspring to see if this happens and/or we need to see data related to mutations across a population to determine how common this is. H

---

6. (2 min.) Assign Lesson 17a - Home Learning , emphasizing that it may help provide some of the data we were looking for in order to answer some of our questions. Assign a due date that corresponds to when you plan to do lesson 17b with students. I

group comes up with.

Make sure to have students think through questions Q7 through Q9 before the next lesson and before step 6. If time is short, you could assign Q7 through Q9 as a precursor home-learning assignment for this evening before going on to step 6.

If you assign these questions as home-learning tonight, follow up with the assignment the next time you meet. Have students share out their responses in the first 5-10 minutes of the next day, and then move on to what is outlined here in step 6: assigning lesson 17a - Home Learning for completion outside of class that following night or due on a future date. (see I)

Additional Guidance

I You will use students' discoveries from this home-learning to build a class model of how DNA can be used to determine how closely related two individuals are in lesson 17b. But the timing of doing lesson 17b is flexible. It can be done before lesson 18 or between lessons 18 and 21. But it must be completed before starting lesson 22.

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 17b: How can our new discoveries about how DNA is inherited help us figure out to which populations an individual junco belongs?

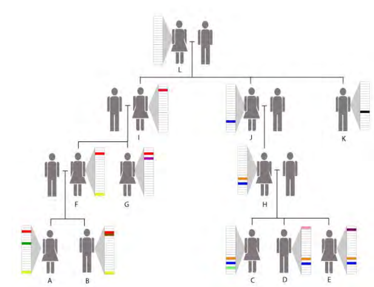
High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students built a consensus model to represent a line of common ancestry for the mountain and UCSD juncos and used it to raise questions about whether each population really is its own group, or whether individuals interbreed between groups. They determined that there are some migrants between groups each year, which further motivated wondering whether they are interbreeding.

T

This Lesson...What we are doing now : You will help students apply information about mutation rates, mitochondrial DNA, and sex chromosomes that they gathered from their home-learning readings to build a model showing how mutations accumulate from one generation to the next across different branches of a family tree. They use this model to calculate relative amounts of mutated DNA in common for different family members, and predicted amounts of mutated DNA in common across generations.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L17b: How can our new discoveries about how DNA is inherited help us figure out to which populations an individual junco belongs ? 60 min. S *Building toward* *NGSS PEs:* *HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	A variety of phenomena (originally introduced in the L17a home-learning assignment) are referenced for this lesson; this includes data related to mutation rates in humans, fruit flies, mice, and bacteria, and the relative number of genes in mitochondrial DNA, and relative amounts of genes on the Y vs. X chromosomes compared to the total number of genes in the human genome.	**Develop and use a model** based on evidence *(constant mutation rates in mtDNA)* to illustrate and/or predict the relationships *(relative amount of genetic information in common)* between components of a system *(individuals across four generations that share a single female ancestor in common).* **Use Computational and Mathematical Thinking** to support a claim that amount of *mtDNA (in non-coding regions) that is different between any two individuals due to mutations that were passed on from one generation to the next, would be directly proportional to the number of generations*	Since our pattern of inheritance model that we developed in Lesson 17a, was based on the assumption that 50% of the DNA you get comes from mom and dad, and that your DNA would match 50% of each of their DNA exactly, this raised two other questions: *Is it ever possible that a child ends up with some DNA that isn't completely identical to the DNA of parents? Do offspring end up with 50% of their mom's DNA and 50% of their dad's DNA?* In our Lesson 17a home-learning assignment, we gathered information from text and used mathematical thinking to help answer these questions. We reported out our discoveries from that assignment here. These included: • No, it's not identical. All organisms get mutations in their DNA from one generation to the next; the rate of mutations among mammals is relatively constant. This changes their DNA they get from their parents a very little bit. • No, its not 50% because a small amount of the DNA that mom passes on to all of her offspring is in the mitochondria of her egg cell to her offspring; dad does not pass on mitochondrial DNA. And if the offspring is a male, then the Y-chromosome which comes from dad, contributes a smaller amount of DNA than the X-chromosome. • But all of these mechanisms contribute a relatively small amount of variation compared to our simplified model that assumed half of the DNA comes from mom and half comes from dad through sexual reproduction. We used these discoveries to build a model showing how mutation patterns in DNA from these small effects would compare across different branches of a family tree, across three generations (from a set of great-grandparents down through all their great-grandchildren. The model included ideas that we developed through our home-learning assignment: • Random mutations appear in a very small portion of the DNA that children inherit from their parents (via. gametes). • Some of that DNA comes just from mom (e.g. mtDNA) or dad (e.g. Y-chromosome). • The odds are that every mutation that a sibling inherits will be different. • Whatever mutation a female inherits in their mtDDA is one she would pass on to all their offspring. • Whatever mutation a male inherits in his Y-chromosome is one that he would pass on to all of his sons. • Additional mutations appear in each new generation at a constant rate. 

		it has been since they shared a common ancestor.	We used the mutation accumulations shown in the 3 generations family tree model to calculate 1) relative amounts of mutated DNA in common for different family members, and 2) predicted amounts of mutated DNA in common across generations. From our calculations, we noticed some patterns: • The amount of DNA that is different (due to mutations) between siblings is less than between cousins, which is less than between second cousins. • The amount of mtDNA (in non-coding regions) that is different between any two individuals due to mutations that were passed on from one generation to the next, would be directly proportional to the number of generations it has been since they shared a common ancestor. **Next steps: We argued that we could apply these patterns back to the original questions that led us here: "How Can Our Discoveries Help Figure Out How Long Ago Two Different Populations of Descendants Shared A Common Ancestor?"**

Next Lesson….Where we're going: Students will use the ideas of mutations accumulated across generations as a way of measuring common ancestry in later lessons. They will argue why doing such comparisons in the DNA in juncos helped scientists determine with greater certainty how close different population of juncos were, and how distantly related they were (how long ago they shared a common ancestor), rather than simply looking at physical traits, behavioral traits, and geographic distribution of their populations alone.

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Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 17b - Student Activity Sheets (1)

Materials for Each Pair of Students

- Optional: A dozen different colored pencils to share.

Materials For Whole Class

- Lesson 17b - PI Mutation Accumulation Across Generations Diagram
- 20 popsicle sticks in a can, numbered 1 through 20.

1 dozen different colors to mark the projected images of Lesson 17b - PI Mutation Accumulation Across Generations Diagram. Possibilities include:

- Showing the diagram under a document camera and coloring it with colored pencils.
- Projecting the diagram onto poster paper, and using a marker to color the loci on the poster paper.
- Projecting the diagram onto a white board and using a dozen different colored white board markers (e.g. EXPO Low-Odor Dry-Erase Markers, Fine Point, Assorted Colors, Pack Of 12)

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Getting Ready: Teacher Preparation

Background Knowledge

The karyotype model developed in this lesson and the related home-learning assignment build off prior knowledge that students would have developed in middle school:

LS3.A: Inheritance of Traits

- Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits. (MS-LS3-1)
- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. (MS-LS3-2)

LS3.B: Variation of Traits

- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. (MS-LS3-2)
- In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. (MS-LS3-1)

Linking Our Understanding to Scientific Terminology

- Common ancestor
- Generation
- Mitochondrial DNA (mtDNA)
- Mutation rates

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Learning Plan: How can our new discoveries about how DNA is inherited, help us figure out which populations an individual junco belongs too? (60 min)

Teacher Supports & Notes

1. (10 min) Ask students to take out their Lesson 17 Home-learning assignment and prepare to share out their discoveries. Review the questions that led us to investigate these data packets further by restating: "Our model in part 2 assumes that all the DNA that a child inherits is 100% identical to the DNA found in mom and dad (50% from each). We were wondering? Is it ever possible that a child ends up with some DNA that isn't completely identical to the DNA of parents? Do offspring end up with 50% of their mom's DNA and 50% of their dad's DNA?"

Listen for *student responses* such as the following and record them on the board:

No, it's not identical. All organisms get mutations in their DNA from one generation to the next; the rate of mutations among mammals is relatively constant. This changes the DNA they get from their parents a very little bit.

No, its not 50%. A small amount of the DNA that mom passes on to her offspring is in the mitochondria of her egg cell to her offspring; dad does not pass on mitochondrial DNA.

No its not 50%. The Y-chromosome has a smaller amount of DNA than the X-chromosome, so when a boy is born it is because dad passed on the Y-chromosome and mom passed on the X-chromosome; in this case mom passed on more DNA than dad.

Summarize all of the mechanisms and pose a new question: "If mutations make it possible that a child ends up with some DNA that isn't completely identical to the DNA of parents, and the mitochondrial DNA and Y-chromosome DNA contributes some DNA from just mom or dad, then is this a big difference or minor difference on our 50/50% assumptions of our karyotype model of inheritance?"

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Listen for *student responses* such as:

This is a minor difference. The relative amounts of each of these differences doesn't contribute much to the vast amount of DNA that comes half from mom and half from dad through meiosis.

---

2. (5 min.) Tell students that we are going to put all these ideas together, to create a model of how mutations might accumulate in something like mitochondrial DNA or the DNA of a Y-chromosome from one generation to the next. Emphasize that this model might help us answer the questions related to how long ago two different populations shared a common ancestor.

Instruct students to turn to the first page of the Student Activity Sheet. Project the PI Mutation Accumulation Across Generations Diagram. Help orient students to what is represented in the model.

Suggested Prompts: A

- ➔ This model represents a family tree (or a pedigree). How many generations are shown on this family tree?
- ➔ Where is the most recent generation shown in this diagram? How many individuals are shown in the most recent generation? How many are females?
- ➔ What is the relationship of the generation shown in the top of the diagram to the generation shown in the bottom of the diagram?
- ➔ Which letters are people who are siblings?
- ➔ How can you tell who the parents of B are? How about G?
- ➔ Are there some individuals who you can't tell who their parents are?

Listen for *student responses* such as:

Additional Guidance

A Depending on when this unit is taught in the year students might have already worked with pedigrees. If students already have experience with pedigree representations, you will want to use a different line of questioning, such as:

- Describe what we are seeing in this pedigree.
- What does this information tell us about who is related to whom?

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Four generations are shown on this family tree.

The most recent generation is at the bottom of the diagram. There are seven individuals in the most recent generation and four of them are female.

I, J, and K are siblings; F and G are siblings; A and B are siblings; C, D, and E are siblings.

B's parents are the female labelled F and the male to the left of the female labeled F. The connected line between them shows that they had offspring together and the line that drops down shows who their offspring are. G's parents are I and the male to the left of I.

Some of the males are from outside this family and we don't see who their parents are.

---

3. (10 min) Remind students that we know that most of the DNA that all people have is exactly the same. 99.9% is DNA they have in common, while 0.1% is DNA that is different between people. Point to the stack of boxes shown next to each female. Tell students that this represents the vast majority of DNA that everyone has in common, and in this model we are showing only some of the mitochondrial DNA, which we know is passed from female to all of her offspring and in this model we are going to track that DNA through the females in this family tree. Point out that there are 20 boxes in this strand of DNA, and that we can think of those boxes as genes, or we can think of them as base pairs, in a section of DNA, but either way, we are going to use those boxes to keep track of mutations across generations by assuming a constant mutation rate.

Instruct students to use a dozen different colored pencils to keep track of mutations across generations if they are available, otherwise simply mark the location of where the mutation occurred in the DNA in pencil.

Add the following annotation to the side of the model: "This model will assume a constant mutation rate of 5%, or 1 out of 20 loci on the DNA (either the locations of genes or the locations

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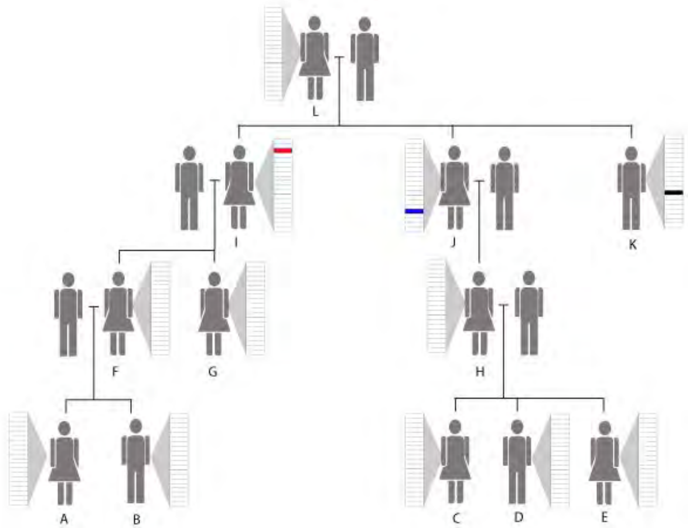
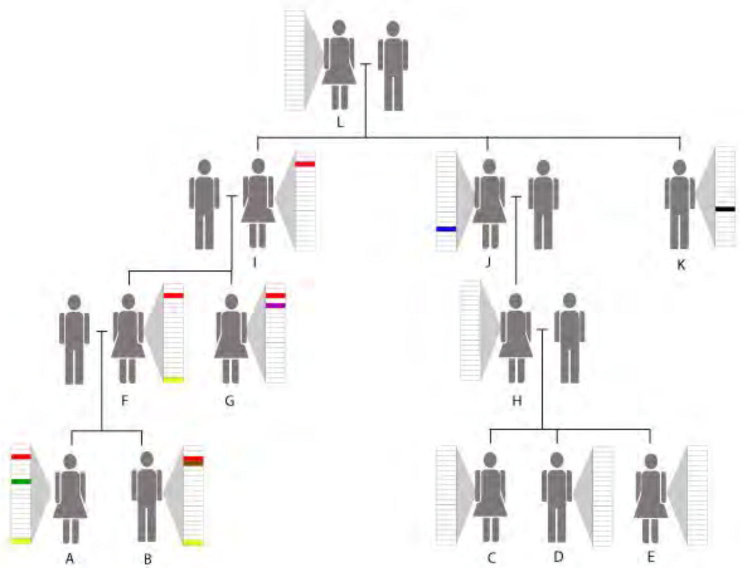
of base pairs)."

Say, "Let's show a mutation in the mitochondrial DNA being passed on from L to her offspring by selecting a location for a random mutation. Let's pick a random number 1 through 20."

Have a student draw a popsicle stick from a can and read the the number on the stick. Using the number the student reads, count down from the top box on individual H, and color in that box using a red mark (the example shown here assumes the number 3 was selected first).



Then point out that the great grandmother had another child -- female J. Remind students that when this person is born she is born with a different random mutation than her sibling, but these mutations are in a portion of the mtDNA, that doesn't cause a change in the expressed trait as this part of the DNA contains no genes.

