Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

Synopsis: *In this second part of this 3 part unit on evolution, students investigate the case of the UCSD juncos. These birds appear to be far bolder than other juncos that they are closely related to. This case sparks questions about whether behavior can be inherited. Students analyze data from this case study, as they wrap up their experiments with antibiotics and bacteria. They use what they figure out from both the juncos and their bacteria experiments, to complete their mission as citizen scientists, developing more effective infographics to sway individual health choices related to the misuse of antibiotics.*

What students figure out: *By the end of the unit, students develop ideas about natural selection & evolution including:*

- *Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species and the emergence of new distinct species, as well as the extinction of other species.*
- *Genetic information provides evidence of evolution; multiple lines of descent can be inferred by comparing the DNA sequences of different organisms.*
- *Natural selection occurs only if there is both variation in the genetic information among organisms in a population and variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. Natural selection leads to adaptation.*
- *Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment.*

NGSS PERFORMANCE EXPECTATIONS BUNDLE

MS. Natural Selection and Evolution

HS-LS4-1	**HS-LS4-4**
HS-LS4-2	*HS-LS4-5*
HS-LS4-3	

Bolded PEs are targeted in this Bend (1)
Italicized PEs are targeted in Bend 2 & 3

Targeted NGSS Performance Expectation(s):

- **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-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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Targeted Scientific Practice(s)	Targeted DCI(s)	Targeted Cross-Cutting Concept(s)
Obtaining, Evaluating, and Communicating Information ● Communicate scientific information (e.g., about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (including orally, graphically, textually, and mathematically). (HS-LS4-1) **Constructing Explanations and Designing Solutions** ● Construct an explanation based on valid and reliable evidence obtained from a variety of sources (including students' own investigations, models, theories, simulations, peer review) and the assumption that theories and laws that describe the natural world operate today as they did in the past and will continue to do so in the future. (HS-LS4-2) (HS-LS4-4) **Analyzing and Interpreting Data** ● Apply concepts of statistics and probability (including determining function fits to data, slope, intercept, and correlation coefficient for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. (HS-LS4-3) **Engaging in Argument from Evidence** ● Evaluate the evidence behind currently accepted explanations or solutions to determine the merits of arguments. (HS-LS4-5) - - - - --- - - - ***Connections to Nature of Science*** - - --- - - - - - **Scientific Knowledge is Based on Empirical Evidence** ● A scientific theory is a substantiated explanation of some aspect of the natural world, based on a body of facts that have been repeatedly confirmed through observation and experiment and the science community validates each theory before it is accepted. If new evidence is discovered that the theory does not accommodate, the theory is generally modified in light of this new evidence. (HS-LS4-4)	**LS4.A: Evidence of Common Ancestry and Diversity** ● Genetic information, like the fossil record, provides evidence of evolution. DNA sequences vary among species, but there are many overlaps; in fact, the ongoing branching that produces multiple lines of descent can be inferred by comparing the DNA sequences of different organisms. Such information is also derivable from the similarities and differences in amino acid sequences and from anatomical and embryological evidence. (HS-LS4-1) **LS4.B: Natural Selection** ● Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. (HS-LS4-3) (HS-LS4-4) ● The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. (HS-LS4-3) **LS4.C: Adaptation** ● Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally, and physiologically well suited to survive and reproduce in a specific environment. That is, the differential survival and reproduction of organisms in a population that have an advantageous heritable trait leads to an increase in the proportion of individuals in future generations that have the trait and to a decrease in the proportion of individuals that do not. (HS-LS4-3) (HS-LS4-4) ● Adaptation also means that the distribution of traits in a population can change when conditions change. (HS-LS4-3) ● Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions, and the decline–and sometimes the extinction–of some species. (HS-LS4-5) ● Species become extinct because they can no longer survive and reproduce in their altered environment. If members cannot adjust to change that is too fast or drastic, the opportunity for the species' evolution is lost. (HS-LS4-5) ● Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment. (HS-LS4-2)	**Cause and Effect** ● Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. (HS-LS4-2)((HS-LS4-4)(HS-LS4-5) **Patterns** ● Different patterns may be observed at each of the scales at which a system is studied and can provide evidence for causality in explanations of phenomena. (HS-LS4-1)(HS-LS4-3) ---------- ***Connections to Nature of Science*** --------- **Scientific Knowledge Assumes an Order and Consistency in Natural Systems** ● 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. (HS-LS4-1)(HS-LS4-4)

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- CO Design team starts work on Alpha version of storyline in Summer of 2015.
- Alpha version of storyline piloted in Colorado Public Schools in 2015-2016.
- Design team expanded in Fall of 2015
- Design team expanded in Summer of 2016
- Beta version revisions made in summer 2016
- Beta pilot in fall of 2016 in KY and CO.
- 1.0 field trials in MI planned for spring of 2017.