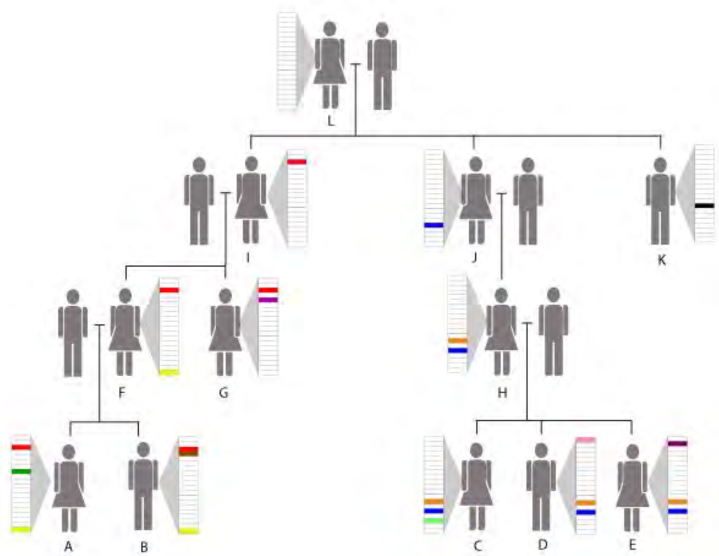


Have a student draw a popsicle stick from a can and read the the number on the stick. Using the number the student reads, count down from the top

box on individual J, and color in that box using a blue mark.

Now repeat this process with individual K, adding a black mark to the location in their mitochondrial DNA that was mutated. B

Go back to individual I, emphasizing that all of her children would inherit a copy of her DNA, which now includes this red mutation, and each would get an additional random mutation. Have students draw popsicle sticks from the can and read the the number on the stick. Using the number the student reads, add a different color mutation for F, and a different color mutation for G. Make sure to include the red mutation in their DNA as well.



Repeat this process for individual F and her offspring: A and B.

Now repeat this process again starting back with individual J, using different colors for each new mutation.

Ask students if they have any questions about the model so far.

Discuss Q1 as a class and have them summarize the class ideas together on the bottom of their student activity sheets.

Additional Guidance

B In this simulation you will keep the popsicle sticks removed from the can. But this is a simplification that is designed to prevent drawing the same numbered stick more than once. You can share this simplification with students, arguing that if the mutation rate is actually 1 out of 10,000 then drawing the same number more than once would be far rarer than we are simulating in this model. You can also emphasize that such rare probabilities would still affect how certain we could be about what this model predicts, just like the slight differences in 50% alleles from mom vs. dad, that we assumed earlier and found was slightly off. You can emphasize that figuring out how to calculate statistics to determine how certain you can be of your predictions when you have large data sets and small sources of error or randomness is an important area of study for people who investigate patterns of inheritance and DNA. You may want to emphasize that studying statistics and these areas of biology is an area of overlap between math and science where a lot of exciting discoveries are being made.

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Q1 Prompt:

➔ Could we build a similar model for predicting accumulation of mutations in Y-chromosomes in males from one generation to the next? Explain.

Listen for *student responses* such as:

Yes, it should work much the same way, but it would follow the males within the family tree and start with a male ancestor.

---

4. (10 min.) Have students complete part 2 with a partner. C **Then after working on this for 7 minutes, bring students back together to share out their responses to question 3 in the last 3 minutes.**

Q3 Prompt:

➔ Why does individual C have more DNA in common with D, than they do with individual B?

Listen for *student responses* such as:

Because C and D are more closely related than C and B.

Because B has accumulated more different mutations than C has.

Because B and C have a common ancestor that is female (their mom) only one generation ago, but C and D have a common ancestor that is female (their great grandma) three generations ago.

Emphasize that this type of mathematical thinking might be useful in helping us develop an answer to our question about whether our new discoveries about how DNA is inherited could help us figure out which populations an individual junco belong to. It seems like there are some patterns in human families that we are seeing that might be applicable in junco families too.

Formative Assessment Opportunities

C Walk around to listen in on student discussions and calculations around Q2 in part 2:

Individuals we are comparing	What percentage of mtDNA do they share in common?	What percentage of mtDNA is different between them?
Any mom and daughter compared to one another	95%	5%
Any two siblings compared to one another	90%	10%
Any grandchild compared to their grandma	90%	10%
Any great-grandchild compared to their great-grandma	85%	15%

Individuals we are comparing	When did they last have a common ancestor?	What percentage of mtDNA do they share in common?	What percentage of mtDNA is different between them?
C and D	1 generation ago	90%	10%
F and G	2 generations ago	80%	20%
B and C	3 generations ago	70%	30%

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5. (10 min.) Have students complete part 3 with a partner. D **Then after working on this for 7 minutes, bring students back together to share out their responses to questions 6 and 7 in the last 3 minutes.**

Q6 Prompt:

➔ Using actual mutation rates in humans & other mammals, what % of mtDNA do you predict would be different between 2 individuals that shared a common female ancestor 8 generations ago?

Q7 Prompt:

➔ Using actual mutation rates in humans & other mammals, what % of DNA in the Y-chromosome would be similar between any 2 males that shared a common male ancestor 10 generations ago?

Listen for *student responses* such as:

In 8 generations we predict that 0.16% of the DNA would be different.

In 10 generations we predict that 98.84% of the DNA would be different.

Emphasize that it seems like we are seeing some really powerful patterns here that would allow us to draw comparisons between the DNA of any two individuals in such a way that we could determine how closely related they are.

6. (10 min.) Remind students of the goal we had coming into this lesson related to the question: "How Can Our Discoveries Help Figure Out How Long Ago Two Different Populations of Descendants Shared A Common Ancestor? Have students work in partners to try to apply their

Formative Assessment Opportunities

D Walk around to listen in on student discussions and calculations around Q5 in part 3:

Most recent common ancestor	Differences in mtDNA predicted in our model.	Similarities in mtDNA predicted in our model.	Differences in actual mtDNA predicted in humans and other mammals	Similarities predicted in actual mtDNA predicted in humans and other mammals
	1 out of 20 = 5%	19 out of 20 = 95%	1 out 10,000 = 0.01%	9,999 out of 10,000 = 99.99%
1 generations ago	10%	90%	0.02%	99.98%
2 generations ago	20%	80%	0.04%	99.96%
3 generations ago	30%	70%	0.06%	99.94%
4 generations ago	40%	60%	0.08%	99.92%
5 generations ago	50%	50%	0.10%	99.90%

Formative Assessment Opportunities

E You could collect these responses to assess students understanding at this point at the end of the period. Or if more time is needed to complete these, you could ask students to complete them as home-learning and collect them at the start of the next class.

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ideas to this question by completing the Conclusions & Next Steps sections of their Student Activity Sheets. E

---

7. (5 min.) Ask a couple students share out their arguments in response to these last two questions.

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 18 What alleles are found in both populations?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students gathered information about how much DNA is unique among different people and applied what they figured out to a karyotype based model for patterns of inheritance between offspring and parents. They used this model to argue for how it could be used to help identify who the dad of a child is (if we knew the alleles that each individual had in their DNA).

<table>
<tr><td>T</td><td colspan="3">This Lesson...What we are doing now: Students analyze data regarding the alleles found in mountain vs. UCSD population of birds. They use the patterns in this data to argue that the populations are either not interbreeding or if they are, the offspring aren't surviving.</td></tr>
<tr><th>Lesson Question</th><th>Phenomena</th><th>Lesson Performance Expectation(s)</th><th>What We Figure Out (CCCs & DCIs), New Questions and Next Steps</th></tr>
<tr><td>L18: What alleles are found in both populations?

(30-40 min.)

S

Building toward
⬇
<u>NGSS PEs:</u>
HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5</td><td>Blood tests from UCSD and mountain juncos show patterns in the alleles found in each population; additional physiological measurements of the birds show differences in wing & tail sizes between the individuals found in each population.</td><td>Obtain and Communicate Information from scientific literature adapted for classroom use to determine patterns in the relative proportions and percentage of alleles found in one juncos population vs. another</td><td>Because we wanted look at some of the DNA in these different birds to help us tell if a male parent from one population is mating with a female from another population, we read a study on the type of alleles found in mountain birds for a particular gene.

We noticed some patterns in this data compared to the alleles found in UCSD birds:
There are many mountain bird populations, some are the ones that visit UCSD, some visit other parts of California in the winter, and return to the mountains in the summer.
Four of the five loci (gene locations) showed a decrease in the number of alleles in the UCSD population as compared to the other populations of mountain birds.
One allele (208) at locus Gf05 was found in 62.5% of the campus birds, while the allele was found at very low frequencies across the mountain populations (and not found at all in some populations).
We argue from evidence:
There are some alleles in the mountain gene pools that aren't in the UCSD gene pool.
There are some alleles in the UCSD pool that are missing from the mountain gene pools.
This is evidence that they aren't interbreeding (or if they are, the babies aren't surviving).
But this raises more questions:
If they did interbreed and have offspring, how would the chances that their offspring (hybrids) would survive and reproduce in the environment they were born into compare to the non-hybrids living in that environment?
What advantages would there be for the offspring of the UCSD birds that only mate with other UCSD juncos?
If they aren't interbreeding, what is keeping them from doing that?
Are there ways that juncos from each population can tell whether a potential mate is from their own population or is an outsider?
Next steps: We decide to investigate these question further, to look for evidence if there other trait differences in these juncos that might help them tell each other apart and/or might lead them to mate with someone from their own population rather than mating with an outsider.</td></tr>
</table>

Next Lesson....Where we're going: Students will analyze data regarding physical, behavioral, and physiological traits found in the junco vs. mountain populations and use these differences to explain how they might lead a junco to mate with someone from their own population rather than an outsider.

Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 18 - Student Activity Sheets (1)
- Lesson 18 - Student Article & Data Packet (1)

Preparation of Materials (5 min.)

- Make copies of student sheets.
- Use scissors and red/pink paper to cut out a dozen or so heart shapes to add to the Common Ancestry Board for use in step 6.

These materials were developed with funding through a grant from the Gordon and Betty Moore Foundation to Northwestern University and the University of Colorado Boulder.

Getting Ready: Teacher Preparation

Background Knowledge

This lesson draws on ideas that students would have developed in middle school and revisited in previous lessons:

LS3.A: Inheritance of Traits

- Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits. (MS-LS3-1)
- Variations of inherited traits between parent and offspring arise from genetic differences that result from the subset of chromosomes (and therefore genes) inherited. (MS-LS3-2)

LS3.B: Variation of Traits

- In sexually reproducing organisms, each parent contributes half of the genes acquired (at random) by the offspring. Individuals have two of each chromosome and hence two alleles of each gene, one acquired from each parent. These versions may be identical or may differ from each other. (MS-LS3-2)
- In addition to variations that arise from sexual reproduction, genetic information can be altered because of mutations. Though rare, mutations may result in changes to the structure and function of proteins. Some changes are beneficial, others harmful, and some neutral to the organism. (MS-LS3-1)

Alternative Student Conceptions

- Students may not readily explain the difference between genes and alleles. This lesson will help students recall that chromosomes are long bundles of DNA , which have sections within them (genes) at specific locations (loci) that provide information to cells on what proteins to build. That information comes in the form of an allele, and there are two alleles that provide genetic information. Those alleles may be the same (homozygous) or different (heterozygous) in each individual and there may be more than two types of alleles found across all the individuals in a population.

Linking Our Understanding to Scientific Terminology

- Hybrids
- Loci
- Alleles
- Genes
- Chromosomes
- DNA
- Genotype

These materials were developed with funding through a grant from the Gordon and Betty Moore Foundation to Northwestern University and the University of Colorado Boulder.

Learning Plan: What alleles are found in both populations? (30-40 min)

1. (5 min) Refer to the common ancestry model on the board, pointing to the section between both populations where question marks were added. A **Remind students that we had some questions about whether something was happening here. Have students complete the first three questions in their student activity sheets to link to this area, either on their own or with a partner.**

---

2. (3 min.) Have a few students share out their responses to these questions.

Suggested Prompts:

- ➔ What did we decide we could figure out by comparing the relationship between the alleles found in the mountain population males, and the alleles in the UCSD offspring?
- ➔ Do you think it would be necessary to sample all of the birds in the population or could scientists compare DNA from a smaller sample of birds from both areas and still draw reliable conclusions?

Listen for *student responses* such as:

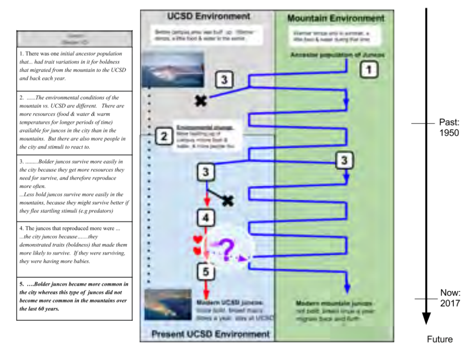
We decided that comparing alleles between populations could help us determine if they are interbreeding.

Larger samples make you more certain, but it may not be necessary to sample every single bird in the population to determine whether they are probably interbreeding or not.

Teacher Supports & Notes

Additional Guidance

A The Common Ancestry model from lesson 16 is shown below.



These materials were developed with funding through a grant from the Gordon and Betty Moore Foundation to Northwestern University and the University of Colorado Boulder.

3. (15-20 min.) Tell students that they are going to read some excerpts of the methods, data, and findings that a group of scientists collected by sampling some of the birds in the UCSD population and some of the birds from the mountain populations, to try to determine if they are interbreeding.

Have students read the Lesson 18 - student article & data packet first, and then complete the 2nd page of the student activity sheet to summarize what they learned. B

In the last 5 minutes, have a few students share out their responses to these questions. Listen for *student responses* such as:

> *If the UCSD males were interbreeding with mountain females, then allele 208 (at locus Gf05), which is in over 60% of the UCSD population would end up getting passed onto someone in the mountain populations. But there is a very small percentage of the mountain population (and sometimes none - such as in the LG population) found with that allele. So either intermating is really rare, doesn't happen, or if it does happen, the offspring don't survive in the mountains.*
>
> *If the mountain males were interbreeding with UCSD females and having offspring that survived at UCSD, then there shouldn't be alleles in the mountain population that are missing from UCSD population.*
>
> *Maybe shorter wing lengths in the UCSD juncos is one thing that keeps them from migrating back with visiting mountain birds and mating with them in the mountains.*

---

6. (7-12 min) Go back to the Common Ancestry Model posted in the room, referring to the question marks shown in the model. Emphasize that it seems like we have evidence that the birds aren't migrating from one population to another, and not interbreeding. Or if they are interbreeding, they aren't having offspring that survive and become part of each population.

ELA Support

B If you aren't familiar with the reading levels of your students, this is a good opportunity to connect with their ELA teachers. Once you've determined their reading levels, consider supporting struggling readers by meeting with them in a small group and using guiding questions to help students make more sense of this scientific text.

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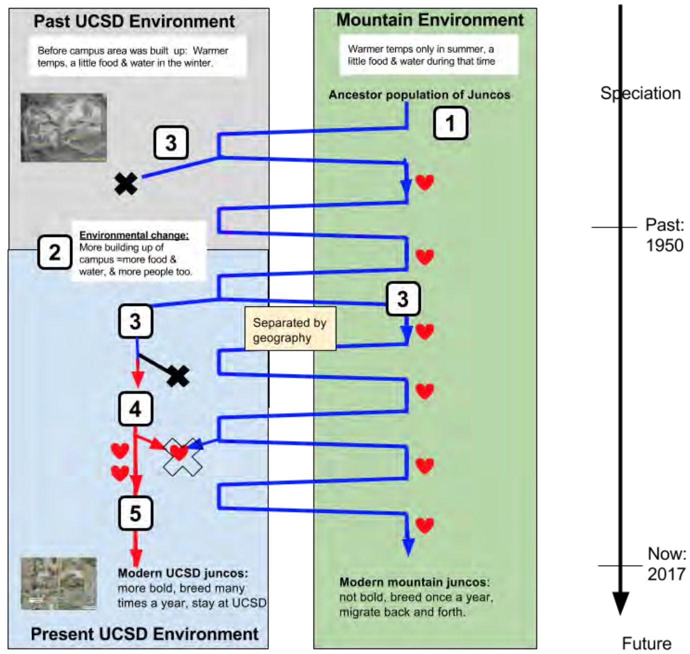
Add a series of hearts to the model showing that each population is breeding in its own environment and an X over a heart between two lines from both populations showing that they aren't interbreeding with each other, or at least aren't interbreeding and having offspring that survive. And example of this model update is shown to the right. C



Point out that this model revision raises some new questions.

Suggested Prompts:

- ➔ If they did interbreed and have offspring, how would the chances that their offspring (hybrids) would survive and reproduce in the environment they were born into compared to the non-hybrids living in that environment?
- ➔ What advantages would there be for the offspring of UCSD birds that only mate with other UCSD juncos? What environment would those offspring thrive in?
- ➔ What advantages would there be for the offspring of mountain juncos to only mate with other mountain juncos? What environment would those offspring thrive in?
- ➔ If they aren't interbreeding, what is keeping them from doing that?

Differentiation Strategies and Alternate Activities

C You may want to pause here to revisit this complex model. Ask students to restate and explain the parts of this model either by turning to an elbow partner or by sharing out to the whole class.

If you wish to collect formative assessment data on students' comprehension of the model, you could print out a copy of the model and ask students to label and explain the purpose/meaning of each part of the model.

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➔ Are there ways that juncos from each population can tell whether a potential mate is from their own population or an outsider?

Listen for *student responses* such as:

Maybe combining half of the alleles from a mountain bird with half of the alleles from a UCSD bird would make it not bold enough to have a good chance for surviving on campus, and too bold to have a good chance for surviving in the mountains.

We aren't sure what would keep birds from interbreeding with outsiders. Maybe they have ways they can tell each other apart.

Have students turn and talk with an elbow partner to brainstorm possible ideas about this question: "What are some ways that juncos from each population might be able tell whether a potential mate is from their own population or is not (an outsider)?" D **Emphasize that we should investigate this question further, to look for evidence if there are other trait differences in these juncos that might help them tell each other apart and/or might lead them to a mate with someone from their own population rather than mating with an outsider.** E

Strategies for this Initial Ideas Discussion

D Some students may claim, "Birds can't tell each other apart," while others may give examples related to the songs they sing or the colors of their feathers.

The goal here is to simply raise the possibility of being able to tell one type of mate from another to motivate the next lesson question and the need to investigate this open question further.

Differentiation Strategies and Alternate Activities

E You may want to have students brainstorm possible ideas further as part of a home-learning to follow-up on at the start of the next lesson. Space for this is provided on the Student Activity Sheets as a "Next Steps" section.

Another small portion of the home-learning that could be added to tonight's assignment could be the chart on the first page of the student activity sheets in the next lesson (see teacher guide of next lesson).

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 19: Are there other trait differences that could lead a junco to mate with someone from their own population rather than an outsider?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students analyzed data regarding the alleles found in mountain vs. UCSD population of birds. They argued from evidence that the populations are either not interbreeding or if they are, the offspring aren't surviving. This led them to wonder what might be leading a UCSD junco to mate only with someone from their own population, rather than a visiting junco from another population.

This Lesson...What we are doing now: Students will analyze data regarding physical, behavioral, and physiological traits found in the UCSD junco vs. the mountain populations. They will use these differences to explain how they might lead a junco to mate with someone from their own population rather than an outsider. They will brainstorm experiments that might be designed to test the question "Can birds really identify and/or prefer potential mates based on these trait differences (e.g. color or song)?"

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L19: Are there other trait differences that could lead a junco to mate with someone from their own population rather than an outsider? (35-40 min). *Building toward* ⬇ *NGSS PEs:* *HS-LS4-1,* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	Additional physical, behavioral, and physiological trait differences between the UCSD and mountain junco populations are introduced in the [Chapter 6 junco video]() (9:59-11:20 & 12:38-13:23 & 14:20-15:17). 	**Plan an investigation** that would produce data to serve as the basis for making evidence-based claims to answer the question, *"Can birds really can identify (effect) and/or do they prefer potential mates (effect) based on these trait differences (e.g. color or song) (cause)?"*	We saw in lesson 16 and 18 that there were some differences in wing length and tail length in these two population in addition to the boldness differences we learned about in Bend 2. We explained why a UCSD junco that mates with another UCSD junco is more likely to have offspring with trait variations that grant them a competitive advantage for survival at UCSD, than if they had an offspring from mating with a mountain junco. We looked at more data from the Chapter UCSD juncos video we saw other trait differences that seem related to which line of juncos they descended from: • Physical differences in UCSD juncos: less dark coloring in head feathers, less white in tail feathers. • Behavioral differences in UCSD juncos: Males are less aggressive, better parents, and stay with one mate more. And males sing at a higher song frequency. • Physiological differences in UCSD juncos: Less testosterone production. We argue that any one of these trait differences might lead a UCSD junco to mate with someone from its own population rather than an outsider: • Maybe the differences in feather colors help birds recognize other birds like them. • Maybe the differences in bird songs help birds recognize other birds like them.. While we think these trait differences might explain why birds are breeding with others from their own population, rather than outsiders, it is all based on the assumption that birds can tell each other apart or select mates based on their color or their song. *But can birds really can identify and/or prefer potential mates based on these trait differences (e.g. color or song)?* **Next steps: We brainstormed how an experiment might be designed to test that question.**

Next Lesson....Where we're going: Students will analyze data (methods and results) from investigations on the role of plumage and vocalization on mating behaviors in birds. They will use the results from these studies to argue that such interactions would lead birds to having preferences for mates that look and act like their parents. This will lead to identifying mechanisms that contribute to speciation as well as ways that revise the common ancestry model to represent a new idea related to a new question: Has this (speciation) happened in other environments for other lines of junco ancestors/descendants?

Getting Ready: Materials Preparation

Materials For Each Student

- [Lesson 19 - Student Activity Sheets (1)]

Preparation of Materials (5 min.)

- You will need an LCD projector and computer to preview Junco Video (Do NOT show title "Evolution in Action." Be sure to click full screen before showing video to students). Show these clips: / 9:59-11:20 / 12:38-13:23 / 14:20-15:17 /

Getting Ready: Teacher Preparation

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From Middle School Performance expectation in NGSS:

MS-LS1-4. Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors…...affect the probability of successful reproduction of animals ….. [Clarification Statement: Examples of behaviors that affect the probability of animal reproduction could include …. vocalization of animals and colorful plumage to attract mates for breeding...]

ns

Though an NGSS performance expectation for middle school (MS-LS1-4) makes reference to animals' behaviors related to vocalization and color plumage to attract mates for breeding, this particular PE also references animal behaviors related to successful plant reproduction (e.g. pollination), as well as plant structures (e.g. hard shell, colorful flowers). Therefore it is assumed that earlier experiences in middle school with this PE, may have focused more on the part of this PE dealing with trait variation related for reproduction rather than trait variation related to animal mating.

Therefore students may initially think that mating between birds is random. After brainstorming how bird song and feather color may be related to how birds tell each other apart, students will likely suggest that variation in such behaviors may be related to attracting mates.

Linking Our Understanding to Scientific Terminology

- Extrapair mating
- Song frequency
- Plumage

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Learning Plan: Are there other trait differences that could lead a junco to mate with someone from their own population rather than an outsider? (35-40 min)

1. (5 min) Ask students to summarize the two main types of trait differences we have discovered in the UCSD vs. mountain juncos. Co-construct a chart similar to the one in 19.1 on the first page of the student activity sheets to summarize what we know with the class [A] [B]:

Listen for *student responses* and co-construct summary statements (shown in red text) such as:

Trait	Mountain Junco evidence	UCSD Junco evidence	Do we have evidence that this is an inherited trait difference?
A. Boldness and exploratory behavior	*Blood sampling data showed that mountain juncos produce less cortisol, which is related to less bold and exploratory behavior.*	*The same data showed that UCSD juncos produce more cortisol, which is related to bolder and more exploratory behavior.*	*Common garden experiments provide evidence that is related to alleles inherited from both parents.*
B. Wing & tail length	*Measurements collected from a variety of mist nets, showed that wing & tail lengths are longer, which is related to birds that can migrate long distances.*	*Wing & tail lengths are shorter, which is related to birds that can't migrate long distances.*	*Common garden experiments provide evidence that is related to alleles inherited from both parents.*

Teacher Supports & Notes

Differentiation Strategies and Alternate Activities

A This chart could be assigned as home-learning in the previous lesson and then used as a point of reference for discussion of the first question (Q1) (see next step).

Formative Assessment Opportunities

B This can also be used as a formative assessment piece in order to check for understanding before moving on. It is important that students are basing their decisions and ideas in evidence and using scientific reasoning and not speculation.

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2. (7 min). Have students complete Q1 with a partner. Then ask for a few volunteers to share their responses.

<u>**Suggested Prompts:**</u>

➔ Why would a UCSD junco that mates with another UCSD junco be more likely to have offspring with trait variations that grant them a better competitive advantage for survival at UCSD, then if they had an offspring from mating with a mountain junco?

Listen for *student responses* such as:

Alleles for boldness give you an advantage for surviving at UCSD, but if you have a parent that is from the mountains, then it is likely you wouldn't end up inheriting alleles for bolder behavior; half of your alleles would be for less bold behavior.

Alleles for shorter wingspan and tail length might also give you an advantage for surviving at UCSD, because you don't need to migrate, and smaller wing span and shorter wings should require less energy and less food, than a bigger body with longer wings would. So if you don't need to fly far away, it is more food/fuel efficient to be more compact. So mating with a UCSD junco would ensure that the offspring get alleles for this shorter body plan, but mating with a mountain junco would give the offspring some alleles that could lead to a bigger body plan. C

3. (2 min). Ask students to turn and talk with a partner for a minute or two about this question: "What other trait differences might there be in these juncos that could <u>lead</u> a junco to mate with someone from their own population rather than with an outsider?" D

Strategies for this Building Understandings Discussion

C This will be the first time that students may consider why there would be a more competitive advantage for survival with shorter wings and tail lengths in one environment than another. It may be useful to raise an analogy of airplanes asking questions like:

- Why do some airplanes have longer wings than others?
- What is the advantage of a smaller airplane with a smaller wing span?
- Is there a relationship between fuel efficiency and the size of a vehicle?
- What relationship might there be between metabolism (how fast food is burned for energy) and the size of the organism?
- Why would smaller limbs take less energy to move and less food to fuel than longer limbs?

Strategies for this Initial Ideas Discussion

D The goal here is to brainstorm a few additional possibilities, in order to motivate investigating the next data set. Write this question on the board and actually underline or circle the word lead in the sentence. Emphasizing the word **lead** in this prompt will help raise the possibility

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4. (8 min). Building Understanding -- Ask students to turn to the second page of their student activity sheets and use the table there to record any other differences they learn about related to this question in the video clips you will show them. Tell students that you will show three clips, and that you will show them twice, so that on the second viewing they can record what they discover.

Play these sections of the Chapter 6 junco video:

- **9:59-11:20 // 12:38-13:23 // 14:20-15:17**

Play the clips a second time and have students complete the table on the second page of their student activity sheets.

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5. (13 min) Making Predictions and Planning an Investigation -- Instruct students to complete the last two questions either independently or with a partner. E

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5. (10 min) Have students share out their responses to the last question. F

that there might be potential mechanisms behind who ends up mating with whom.

Formative Assessment Opportunities

E Since students have thought through similar experimental designs in lesson 11a, this is an opportunity to assess student's growth in planning investigations. You may want to ask students to take their draft ideas from this step home to formalize their plan in greater detail as a home-learning assignment. This would involve outlining a research question, a procedure (referencing a specific bird of their choice), and a drawing of the different conditions they would test, as well as the observations/data they would collect.

Strategies for this Initial Ideas Discussion

F Consider having students present their ideas to the whole class using a document camera. Though students will not carry out their investigations this will give them an opportunity to share their ideas. If students do have time to present at the end of this lesson, start the next lesson out with them sharing some of their ideas they came up with.

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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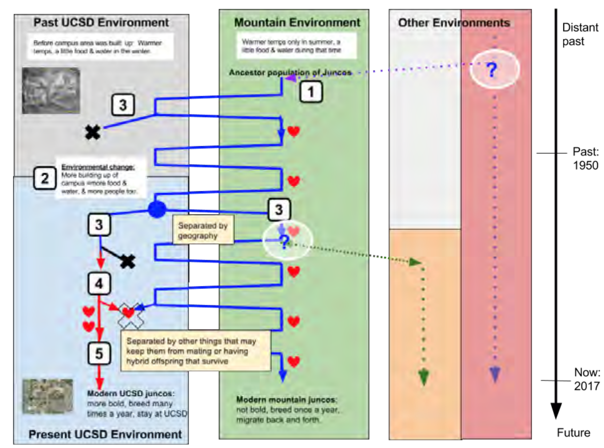
Lesson 20: Can birds really tell who they want to breed with by the feather color and song of their potential mates?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students analyzed data regarding physical, behavioral, and physiological traits found in the UCSD junco vs. mountain populations. They used these differences to explain how they might lead a junco to mate with someone from their own population rather than an outsider. And they brainstormed experiments that might be designed to test the question can birds really can identify and/or prefer potential mates based on these trait differences (e.g. color or song).

T	**This Lesson...What we are doing now:** Students will analyze data from scientists' investigations on the role of plumage and vocalization on mating behaviors in birds. They will use this evidence to argue that such interactions would lead birds to having preferences for mates that look and act like their parents. You will help students identify mechanisms that contribute to speciation as well as helping them revise the common ancestry model to represent a new idea and a new question: Has speciation happened in other environments for other lines of junco ancestors/descendants?

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L20: Can birds really tell who they want to breed with by the feather color and song of potential mates? (60 min.) S *Building toward* ⬇ *NGSS PEs:* *HS-LS4-1,* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	3 different articles provide information about methods and results from scientists who conducted studies on how feather color and song affect mating behavior.	**Obtain and Communicate Information** from scientific literature adapted for classroom use to determine patterns *in the data from experiments conducted by scientists to serve as evidence to make a claim about our question, "Can birds really identify (effect) and/or do they prefer potential mates (effect) based on these trait differences (e.g. color or song) (cause)?"* **Revise a model** *(for Common Ancestry to represent our new question, "Has speciation of juncos happened in other points in time and in other environments?"* illustrating the relationships between other systems *(different environments and environments, different populations of juncos in each, and common ancestors shared between them).*	Last time we had brainstormed how scientists might conduct an experiment to answer this question. We came up with ideas like painting a bird different colors, pasting feathers on it, and playing a tape recording of a song of different kinds of birds. So now we decided we needed data from those sorts of experiments in order to help us answer our question from last time, "Can birds really tell who they want to breed with by the feather color and song of potential mates?" We each gathered information from different research studies on this and reported our discoveries (there is evidence that birds really do decide who to breed with based on feather color & song of potential mates) We used this to argue that these differences (in song and plumage) between UCSD and mountain juncos may be helping keep them from interbreeding. We wondered if the UCSD juncos should be considered a new species, since we learned that when scientists are think that different lines of descendants can no longer breed together or produce offspring that survive, they refer to those different populations as different species. We brainstormed mechanisms that might have led to this potential speciation event (of the UCSD and mountain juncos). This led us to wonder "*if juncos ended up migrating to other environments that are changing (in the future), would new species of juncos start forming in those environments?"* We revised our Common Ancestry Model to include representations of this question, "*Has speciation of juncos happened in other points in time and in other environments (in the past)?"*  **Next steps: We decided that in order to help us figure out if this has actually happened, we will need to investigate any other environments where juncos might be found.**

Next Lesson....Where we're going: Students will compare trait variations in juncos found across N. America through photographs and video clips and they will compare the breeding ranges of where these different looking juncos are found.

Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 20 - Student Activity Sheets (1)

Preparation of Materials (5 min.)

- Make copies of three student articles and student activity sheets for each group of 3 students.

Materials For Each Group of 3 students

- Lesson 20 - Student Article 1(1)
- Lesson 20 - Student Article 2 (1)
- Lesson 20 - Student Article 3 (1)

Safety

- N/A?

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Learning Plan: Can birds really tell who they want to breed with by the feather color and song of their potential mates? (60 min)

1. (5 min) The end of the last lesson had students brainstorm ideas for investigations that could answer the question that this lesson addresses. If students haven't gone public with their ideas at the end of the last lesson give extra time for them to do that now. If they have gone public, then refer to some of the ideas they came up with to launch this lesson. A

---

2. (5 min). Tell students that, "These are productive ideas. Many are similar to the ones that scientists have tried. Let's take a look at the results of what they tried in order for us to answer our original question, 'Can birds really tell who they want to breed with by the feather color and song of their potential mates?' "

Assign different students different articles to review B **and tell them to take out their Student Activity sheets for this lesson. Point out that the space on their student activity sheets provides them space to record important ideas from their own article to share with the class.**

Ask students to remind us all of their thinking routines for analyzing articles and gathering information from text that they used in previous lessons. Emphasize the value in reusing those same approaches here. C

Listen for *student responses* such as:

We should keep track of connections to what we already know or prior questions it answers.

Teacher Supports & Notes

Additional Guidance

A Refer to the bulleted list of their ideas they shared last time or show a few of their ideas that you collected last time to help remind us of what we were thinking would be ways to investigate this question. And then ask students if they have any other ideas the would like to add.

Differentiation Strategies

B The articles have three different levels of text complexity. Here is an opportunity to differentiate the assignments of articles for students based on a match between text complexity and reading levels.

You may also want to meet with struggling readers in a small group to support their understanding of the text.

Helping support students in literacy and ELA learning goals

C Thinking routines allow for students to engage in structured exploration of materials. The most important aspect of

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We should keep track of any new ideas and new directions it helped raise.

We should keep track of any new questions it raised for us.

---

3. (12min) Have students read independently and record information on Q1.

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4. (13 min) Then when they are done, bring the class back together to have a Consensus Building Discussion around the original lesson question.

Suggested Prompts:

- ➔ What claim can we now make about our question, "Can birds really tell who they want to breed with by the feather color and song of their potential mates?"
- ➔ What evidence from your study supports this claim?
- ➔ Do others have additional evidence from this study that further supports that claim?

Listen for *student responses* that draw on the evidence from their readings.

Ask students to think about how this would affect the chances of interbreeding between two populations of birds that have different feather color and mating songs already in their populations.

Suggested Prompts:

- ➔ If birds in one population are singing a certain way when they mate and have certain feather/plumage in common and birds in a different population have a different song and

any thinking routine is that it allows students to make their thinking visible so they can go public with their ideas.

The Connect, Extend, Question routine asks students to engage with the following questions:

- Connect: How are the ideas and information presented connected to what you already know (did it answer any prior questions?)
- Extend: What new ideas did you get that extended or broadened your thinking in new directions?
- Question: What new questions arise after reading the new material?

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plumage, what would this do to the chances of them interbreeding with each other?

- ➔ How might these sorts of trait variations end up forming barriers to individuals from different groups interbreeding?
- ➔ If these sorts of trait variations can create additional barriers to interbreeding, what do we predict will happen to the UCSD and mountain juncos in future years? Is it likely that we will see them interbreed?
- ➔ If they don't interbreed for hundreds of years into the future, how do you think this will affect the way that both populations look and act? Will they be more, less, or no different from one another than they are now?

Listen for *student responses* such as:

These preferences would decrease the chances of interbreeding between individuals who look and sing very differently from those in the group you were born into.

The UCSD and mountain juncos probably won't interbreed in the future, if their white tail feather color and mating song are already quite different and are what they are using to select mates.

If they don't interbreed, their future offspring probably won't become more similar to both of them, so it seems like in the future the birds in each of their groups will either remain as different as they are now, or maybe become even more different.

---

5. (10 min.) Have students bring their chairs over to form a scientist's circle around the Common Ancestry Board model and refer to the representations shown in it so far to introduce the following ideas for students:

- **When scientists are sure that the different lines of descendants can no longer breed together or produce offspring that survive, they refer to those different populations as**

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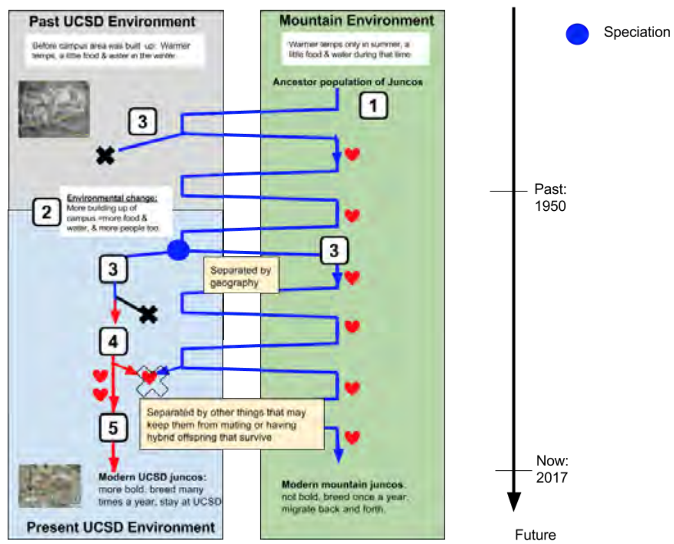
different species. Point to the two different lines of descendents in the model.

- **Sometimes when they don't feel like they have enough data to know for certain as to whether the individuals from each population could interbreed and have successful offspring, they refer to the different groups as sub-species.**
- **Scientists are currently debating whether they have enough evidence to consider whether UCSD juncos are different species from the mountain juncos or not.**
- **If these two lines of descendants eventually end up being classified as two new species, then the point at which that divergence/split occurred (early 1980s) would be referred to as the start of speciation, which is the thing that causes new species to form.**



Add a blue dot to the model and to the key to represent this.

Ask students to identify some of the mechanisms that have led to this (or may continue to lead to this) outcome (speciation) in the UCSD juncos vs. mountain juncos.

Suggested Prompts:

- ➔ What are some of the things that might have caused the original founders of the UCSD population to stay and not migrate back?
- ➔ What are some of the things that led the UCSD descendants to thrive at UCSD?
- ➔ What are some barriers that keep the mountain juncos from migrating and staying at UCSD and surviving?

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➔ What are some barriers that are keeping the UCSD and mountain juncos from interbreeding ?

Listen for *student responses* such as:

Maybe the founders got lost. Maybe the weather was different that year. Maybe it was just random.

The UCSD descendants have trait variations (they are bolder) that help them thrive that the mountain juncos do not have (less bold).

The UCSD juncos start mating at an earlier time than the mountain juncos arrive on campus.

The UCSD juncos have different feather colors and mating songs than the mountain juncos, so they may prefer mating juncos that look and sound like them.

---

6. (10 min.) While remaining at the Common Ancestry Board, raise a new question, "If we are thinking there is evidence that the UCSD juncos might be or might soon be considered a new species, how common do you think this speciation phenomenon is? Do you think that if other environments changed besides the UCSD campus, and juncos ended up migrating there, that new species of juncos might start forming in those environments?"

Accept all *student responses*

Point to the right side of the Common Ancestry model, and suggest that we modify it to represent the new kind of thing we are wondering about: Have we ever seen this (speciation) happen in other environments for other lines of junco ancestors/descendants?

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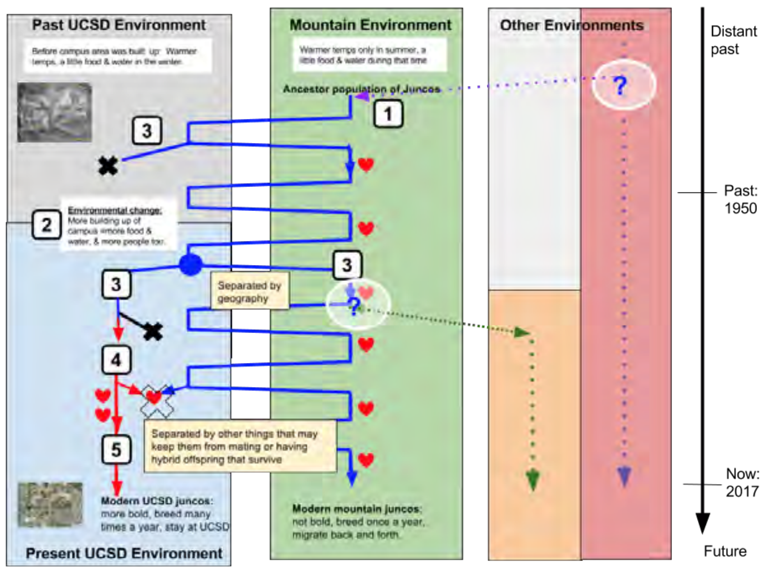
As shown to the right, add strips of colored poster/butcher paper to represent other environments. Add strings to represent the dotted lines with arrowheads (you can tape those on using colored paper) and add big question marks at the speciation branch points. For each thing you add with the students, ask them what it represents. D



Listen for *student responses* such as:

The gray to orange change in color represents an environment in the same place whose conditions have changed over time.

The red environment color represents a different environment in a different place than the orange one.

The lines represent populations of juncos.

The branch points represents speciation events.

The further back the lines go to the top of the model, the further back in time we are referring to.

The question marks represent what it is we are wondering about -- has this happened in

Strategies for this Consensus Building Discussion

D The goal of this discussion is to extend what we know about the junco case, to a more general model for Common Ancestry and speciation. At this point what you will be adding to the model is a conjecture, so include multiple students in the co-construction of the things we are adding to the model.

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other points in time and in other environments?

---

7. (5 min.) Remain at the Common Ancestry board, and ask students to turn and talk with someone next to them about what sort of data we would need in order to test this model we made -- in order to help us figure out if this has actually happened, "Have juncos formed different species in different environments in the past?"

After turning and talking, have students briefly share out their initial ideas. E

Listen for *student responses* such as:

We need to look at other environments.

We need to find out if there are juncos anywhere else.

Keep track of student ideas and refer to them at the start of the next lesson to build coherency in the launch of that lesson, and to remind students that the ideas for what we need to investigate next came from them.

Strategies for this Initial Ideas Discussion

E This discussion will be brief. Consider going quickly around the scientist circle asking the first pair of students, "What ideas did you both have?" and then asking the next pair, "How did your ideas compare?" It is likely that you will have lots of agreement on the idea of looking for different environments that juncos might be found in. After having established that agreement, you can say that this must be what we will need to do next time then.

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 21: What other juncos do we find in North America?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students gather information and analyze data from different investigations that scientists have conducted to provide evidence that different birds do respond to and prefer certain patterns in plumage and vocalization (song) when seeking out a mate. They revise their Common Ancestry Model to represent the questions they wanted to investigate in future lessons.

This Lesson...What we are doing now: Students will compare trait variations in juncos found across N. America. through photographs and video clips and they will compare the breeding ranges of where these different looking juncos are found.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L21: What other juncos do we find in North America? 30-35 min. *Building toward* ⬇ *NGSS PEs:* *HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	 Diversification 1: The Dark Eyed-Junco Video (from 0:00 to 8:09 - broken into 4 separate clips) provides information on the distribution of different juncos populations in the U.S. and Canada, and how the environments they breed in compare.	**Analyze and interpret data** *(photos, field video, and maps)* to determine patterns in phenomena *(physical traits and breeding ranges of juncos)* in order to predict *the most likely locations we might find individuals from different populations interbreeding with one another.*	When we analyze some photographs of other juncos found in different parts of North America, we notice different patterns in how they look. We see ● different color feathers (e.g. red, brown or gray/blue, white) found in different parts of their body (head, wings/tails, breasts); and ● different colored beak and different colored eyes (yellow eyes vs. dark eyes). We argue that the reason for all these different looking juncos in North America might be due to the environments they are found in. We want to know more about the environments where these types of juncos are found.  We gather information from a video clip about the distribution of different looking juncos, and notice some interesting patterns: ● Different looking juncos have different breeding ranges. ● The ranges of some juncos in the United States and Canada are adjacent to other junco ranges, while the range of juncos to the south (in Mexico) is not (and is more fragmented). ● Some environmental characteristics (mountainous, wooded) are similar for all breeding ranges; while other are different (e.g. temperature change across seasons). ● They are all considered the same species. We predicted how we could find evidence of them being the same species by identifying likely locations where we might find individuals from the six groups mating with each other. We found additional evidence from the last portion of the video clip, showing these juncos interbreeding with each other along boundaries where their breeding ranges meet. This then led us to wonder: *How closely related are all these juncos, if they can still interbred with each other?* **Next Steps: We think genetic information can help us figure this out, since we develop a model in L17b, that showed that since some DNA is inherited just from mom, and that DNA accumulates mutations at a constant rate from one generation to the next, we can then compare mutations in that DNA to determine how closely related these groups of juncos are (how long ago these different lines of juncos descended from a common female ancestor).**

Next Lesson....Where we're going: Students will analyze data on the mutations found in mtDNA from juncos found across N. America to support arguments for which juncos are more closely related to each other than others. They will gather information from two video clips (field observations and conclusions) that scientists made about these juncos and compare them to their own conclusions. You will help them take stock of all the mechanisms of evolution and the evidence that have for these that help explain the distribution of different subspecies and species of juncos across N. America.

Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 21 - Student Activity Sheets (1)
- Lesson 17b - Student Activity Sheets (students will refer to what their answers this document in this lesson and the next)
- Optional home-learning: Wikipedia reading on Guadulupe Junco

Materials Reused Between All Classes

- Lesson 21 - PI Other Juncos Photos (1 **colored** copy for every pair of students, to be collected and reused between each class period)

Preparation of Materials (10 min.)

- Since lesson 21 is relatively short, It is recommended you start lesson 22 right at the end of lesson 21. Read lesson 22 teacher guides for additional materials to prepare for students for this lesson.
- Print class set of colored copies of Lesson 21 - Other Juncos Photos (1 **colored** copy for every pair of students)
- You will need an LCD projector and computer to preview the Diversification 1: The Dark Eyed-Junco Video . Be sure to click full screen before showing video to students). Show only these clips:
    - 0:00 to 4:17
    - 4:17 to 6:58
    - 6:58 to 7:05
    - 7:05 to 8:09

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Getting Ready: Teacher Preparation

Background Knowledge

Students will draw on information they recorded in the mutation accumulation model in mitochondrial DNA from their student Activity sheets in lesson 17b, to answer the last question in this lesson.

Alternative Student Conceptions

Linking Our Understanding to Scientific Terminology

- Species
- Sub-species

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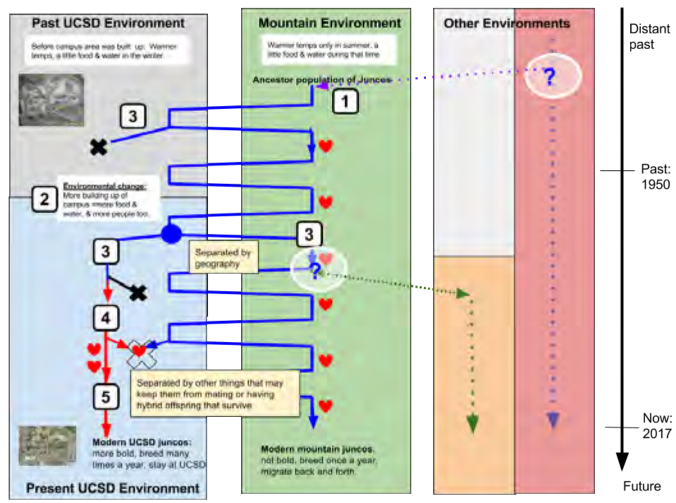
Learning Plan: What other juncos do we find in North America? (30-35 min)

Teacher Supports & Notes

1. (5 min) Direct students' attention to the the Common Ancestry Board that they updated last time, and point to the newly added question marks added to the board and ask them what we were wondering about last time that led us to add this section to our boards. A



Listen for *student responses* such as:

Would juncos form a new species if some of them migrated to a different environment?

Are different species of juncos found in other environments?

Did the mountain juncos descend from ancestors that used to live somewhere else?

Where else are juncos found?

Then after raising questions about different species, different environments, and migration, ask some additional questions related to predictions about any juncos we might find in different environments.

Suggested Prompts:

Differentiation Strategies and Alternate Activities

A You may want to have students meet you at the Common Ancestry Board as they come in and start the class for the first couple of steps in today's activity.

Periodically meeting in a scientist's circle around these public representations of where the class left off in their thinking can help build a stronger sense of shared mission and cooperative learning community. But standing in a scientist's circle can be more distracting for some students than sitting in one. Consider having a set of chairs already set up for this purpose when the class starts.

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- ➔ If we found populations of juncos living in different environments in North America, how do we expect they would compare to the two populations of juncos we have looked at in the California mountains and at UCSD?
- ➔ Would you expect them to have the same traits as either of these populations?
- ➔ If you found a junco population living 100 miles away do you expect it would be similar to the ones living near the areas we have studied? How about 1000 miles away? 10,000 miles?

Accept all *student responses.*

And then ask students, "How would we go about investigating these questions further?"

Listen for *student responses* such as:

We would need to observe the juncos found in different environments and make some comparisons.

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2. (5 min) Pass out color printouts of Lesson 21 - PI Other Juncos Photos, one to every two students. Have students work with someone next to them to analyze the photographs of these juncos that were part of populations found in different parts of North America. Have them record their observations on the first page of their student activity sheet, and complete Q1.

Collect the photos to reuse for the next class.

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3. (8 min). Then ask students to turn to the second page of their student activity sheets and use the table there to record any other differences they learn about related to this question in the video clips you will show them. Tell students that you will show a video clip that is a little over 4 minutes long.

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Play only this section of the [Diversification 1: The Dark Eyed-Junco Video]
- **0:00-4:17**

Then have students record their discoveries in Part 2.

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4. (5 min). Play only this sections of the [Diversification 1: The Dark Eyed-Junco Video]
- **4:17-6:58**

Pause the video. Have students read Part 3 and draw their predictions for Part 3 on the map provided on their student activity sheets.

Then play the video from 6:58 to 7:05 and pause at 7:05.

Suggested Prompts:
➔ How do your predictions compare to the areas shown on the map?

Continue playing the video from 7:05 to 8:07. Then stop the video at 8:07.

---

5. (5 min). Summarize the fact that even though Miller didn't have a way to show how closely related these juncos might have been, we had figured out a way to do that in Lesson 17b.

Have students turn to the last page of their Lesson 21 student activity sheets. Also tell them to take out Lesson 17b student activity sheets.

Tell them to keep that first page of Lesson 17b student activity sheets in front of them as they answer the last question (Q4) on their Lesson 21 student activity sheets, How could comparing

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the differences in mitochondrial DNA (mtDNA) between these birds, help us determine how closely related these birds are to one another?

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6. (3-8 min). Ask for student volunteers to share their responses with the whole class. Listen for *student responses* such as: B

We think genetic information can help us figure this out since we developed a model in Lesson L17b that showed that since some DNA is inherited just from mom, and that DNA accumulates mutations at a constant rate from one generation to the next, we can compare mutations in that DNA to determine how closely related these groups of juncos are.

Strategies for this Building Understandings Discussion

B The goal of this discussion is to help students articulate connections between the ideas developed in lesson 17b with the next lesson (which will have students comparing data from mtDNA in juncos).

Ask multiple students to summarize these ideas before moving on to the next lesson. Then, since the next lesson is more than one period long, it is recommended you start the next lesson, even if there are only 10 minutes left in the period -- as having the students make predictions on the first page of the next lesson will help them develop further coherence between these two lessons.

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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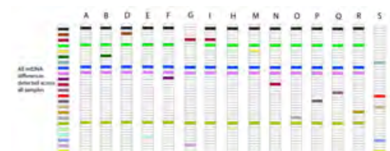
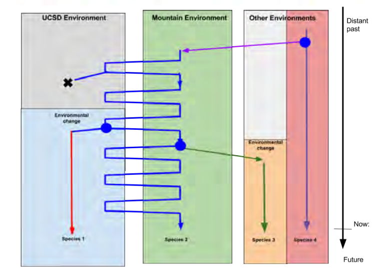
Lesson 22: How closely related are the different populations of juncos found in North America?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson….Where we've been: In lesson 17b, students applied information about mutation rates, mitochondrial DNA, and sex chromosomes that they gathered from their home-learning readings to build a model showing how mutations accumulate from one generation to the next across different branches of a family tree. They use this model to calculate relative amounts of mutated DNA in common for different family members, and predicted amounts of mutated DNA in common across generations. In Lesson 21, students discovered that different looking juncos breed in different parts of the U.S. and that some interbreed with each other. They argued that DNA can help us determine how closely related these juncos are.

This Lesson…What we are doing now: Students will analyze data on the mutations found in mtDNA from juncos found across N. America to support arguments for which juncos are more closely related to each other than others. They will gather information from two video clips (field observations and conclusions) that scientists made about these juncos and compare them to their own conclusions. You will help them take stock of all the mechanisms of evolution and the evidence they have for these that help explain the distribution of different subspecies and species of juncos across N. America.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L22: How closely related are the different populations of juncos found in North America? 100 minutes (2 periods of 50 min each) *Building toward* *NGSS PEs:* *HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	The methodology and data sections from of a scientific paper show patterns in junco mtDNA and where it was sampled from.  Two video clips: from Diversification 1: The Dark Eyed-Junco Video and from Diversification 2: The Dark Eyed-Junco Video provide additional information about field research on the juncos.	**Analyze data** using graphical displays (maps, charts, and tables) to identify patterns *in temporal, spatial, and genetic relationships (how closely related different populations of juncos are based on relative similarity of mtDNA from populations sampled at different locations).* **Construct explanations** (an outline) applying models to link evidence to the mechanisms (cause) and outcomes (effect) of evolution related to two phenomena: There are populations of juncos that look and act differently across N. America; and some of these populations of juncos are separate species.	We analyzed haplotypes detected in mtDNA from various sites where juncos were sampled across North America.  We used the patterns we noticed in the data to make arguments for which populations of juncos are more closely related to one another vs. which ones shared a common ancestor longer ago than others.  From this we summarized two phenomena and related questions that we can answer with a similar model (our Common Ancestry model): • There are junco populations that look and act differently across N. America. • Some of these populations of juncos are separate species. We argued from evidence that they all descended from a common ancestor, some more recently than others. And we evaluated the analysis of the data and conclusions that scientists made in the field (from two short video clips) and saw they were much the same. We summarized the evidence that we have for the mechanisms that contribute to explaining how the model works. We referred to the combination of the mechanisms and outcomes as evolution. These mechanisms included • trait variations in a bird's appearance, behavior, and physiology due to genetic information inherited from parents; • environmental changes over time and different environments in different locations; • migration and geographic isolation; • sexual reproduction and mutation; and • natural selection. **Next steps: We want to identify what we learned from juncos that we might need to look in order answer our driving question completely, "Why Don't Antibiotics Work Like They Used To?"**

Next Lesson….Where we're going: Since students have identified the mechanisms of evolution that were not part of previous explanations used for bacteria, but now seem like important ones to investigate further, and mutation will be one of these mechanism, they will look into the role of that mechanism further in helping explain the driving question of the unit.

Getting Ready: Materials Preparation

Materials For Each Student

- Lesson 22 - Student Activity Sheets
- Completed Lesson 17b -- Student Activity Sheets (students will refer to what their answers were this document in this lesson and the next)
- Optional home-learning assignments (see teacher supports & notes)
  - wikipedia page on Guadalupe Juncos
  - Journal Article on Guadalupe Junco from *Evolution*

Materials Reused Between All Classes

- Whiteboard markers

You will need an LCD projector and computer to project the following:

- Lesson 22: PI Map of Junco Sites & Model of mtDNA Mutations Detected
- Lesson 22 PI - haplotype comparisons
- The chart from the last two pages of Lesson 22 - Student Activity Sheets

Preparation of Materials (10 min.)

- You will also use the projector to preview the following two video clips:
  - Diversification 1: The Dark Eyed-Junco Video. Be sure to click full screen before showing video to students. Show only 8:09 to 14:09.
  - Diversification 2: The Dark Eyed-Junco Video. Be sure to click full screen before showing video to students. Show only these clips:
    - 0:00 to 2:20
    - 4:10 to 5:22
    - 7:44 to 10:11
    - 16:20 to 18:07

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Getting Ready: Teacher Preparation

Background Knowledge

Students will draw on information they recorded in the mutation accumulation model in mitochondrial DNA from their Student Activity sheets in lesson 17b, to answer the last question in this lesson.

Alternative Student Conceptions

Students may not have thought of evolution as a model that refers to both the outcomes and mechanisms at work behind the type of population changes they will have evidence for in this lesson. Students may have thought of natural selection alone as being equivalent to evolution, rather than natural selection being one of the mechanisms (but not the only one) at work to cause population changes over time. This may be the first time that you are referring to the suite of mechanisms in the model as evolution -- and at the end of the lesson you may want to point out and celebrate the accomplishment that the students really figured out and co-constructed this model from evidence, rather than simply learning about it -- no small feat to invent the idea of macro-evolution to explain phenomena rather than reading about it in a book!

Linking Our Understanding to Scientific Terminology

- Species
- Sub-species
- Evolution
- Glaciation
- Geographic isolation

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Learning Plan: How closely related are the different populations of juncos found in North America? (100 min) 2 x 50 min.

Teacher Supports & Notes

Day 1

1. (8 min) Project Lesson 22 - PI Map of Breeding Ranges of North American Juncos so students can see a color version of the map as they complete this step. Ask students what additional information this map shows compared to the map they looked at in the last lesson.

Listen for *student responses* such as:

There are more than six kinds of juncos shown.

Parts of Mexico and Central America also show breeding regions for juncos.

Tell students that, "We are going to compare the mitochondrial DNA of all of these populations of juncos, just like was suggested at the end of the last lesson to see if we can determine how closely related these different populations of juncos are. But before we do that, let's make some predictions about the new populations we see added to this map in Central America."

Give students about 4 minutes to read through page 1 of their student activity sheets and complete the prediction questions.

Then have students share their predictions with the whole class or with partners..

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2. (5 min) Tell students that we are going to dig into some of the research about the

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mitochondrial DNA found in junco populations sampled at various locations shown on the first page of the students activity sheets. Project Lesson 22: PI Map of Junco Sites & Model of mtDNA Mutations Detected. Tell students that, "This projected image shows a color-coded version of the map and model shown on the second page of your student activity sheet, which will help you refer to the sites where juncos were sampled, and help you visualize a model of the mutations measured in a section of mitochondrial DNA from samples of blood and feathers taken from birds at those sites."

Have students read the methodology section on the second page of their student activity sheets and complete Q3 at the bottom of that page.

Ask student if they have any questions.

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3. (15-17 min) Project the Lesson 22 PI - haplotype comparisons as color reference. Tell students that they are going to use a representation of the mtDNA data to investigate the predictions they made on the first page and present their findings on Part 3 (questions Q4 through Q10) with their partner after they analyze the data and answer these questions in the next 15-18 minutes. A

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4. (10 min) Ask for student volunteers to share their findings from Q7 through Q9 to the rest of the class. B

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5. (10 min) Tell students that, "We are now going to compare the analysis, reasoning and conclusions that scientists made after looking at similar data in a short video clip that is six minutes long and then answer the two questions in Part 4."

Formative Assessment

A As partners are working, join some of the groups and ask them to explain their reasoning to give them a bit of informal practice and confidence for sharing their findings at the next step.

Strategies for this Building Understandings Discussion

B As some groups of students finish before other groups, ask them if if they would be willing to briefly share their results with the class. If so, tell them that you will have them draw their analysis to Q7 on a projected image on the board, and share their reasoning for their answers for Q8 and Q9.

One good way to do this is to project an image of Lesson 22 PI - haplotype comparisons onto a whiteboard for student to annotate (circle) with whiteboard markers as they present their results. Another option is to have students project their analysis of Q7 using a document camera.

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Show the next clip of the Diversification 1: The Dark Eyed-Junco Video. Show only 8:09 to 14:09.

Then give 4 minutes for students to answer the questions in Part 4 (Q11 and Q12).

Day 2

6. (20 min) Emphasize that we should take stock of what we have figured out so far about these juncos found across North America. Direct students' attention to Part 5, Q13.

Co-construct a summary for the first phenomena column of the first 3 rows together. Have students record the agreed upon text for each cell shown in *red italics* below in Part 5 of their student activity sheets.

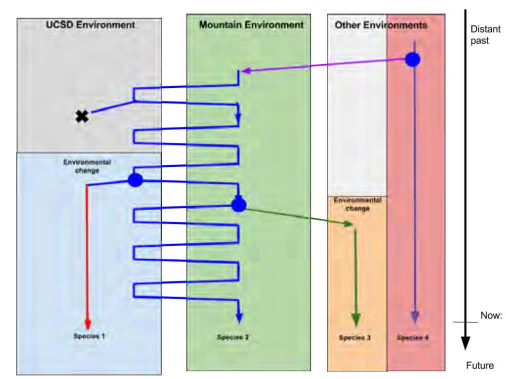
	Phenomena #1	Phenomena #2
What is the phenomena are we trying to explain?	*There are populations of juncos that look and act differently in different parts of North America.*	.
What question can we now answer?	*Are the differences we observe across these populations due to the same sort of model and mechanisms that led to the emergence of the UCSD population?*	
What model do we think can apply to our explanation?	*They all descended from a common ancestor at some point in the past; some shared a common ancestor more recently than others.* C	

Then row by row, ask students to summarize what evidence we have for the mechanisms in that row playing a role in the model that led to this phenomena. After each row is agreed upon, have

Referring to this Classroom Artifact

C Refer to the more general features of the model such as:

- Blue dots show last common ancestor.
- Lines show different populations of descendants.
- Colored changes in the background indicate environmental changes over time in a certain place.
- Different colored banded backgrounds indicate different environments.
- Black x represents a population that migrated to a region but didn't survive (extirpated there).



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students record the agreed upon text for each cell shown in *red italics* below in Part 5 of their student activity sheets.

Mechanisms that contributed to this phenomena	What evidence do we have for this mechanism contributing to this outcome?
A. Physical, behavioral, and physiological trait variations due to genetic information inherited from parent(s)	*We have evidence that there are differences in feather and eye color, body and limb size, hormones, and behavior all related to alleles inherited from parents.*
B. Environmental changes over time and/or between different places	*We have evidence of urbanization at UCSD over the last 60 years.* *We have evidence that the mountain environment is really different from the campus environment. We have evidence of differences (extreme seasons, different creatures living there) in the conditions among the forests that juncos inhabit in various parts of North America.*
C. Migration (or movement of populations from one environment to another)	*We have evidence that juncos moved from mountains to UCSD and back and do this sort of thing in other parts of the U.S.*
D. Sexual reproduction	*We have evidence that junco offspring inherit very close to 50% of their genetic information from each parent, like all sexually reproducing organisms.* *We have evidence that junco offspring have preferences for mates that tend to sound/look like their parents.* *We have evidence that individuals from some population of juncos can interbreed with each other (subspecies).*
E. Mutation	*We have evidence of a slow but constant rate of mutations in genetic information from one generation to the next.*
F. Isolation (geographic or reproductive)	*The UCSD juncos and mountain juncos are only isolated part of the year from each other. Other juncos tend to breed in different parts of North America, but there are some areas where their breeding ranges meet.*

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G. Natural selection	*We have evidence that there is competition for limited resources needed for survival and reproduction in every environment (e.g. limited nesting sites, limited food and water, limited time during a warm season for reproducing babies that will stay warm). In addition, those individuals with advantageous trait variations (for survival and reproduction) have more babies and those that do not, have fewer offspring (or die before having any).*

7. (10 min) Tell students that we are going to look at the juncos a little bit more to see if we can gather a bit more evidence for these mechanisms as well as look at how they might be used to explain one additional phenomena. Tell students they will see four short video clips that will be 8 minutes total in length, that might help us complete our summary table. Show the following four clips of Diversification 2: The Dark Eyed-Junco Video.

- **0:00 to 2:20 // 4:10 to 5:22 // 7:44 to 10:11 // 16:20 to 18:07** D

8. (15-18 min) Direct students' attention back to the table in Part 5, Q13. This time co-construct a summary for the second phenomena column of the first 3 rows together. Have students record the agreed upon text for each cell shown in *red italics* below.

	Phenomena #1	Phenomena #2
What is the phenomena are we trying to explain?	**There are populations of juncos that look and act differently in different parts of North America.**	*Some populations of juncos are separate species (they don't interbreed with other juncos).*
What question can we now answer?	**Are the differences we observe across these populations due to the same sort of model and mechanisms that led to the emergence of the UCSD population?**	*Why do some lines of descendants become new species?*
What model do we think can apply to our explanation?	**They all descended from a common ancestor at some point in the past; some shared a common ancestor more recently than others.**	*We think speciation is caused by a similar model and mechanisms, but maybe just working over a longer period of time, with longer lines of descendants (no interbreeding) during that time.*

Alternate Activities and Differentiation Strategies

D Since the video stops at a point where it hints at a junco in another part of the world, you can use this as an opportunity to naturally motivate a launch into an additional at-home investigation about juncos found on Guadalupe island.

Guadalupe island juncos help foreground the risk of extinction of species of organisms that are geographically isolated and in small numbers, and encounter major changes to the environment -- leading to the chance that the population won't have enough time to evolve and survive in the changed environment. The wikipedia page on Guadalupe Juncos provides a brief overview of these birds and their history on that island. You may want to consider using this as a home-learning assignment along with some questions like:

- In what ways did the environmental conditions of the island change rapidly in the few hundred years?
- Why did that lead to the extinction of many species on the island?
- Why did this species of junco almost go extinct here?
- What changes to the environment have been made to try to save the junco population from going extinct?

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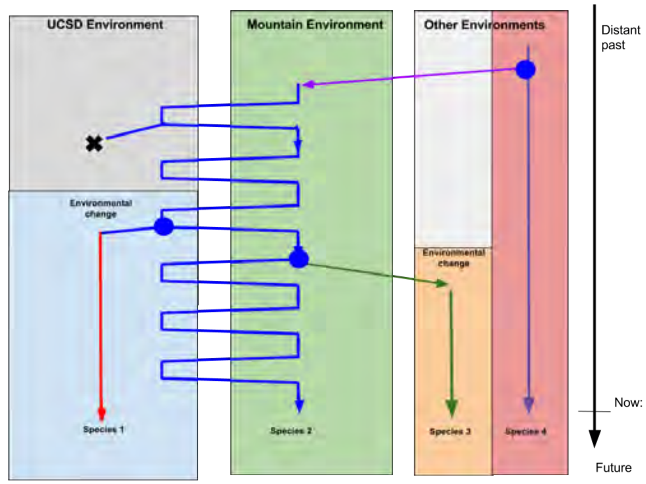
Revisit the Common Ancestry board, pointing out what the lines and blue dots could now represent in terms of our new phenomena. Have students trace the representation of each of these, restating what they show verbally, as you point to each of them:

- **Blue dots still show the last common ancestor, but also indicate the start of speciation.**
- **Lines show different populations of descendants that resulted in different species later in time.**
- **Colored changes in the background indicate environmental changes over time in a certain place.**
- **Different colored banded backgrounds indicate different environments.**
- **Black x could represent a species that went extinct.**



Add any additional evidence students suggest to the rows below. Suggested additions related to the most recent video clip are shown in *red italics* below in Part 5 of their student activity sheets.

What mechanisms contribute to this	What evidence do we have for this
A. Physical, behavioral, and physiological trait variations due to genetic information inherited from parent(s)	We have evidence that there are differences in feather and eye color, body and limb size, hormones, and behavior all related to alleles inherited from parents.

An alternate home-learning reading that is a more complex text structure is the article published in Evolution by Mila, B, et. al, [*Postglacial Population Expansion Drives the Evolution of Long-Distance Migration in a Song Bird.*]

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B. Environmental changes over time and/or between different places	We have evidence of urbanization at UCSD over the last 60 years, *and evidence of glaciation and receding glaciers over tens of thousands of years.* We have evidence that the mountain environment is really different from the campus environment. We have evidence of differences (extreme seasons, different creatures living there) in the conditions among the forests that juncos inhabit in various parts of North America.
C. Migration (or movement of populations from one environment to another).	We have evidence that juncos moved from mountains to UCSD and back and do this sort of thing in other parts of the U.S. *We have evidence that some juncos (particularly those that become new species) stop migrating.*
D. Sexual Reproduction	We have evidence that juncos offspring inherit very close to 50% of their genetic information from each parent, like all sexually reproducing organisms. We have evidence that junco offspring have preferences for mates that tend to sound/look like their parents. We have evidence that individuals from some population of juncos can interbreed with each other (subspecies), *while others can not (they are separate species) and these appear to have shared a common ancestor with the other juncos longer ago (they have been isolated from breeding with them for longer periods of time).*
E. Mutation	We have evidence of a slow but constant rate of mutations in genetic information from one generation to the next. *We are thinking mutations can sometimes lead to new alleles that weren't there in the past (e.g. a mutation causes a new allele to appear which leads to pigment being produced by cells in the eye, resulting in a new eye color).*
F. Isolation (geographic or reproductive)	The UCSD juncos and mountain juncos are only isolated part of the year from each other. *We have evidence that when a population is isolated from others (e.g. islands, sky islands) so that there is no interbreeding between them and their "cousins" for a number of generations, differences in DNA (and probably in many traits too) become more pronounced in descendants over time. This, in turn, would lead to different species.*
G. Natural selection	We have evidence that there is competition for limited resources needed for survival and reproduction in every environment (e.g. limited nesting sites, limited food and water, limited time during a warm season for reproducing babies that will stay warm), and those with advantageous trait variations (for

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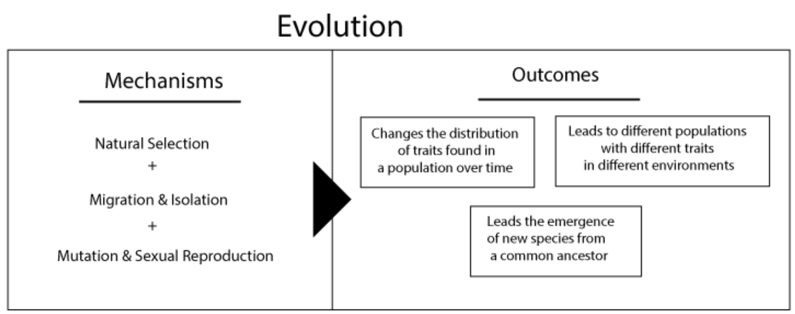
	survival and reproduction) have more babies and those that do not, have fewer offspring (or die before having any).

9. (10 min) Have students bring their student activity sheets with them to the Common Ancestry Board. State that all these mechanisms working together are referred to as evolution. Emphasize that the changes in populations over time they cause are also referred to as evolution. Tell them: "Evolution is a shorthand way to refer to the combined set of mechanisms and outcomes. The mechanisms of evolution include: 1) natural selection (which works on heritable trait variation in populations where the environment has changed) working in combination with, 2) migration and geographic isolation, and 3) sexual reproduction and mutation. These work together to cause the type of population changes that would explain this phenomena about the juncos (the emergence of both new kinds and new types of juncos over time (new sub-species and new species)." E



Draw a poster/summary chart representing this big idea like the one shown above. F

Then read through question 14 together, and have students write their suggestions down. Then ask them for their ideas.

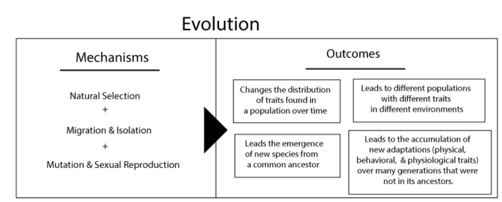
Suggested Prompts:

Additional Guidance

E This may be the first time that you are referring to the suite of mechanisms and outcomes in the model as **evolution** -- and at this point you may want to dwell on that sense of accomplishment of having co-constructed this very complex model as of how populations change over time.

Additional Guidance

F Leave room on this poster to add one additional section under outcomes in the next lesson. One way to do this is to put each mechanisms and each outcome on its own sheet of paper, and tape them to the larger poster paper or butcher paper. This allows you to reorganize and move them around in the next lesson.



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- ➔ Which of these mechanisms are ones we didn't use in our previous explanation of Addie and our driving question?
- ➔ Which are ones you think we would need to investigate a bit further for us to fully explain the phenomena above and answer our driving question?

Listen for *student responses* such as:

We haven't used anything about how mutations work in bacteria -- maybe this is an important part of the explanation of our driving question. G

Ask students what sort of information we would need from something like our Petri dish experiments to understand more about what is happening with mutations and DNA.

Listen for *student responses* such as:

We would need a way to compare the DNA of different individual bacteria from one generation to the next.

Strategies for this Consensus Building Discussion

G Any other ideas, besides mutations, that your students suggest will help motivate the last lesson of the unit. But the very next lesson revisits mutations and their role in bacterial evolution. One way to motivate that transition is to go back to what the class put in the previous question (Q13) in their student activity sheets, for mutation: *"We are thinking mutations can sometimes lead to new alleles that weren't there in the past (e.g. a mutation causes a new allele to appear which leads to pigment being produced by cells in the eye, resulting in a new eye color)."* and ask if we think anything like that might be happening in bacteria → some mutations leading to new alleles leading to new traits in offspring.

Another way to motivate it, is to ask students, "Did we use a mutation in our explanation of Addie? I seem to recall in the NetLogo simulation and in your infographics from lesson 14, that we were thinking that when bacteria reproduce they pass on the exact same trait variations, because we thought they pass on duplicate DNA. Maybe we should revisit that assumption?"

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Alignment With Standards

Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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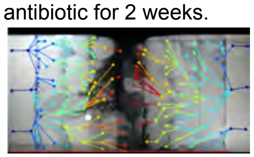
Lesson 23: How would all these mechanisms affect the evolution of bacteria over time?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students analyzed data on the mutations found in mtDNA from juncos found across N. America to support arguments for which juncos are more closely related to each other. They compare information from two video clips that scientists made about these juncos and found similar conclusions. You helped the whole class take stock of the evidence they collected about the mechanisms of evolution in order to explain the distribution of different subspecies and species of juncos across N. America. This led to identifying mechanisms that were not part of our previous explanations used for bacteria, but seemed like a possible piece to investigate further. Mutation was one of these mechanisms.

This Lesson...What we are doing now: Students will investigate the role of mutation in the evolution of bacteria through three information sources (a video clip, a New York Times article, and an article from Nature). Then you will help them summarize all the evidence they have from the entire unit for how the mechanisms of evolution could have contributed to explaining two key phenomena related to bacteria. And they will start identifying parts of the driving question board they can now answer.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L23: How would all these mechanisms affect the evolution of bacteria over time? (95 min) + Optional 30 min. extension *Building toward* ⬇ *NGSS PEs:* *HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	A video from Harvard Medical School shows patterns in lines of descent of bacteria grown across different environments of agar and antibiotic for 2 weeks.  A New York Times article provides information about mutations and new trait variations in the long term *E.coli* evolution project. A Nature article provides additional information about the long term *E.coli* evolution project, as well as information about small mutations that yielded major changes in traits in stickleback fish.	**Obtain, Evaluate, and Communicate Information** integrating sources of information presented in different media and formats *to determine how mutations (cause) can affect the evolution of E. Coli bacteria.* **Construct explanations** (an outline) applying models to link evidence to *the mechanisms (cause) and outcomes (effect) of evolution related to two phenomena: antibiotics don't work like they used to and different kinds of pan-resistant bacteria exist today that didn't in the past.*	We compared the setup of an experiment with *E. coli* bacteria growth on a huge agar plate with different environmental conditions (different concentrations of antibiotics) to our own experiments and saw many similarities. When we analyzed time-lapsed growth over two weeks, we saw some similarities to what we were seeing in juncos: • There are different branches or lines of descendants from a common ancestor, some more recent than others. • Different lines of descendants move into different environments. • Natural selection seems to be at work here too, but mutation seems like it's a bigger part of this explanation than it was for juncos. We compared the setup of a long term experiment with *E. coli* bacteria across 50,000 generations to our own experiments and saw many similarities. We gathered information from an article summarizing the discoveries of the research group conducting these experiments and found that mutations in bacteria led to some lines of descendants that • grow faster than their ancestors; • use glycerol as food when their ancestors could not; • produce cellulose (to be able to float) -- in order to get oxygen from above and food from below; and • reproduce faster in the colder and warmer environments than their ancestors could. Optional: We gathered and shared information from a second article and discovered how very small random mutations can result in very big changes to the traits in bacteria and fish. We built a summary chart of the phenomena and questions we think we can now explain: • Why don't antibiotics work like they used to? • Where did all these different kinds of pan-resistant bacteria come from? And we argued from evidence that our explanation would include these mechanisms of evolution • physical, behavioral, and physiological trait variations due to genetic information inherited from parent(s); • environmental changes over time and different environments in different locations; • migration (or movement of populations from one environment to another); • mutation; • isolation (geographic); and • natural selection.

			We revised our evolution model to also include one additional outcome -- it can lead to the accumulation of new adaptations over many generations that were not in its ancestors. **Next Steps: We started thinking about whether we need to or should update our Infographics in light of all of what we figured out about evolution.**

Next Lesson....Where we're going: Students will close up the driving question board, identifying the questions they posted throughout the unit that they think they can now answer and why. They will reflect on and argue for what might need to be improved in the infographics they created, in light of the new mechanisms of evolution they figured out in recent lessons. And they will spend time revising their infographics one more time before sharing them with the community.

Getting Ready: Materials Preparation

Materials For Each Student

- New York Times Article (1)
- Nature Article (1) also available here (free pdf download): http://www.nature.com/news/2010/100217/full/463864a.html
- Lesson 23 - Student Activity Sheets

Materials For All Classes

- Whiteboard markers
- Poster paper

Preparation of Materials (10 min.)

- You will also use the projector to preview the following video clip: The Evolution of Bacteria on a "Mega-Plate" Petri Dish (Kishony Lab) Video from Harvard medical school.
- You will make copies of two articles for students to read and annotate (or check the links to the site and the pdf of the files if you are having students access these electronically).

These materials were developed with funding through a grant from the Gordon and Betty Moore Foundation to Northwestern University and the University of Colorado Boulder.

Getting Ready: Teacher Preparation

Background Knowledge

This unit does not assume that students have studied mutations prior to it in high school. If they have, it would be good to draw on that prior knowledge more throughout this lesson and the next one.

Alternative Student Conceptions

Students may think of mutations as the result of intentional choice by the organism, or the result of feedback induced from the environment which is inducing mutations in a particular direction.

Help students shift this conception to start to see mutations as random error/changes to the copying/duplicating of genetic code. Emphasize this idea when summarizing the findings from the two articles.

Linking Our Understanding to Scientific Terminology

- Adaptation
- Accumulation

There will be lots of additional new scientific vocabulary used in the second article. Most of the vocabulary introduced is not critical to understanding the larger ideas raised in each section of the article. Encourage students to read for contextual clues so these words are not stumbling blocks to the main points of the article.

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Learning Plan: How would all these mechanisms affect the evolution of bacteria over time? (95 min) + Optional 30 min. extension

Teacher Supports & Notes

1. (10 min) Ask students what some of the mechanisms of evolution were that we thought we needed to investigate a bit further in bacteria that we identified in juncos.

Listen for *student responses* such as:

Mutations!

Tell students that, "We are going to look at three sources of information today. The first is a video clip made by the Harvard Medical School. I am going to pause the clips at 30 seconds in and replay it again and then I want you to make some comparisons to the experiment they set up versus the ones we did in our class with *E. coli*, agar and antibiotics in our Petri dishes, before I show you the results of their investigation."

Play the first 30 seconds of the video from: The Evolution of Bacteria on a "Mega-Plate" Petri Dish (Kishony Lab) Video from Harvard medical school. Then pause the video. Repeat this once.

With the video paused, have students individually complete the first page of their Student Activity Sheets (Q1 through Q3).

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2. (6 min) Tell students that the remainder of the video is time-lapsed images taken from over a 2 week period. Play the remainder of the video. Replay it again and pause it at 1:47.

Have students turn to the second page of their student activity sheets and complete the Making Sense questions (Q4 through Q6) on this page, but not the conclusions question.

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3. (7 min) Complete the conclusion section together as a class (Q7) by asking students to share their ideas and record these on the board. A

Listen for *student responses* such as :

There are different branch lines of descendants from a common ancestor, some more recent than others.

Different lines of descendants move into different parts of the environment (or different environments).

Natural selection seems to be at work here too.

Mutation seems like it's a bigger part of this explanation than it was for juncos.

4. (4 min) Have students complete Q8, Q9, and Q10 with a partner and tell them to be prepared to share their responses to these at the end of this section. B

Then have students quickly share a few of their ideas to help motivate the next step in the investigations.

Suggested Prompts:

- ➔ I saw (or heard) that many of you wrote (or said) that the DNA in the mutant would not be identical to its ancestors. Are most mutations big changes to the DNA or relatively small ones?
- ➔ So if mutations are relatively small, and relatively rare (1 out of 100,000,000 genes that are duplicated/copied), and there are only a few thousand genes in a single bacterium, then why would we still expect to see mutations occurring on this agar plate across 2 weeks?

Strategies for this Building Understandings Discussion

A A new strategy to use here is to ask students to stop and jot for 60 sec. Then turn and talk to a partner for 60 seconds. Then go back to their paper and stop and jot again for another 60 seconds.

Then ask 5 to 6 students to share out what they came up with and add to their own sheets any ideas they hear that they haven't yet written down. Write down the ideas on the board as they are shared.

Strategies for this Building Understandings Discussion

B Go around and look and listen in to student conversations. Write down a few things you heard students saying so that you can refer to them in the suggested prompts below.

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➔ It would be cool if we could figure out how these mutations work and what exactly they are doing to the bacteria. What additional data would you need in order to figure out how mutations are causing some lines of descendants to be able to survive and reproduce into the parts of the plate with more and more antibiotic?

Listen for *student responses* such as:

Mutations are relatively rare.

Bacteria grow really fast, are really small, and the growth rate is exponential.

There are lots of them. You have lots and lots of bacteria that could reproduce in 2 weeks. Remember how many came from one bacterium in 24 hours? I think it was over 1,000,000 in just under 7 hours. That would be 4,288,000,000 genes duplicated in just under seven hours. So even if the rate of mutation is as low as 1 in 100,000,000 genes, that would still be 43 mutations in just seven hours.

We would need a way to compare the DNA/genes/alleles of the descendants and ancestors right before and after a mutation.

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5. (4 min) Tell students in Part 3, they will look at some of the results that Richard Lenski's Experimental Evolution Lab at the University of Michigan had collected, doing an experiment very similar to the one you did with your Petri dishes, but at even bigger scale. Describe the steps they followed: C

1. **They started with 12 identical clones of bacteria (all had exactly the same DNA).**
2. **They added these to a glucose (sugar) and water solution.**
3. **They spread the cells on an agar plate at 37 degrees Celsius.**
4. **They were allowed to grow for a while and then their descendants were taken off the plate and the last two steps were repeated (replated again).**

Differentiation Strategies and Alternate Activities

C You may want to also project this set of steps for students to refer to.

Or you may want to pass out a copy of these steps for them to refer to along with the URL below: http://myxo.css.msu.edu/ecoli/overview.html

These materials were developed with funding through a grant from the Gordon and Betty Moore Foundation to Northwestern University and the University of Colorado Boulder.

5. **For some experiments they changed the environment by adding other things in addition to glucose to the solution or changing the temperature, but for others they kept the environment constant (just glucose). For some experiments they changed the environment multiple times across multiple replatings.**
6. **After every 500 replatings they froze the sample and stored it (this put the bacteria into hibernation) so they could thaw it out later if they need to go back to that point in their experiment and grab a new sample of one of these.**
7. **They repeat and repeat and repeat…they have done this for 50,000 generations, for many, many years now, and have made some cool discoveries.**

Ask students if they have any questions about their methodology. If they do, direct them to read this link: http://myxo.css.msu.edu/ecoli/overview.html

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6. (12 min) Tell students that the discoveries the research group had made and reported on have appeared in various scientific journals. Some of their findings were recently summarized in an article in the New York Times, which they will read to gather information.

Have students turn to Part 2 of their student activity sheets and make notes regarding any information they find about mutations in bacteria and how they can affect the outcomes of natural selection. Remind students of the close-reading strategies they used in previous lessons and record their thinking in the space for Q11. D

Listen for *student responses* such as, mutations led bacteria to :

Grow faster than their ancestors.

Use glycerol as food when their ancestors could not.

Helping support students in literacy and ELA learning goals

D Thinking routines allow for students to engage in structured exploration of materials. The most important aspect of any thinking routine is that it allows students to make their thinking visible so they can go public with their ideas.

The Connect, Extend, Question routine asks students to engage with the following questions:

- Connect: How are the ideas and information presented connected to what you already know (did it answer any prior questions)?
- Extend: What new ideas did you get that extended or broadened your thinking in new directions?
- Question: What new questions arise after reading the new material?

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Produce cellulose (to be able to float) -- in order to get oxygen from above and food from below.

Reproduce faster in the colder and warmer environments than their ancestors could.

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7. (5 min) Optional E : Now tell students that there is a second article that includes additional discoveries from this research group along with another research group that researched mutations in a certain species of fish.

Instruct students to read and annotate the first four paragraphs of the article with one goal in mind, "What question(s) about mutations will the rest of this article address?" Have them write their response to that question in Q12.

---

8. (5 min) Optional E Have groups share their responses to Q12 in a group of two or four. F Tell students after having all group members share and agree on the general questions that the article will address, assign the remaining sections of the article to different group members. Remind students that they will need to share their findings with their group members at the end.

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9. (10 min) Optional E Next have each group member complete Q13 independently.

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10. (10 min) Optional E Have students join their groups, and share their findings with group members. Remind the other members to write a brief summary in Q14 of what they hear from that group member, and then rotate around the group.

Differentiation Strategies and Alternate Activities

E Steps 7 through 10 are optional, but may be necessary if students haven't already studied mutations in prior units in your class.

Differentiation Strategies and Alternate Activities

F If you want to give students more practice working with complex text, have them work in groups of two instead of four. Assign one member (e.g. the person on the left) to read the first and fourth section of the article (Marine gladiators and Of form, function and fitness), and assign the other member to read the second and third section of the article (Catching evolution red-handed and The rise of *Escherichia erlenmeyeri*).

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11. (12 min) Building Consensus -- Emphasize we should take stock of what we have figured out so far about mutations in order to bring this all back to our mechanisms of evolution and our driving question. Direct students attention to the last question, which is a summary chart in Q15.

Co-construct a summary for the first and second phenomena columns of the first 3 rows together. Have students record the agreed upon text for each cell shown in *red italics* below in Part 4 of their student activity sheets.

	Phenomenon #1	Phenomenon #2
What phenomena are we trying to explain?	Many antibiotics that used to help wipe out bacteria infections don't work on them anymore.	There are lots of different kinds of pan-resistant bacteria in the world now, but weren't as many in the past.
What question can we now answer?	*Why don't antibiotics work like they used to?*	*Where did all these different kinds of pan-resistant bacteria come from?*
What model do we think can apply to our explanation?	*Most or all the mechanisms of evolution listed below.*	*Most or all the mechanisms of evolution listed below and a version of the common ancestry model.*

12. (20-30 min) Have students look at each row individually, ask them to summarize the evidence we have for the mechanisms in that row that led to this phenomena. After each row is discussed and agreed upon, have student record the agreed upon text for each cell shown in *red italics* below in Part 4 of their student activity sheets.

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Mechanisms that contributed to this phenomena	What evidence do we have for this mechanism contributing to this outcome?
A. Physical, behavioral, and physiological trait variations due to genetic information inherited from parent(s)	*We know there is variation in how fast bacteria take food (glucose), the things they can eat (glucose vs. citrate), how fast they grow and reproduce, how big they get, how they respond to temperature changes, if they co-operate or not, and the structure of their cell membrane/wall (armour).* *We also suspect there may be other heritable variations in them related to the structures and functions of their cells.*
B. Environmental changes over time **and** **Different environments in different locations**	*We know that hospitals, schools, patients have been changing over the last 100 years:* ● *People are treated with antibiotics when they weren't in the past.* ● *People take antibiotics even when they don't really need them.* ● *There are more types of antibiotics today then long ago.* ● *People use more antiseptics on their hands and on surfaces in their world.* ● *Hospitals use more disinfectants to try to sterilize everything than they may have in the past.* *We know that the environments are different from* ● *the inside of one person to the inside of another (different immune systems, different states of health);* ● *the inside of a person to the world outside of him/her; and* ● *one location in the world to another (playground, Petri dish, water fountain, breathing machine, bathroom, kitchen).*
C. Migration (or movement of populations from one environment to another)	*We know that bacteria don't really migrate on their own. But we do know that bacteria can get moved around from one place to another in lots of different ways (e.g. particularly when people are sick -- hands, coughing, sneezing, body fluids).*
E. Sexual reproduction	*Bacteria don't sexually reproduce, so we don't think this is a relevant mechanism.*

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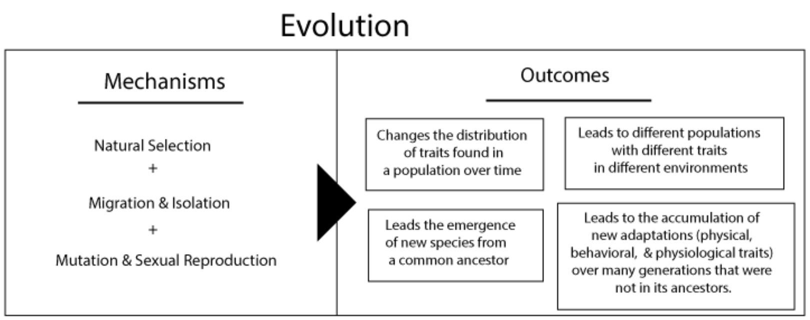
E. Mutation	*This occurs at a slower rate in bacteria than it does in animals and bacteria have simpler genomes. However, because bacteria duplicate so quickly, there can be a lot of mutations in descendants in a short amount of time.* *Mutations are random changes in the DNA. Some of these allow bacteria to produce different substances they hadn't produced before and this could allow them to build structures and/or function in different ways. Some of these new ways of functioning grant these bacteria a competitive advantage in different environments compared to their ancestors. We have evidence of this from our recent readings.* G
F. Isolation (geographic or reproductive)	*We have heard that quarantining people with infections (keeping people from making contact with each other) until the infection is completely wiped out is a way to keep infections from spreading.* *We have some evidence from our Petri dish experiments and from the long term bacteria experiments, that moving bacteria from one isolated environment to another for a bit (replating) seems to speed up the outcomes of evolution.* *We also could think of moving bacteria from one patient to another (before it was completely wiped out) as similar to "replating" -- moving it from one relatively isolated system to another.*
G. Natural selection	*We already have explained how this is the main driver of population change when the environment changes. We need to include all the evidence related to how it causes shifts in the distribution of trait variations in a population. We should remember to include what we know about limited resources leading to competition for survival and reproduction, in which certain trait variations give individuals an advantage or disadvantage over others.*

13. (8-12 min) Have student bring their student activity sheets with them to the Common Ancestry Board again. Add an additional paper to the outcomes section that represents what we learned about the type of changes that can accumulate from mutations. H



Additional Guidance

G You can ask students to refer back to the Conclusions section from part 1, Q7. Also have them give examples that they read about in the first (and second) article.

Additional Guidance

H Have students help describe what we mean by "accumulation" and "adaptations" in the construction of the idea "leads to the accumulation of new adaptations (physical, behavioral, & physiological traits) over many generations that were not present in its ancestors)." Have them cite examples from the bacteria, both from this lesson and from the history of pan-resistant bacteria in our world back from lesson 2 and beyond.

Strategies for Preparing Students for this next Consensus Building

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Ask students if they feel we have an answer to our Driving Question.

Revisit all of the questions on the Driving Question Board. Have students identify which questions they think we can now answer, and have students identify them so that we can talk about those next time.

Make sure to suggest that since our understanding has grown much deeper about the answer to our Driving Question, we may want to consider how to refine our Infographics in light of this. Encourage students to start thinking about this idea before the next lesson.

Discussion

You are preparing students to close up the driving question board in the next lesson. Here are 3 possible ways to do this:

1) Have students put small post-it notes or tabs (or you can cut post-it notes into strips with a stick part on each) and give 3 of them to each student. Have students put their initials on the tabs and then have students put 1 on each question that they think we can now answer. Take turns going around adding tabs to the board one at a time. Take a picture of the board at the end of the period to remind the class where we put tabs for the next lesson.

2) Pass out a sheet of paper with a list of all the questions on the driving question board and have students mark which ones they think we can now answer fully, which we can answer partially, and which we don't yet have an answer for.

3) Have students write down the top 10 questions they think we have developed a most complete answer to on a blank sheet of paper.

Alignment With Standards

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Building Toward Target NGSS PEs

- HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-2: Construct an explanation based on evidence that the process of evolution primarily results from four factors: (1) the potential for a species to increase in number, (2) the heritable genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for limited resources, and (4) the proliferation of those organisms that are better able to survive and reproduce in the environment.
- HS-LS4-3: Apply concepts of statistics and probability to support explanations that organisms with an advantageous heritable trait tend to increase in proportion to organisms lacking this trait.
- HS-LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. HS-LS-4.1: Communicate scientific information that common ancestry and biological evolution are supported by multiple lines of empirical evidence.
- HS-LS4-5: Evaluate the evidence supporting claims that changes in environmental conditions may result in: (1) increases in the number of individuals of some species, (2) the emergence of new species over time, and (3) the extinction of other species.

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Lesson 24: How do we share everything we've figured out to prevent (or slow) the emergence of even more resistant bacteria in the future?

High School Unit: Why Don't Antibiotics Work Like They Used To?

Teacher Guide

Previous Lesson....Where we've been: Students investigated the role of mutation in the evolution of bacteria through three information sources. They summarized all the evidence they have from the entire unit for how the mechanisms of evolution could have contributed to explaining two key phenomena related to bacteria. They started identifying the parts of the driving question board they can now answer.

This Lesson...What we are doing now: You will help students revisit and close up the driving question board, identifying the questions they posted throughout the unit that they think we can now answer and why. You will help them reflect on and argue for what might need to be improved in the infographics they created, in light of the new mechanisms of evolution they figured out in recent lessons. They will spend time revising their infographics one more time before sharing them with the community.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L24: How do we share everything we've figured out to prevent (or slow) the emergence of even more resistant bacteria in the future? 40 min + additional time as needed to make and share revisions (+ 40-80 min) *Building toward* ⬇ *NGSS PEs:* *HS-LS4-1,* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	All prior phenomena	**Obtaining, evaluating, and communicating information** Integrate sources of information to solve a problem (people not following CDC recommendations regarding antibiotic use) by communicating scientific information and ideas *about evolution that help explain (and prevent) the cause for why antibiotic resistance infections are (effect) becoming increasingly common and where new kinds/types of pan-resistant bacteria come from.*	We took stock of our driving question board and identified all the questions we thought we could answer and why. We revisited our role as citizen scientists arguing about ways we might improve our infographic. We raised new questions about: • What people's misconceptions might be -- should we resolve this or not? • What information do people genuinely need to feel the same sense of urgency that we do? • How do we help them understand the key mechanisms of evolution that are at work in a way that makes it understandable yet accurate? • How much information is too much, too complex, or too overwhelming? • Who is our audience and how do we convince them that this is a very big, very scary deal?  We revised our infographics. **Next Steps: We need to share these infographics with our community to complete our mission!**

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Getting Ready: Materials Preparation

Group

- Infographics from Juncos Lesson 15

ls (15 min.)

- N/A

ent

- Student Activity Sheets from Juncos Lesson 15
- [Student Activity Sheets for Lesson 24]

- N/A

Getting Ready: Teacher Preparation

Alternative Student Conceptions

Leading up to this lesson, students have been compiling a great deal of evidence to support the disturbing reality of antibiotic-resistant bacteria. Up until this point, students may not have fully comprehended the significance of bacterial evolution. In this lesson, students will consider the implications of bacterial evolution and determine a way to appropriately inform the public about it.

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How do we share everything we've figured out to prevent (or slow) the emergence of even more resistant bacteria in the future? (2 periods 45 min each)

1. (15-20 min) Creating Explanations - Have students meet in a scientists' circle back at the Driving Question Board to help close it up. Use the work they did at the end of the last lesson to identify the questions we can now answer and have them share out their reasons for why they feel we can now answer those questions. A

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2. (10 min) Shift to having students individually reflect on the questions in Part 1 on their Lesson 24 Student Activity Sheet in order to draw their focus to what they've learned about the mechanisms of evolution and how these are related to the spread of pan-resistant bacteria. Then have students share out a few of their responses. Use the following prompts to help students reflect.

Suggested Prompts:

- Over the course of this unit, how has your thinking changed about pan-resistant bacteria?
- Who, if anyone, needs to know about what you've figured out? Does everyone need the same information?
- How much is too much detail or too complex?
- What mechanisms of evolution are absolutely critical for the public to know are at work?

Listen for *student responses* such as: B

Addie's case was definitely disturbing when we first learned about it, and it was clear that this was a big problem. Then when we did our initial investigations with bacteria it made me realize that people not taking their antibiotics or over-prescribing antibiotics was an even bigger deal than I'd

Teacher Supports & Notes

Strategies for this Consensus Building Discussion

A This is a key moment of closure to their journey. It positions the students as the ultimate evaluators of the intellectual work they did and is really asking them how much they feel they accomplished in terms of the questions that they felt were most important to pursue.

The remainder of this lesson seeks to position the students in this same role, when it comes to revisiting and deciding, what, if anything needs to be revised in their infographics work, in light of all that they have learned.

Strategies for this Initial Ideas Discussion

B This being the final lesson in the unit, it is important to validate all student responses to the suggested prompts while carefully listening for evidence of taught skills. This is an excellent opportunity to

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originally thought. Now after learning so much about the other mechanisms of evolution at work in combination with natural selection, we're realizing that pan-resistant bacteria is a much scarier thing than we'd originally thought. It's something that could potentially affect all of us in a dangerous way now and in the future.
Anyone who has ever been prescribed antibiotics, or who has asked for antibiotics really should know the true risks of what can happen when they aren't taken in full or when they are over prescribed, both for themselves and for future generations of people.
We also think that doctors should really know this information about the mechanisms of evolution so that they don't over-prescribe antibiotics and raise the risk of bacterial evolution.
We would likely present different information to different audiences, depending on their role. Doctors could understand more of the science behind evolution, while the average patient probably wouldn't need that much detail.

3. (10 min) Shift to a Sharing Initial Ideas Discussion, using the prompts on Student Activity Sheet 24, Part 2 - Revisiting the Infographic. Students should refer to the infographics they created in Lesson 15.

Suggested Prompts:
- ➔ Who is the audience for this infographic?
- ➔ Is the information appropriate for the audience? Is it comprehensive?
- ➔ To what other audiences might this information be relevant?
- ➔ How would you adjust the information you communicate to these other audiences?

4. (1 additional period) Provide students an opportunity to share out and defend their revisions. You might consider offering students a similar opportunity to share their work with an authentic audience as you did in Lesson 15. B

collect formative assessment data to determine if students are making logical applications of what they have learned about evolution over the course of the unit.

Students will likely offer that there are multiple audiences that would benefit from the information about pan-resistant bacteria and how it evolves. With that, support students in coming up with ways to differentiate the way they communicate the information to each group based on what they need to know and how it might affect their decision making.

The final result could be used as a summative assessment to determine if students are able to communicate a message effectively to a target audience. If you choose to do this, you will want students to complete this assignment individually.

Additional Guidance

B Offering students an authentic audience for their work demonstrates to them that their work is considered to be important, professional, and worthy of

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sharing. Beyond that, it shows a real-life example of how scientists conduct investigations and complete their work for the express purpose of sharing it with the world. Be sure to emphasize for students that real scientists are always seeking out ways to share their work with other professionals.

This is also a great opportunity to take stock of and celebrate all of the hard work and effort students have put into this unit. In a multi-week unit such as this, it is critical that students feel a strong sense of accomplishment through a formal celebration of their work. Give students a chance to share their work with peers, parents, other teachers or administrators, or community members who might be positively impacted by their research. This will help wrap up the learning and solidify it in students' minds.

To gather another summative assessment point, students could create a Claim Evidence Reasoning essay based on the information communicated in the infographic. This would help you determine how students have come to understand the information individually.

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