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Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

Key to storyline columns:			
Lesson Question (time) *Building toward* ⬇ *NGSS PEs:*	**Phenomena**	**Lesson Performance Expectation(s):** • **Blue bold font: Science and Engineering Practice** • Regular font: Quoted from Appendix F Practices Matrix • *Italicized font: Specific storyline context (phenomena / question)* • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs)	**What We Figure Out** (CCCs & DCIs), *New Questions* and **Next Steps** • Green font: Cross-cutting concept(s) • Orange font: Disciplinary Core Ideas (or pieces of these DCIs) • *Purple italicized font: New questions that we now have* • **Purple bold font: Our ideas for the next (or future) steps to pursue.**

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Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

This Lesson....What we are doing now: 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. 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(s)	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.**

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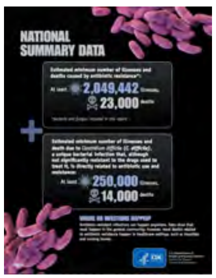
Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

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(s)	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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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.**

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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(s)	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?*

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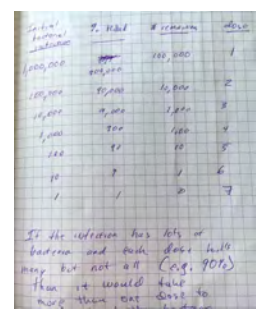
Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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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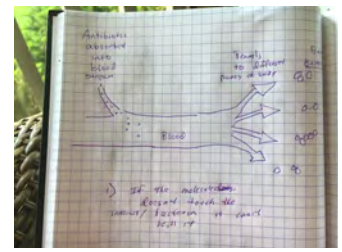
L4: (continued)	Old medicine bottles that say take full dose or something like that. [A written (and visual) summary of how antibiotics work] provides brief summaries of how they interfere with or destroy the functioning of cell structures (e.g. cell walls) unique to bacteria cells, but common between 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.**

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Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

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).

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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 our Petri dishes* along with an application of related scientific reasoning	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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L3b: (continued)	Same phenomena as above	*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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Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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.**

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Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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.**

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Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L5b: What's happening with our antibiotic experiment? (1 period) *Building toward* *<u>NGSS PEs:</u> 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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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.**

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Why Don't Antibiotics Work Like They Used To? (Bend 1 - Bacteria)

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

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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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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.**

This storyline continues into bends 2 and 3, which will motivate looking at other populations of organisms besides bacteria.

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Why Don't Antibiotics Work Like They Used To? (Bend 2 - Juncos)

Synopsis: *In this second part of this 3 part unit on evolution, students investigate the case of the UCSD juncos. These birds appear to be far bolder than other juncos that they are closely related to. This case sparks questions about whether behavior can be inherited. Students analyze data from this case study, as they wrap up their experiments with antibiotics and bacteria. They use what they figure out from both the juncos and their bacteria experiments, to complete their mission as citizen scientists, developing more effective infographics to sway individual health choices related to the misuse of antibiotics.*

NGSS PERFORMANCE EXPECTATIONS BUNDLE

MS. Natural Selection and Evolution	
HS-LS4-1	**HS-LS4-4**
HS-LS4-2	**HS-LS4-5**
HS-LS4-3	

Bolded PEs are targeted in this Bend (2)
Italicized PEs are targeted in Bend 3

What students figure out: *By the end of the unit, students develop ideas about natural selection & evolution including:*

- *Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species and the emergence of new distinct species, as well as the extinction of other species.*
- *Genetic information provides evidence of evolution; multiple lines of descent can be inferred by comparing the DNA sequences of different organisms.*
- *Natural selection occurs only if there is both variation in the genetic information among organisms in a population and variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. Natural selection leads to adaptation.*
- *Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment.*

Targeted NGSS Performance Expectation(s):

- **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-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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T	**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(s)	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) S *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 generalizable 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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			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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This Lesson....What we are doing now: Students will investigate the idea that they need to see if other populations of organisms (a kind of bird called a junco) meet the criteria we need in a new case study we want to investigate.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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.**

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	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(s)	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.**

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T	**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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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) S *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. The environment on the UCSD campus is similar to the mountains in some important ways:

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			- 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"?**

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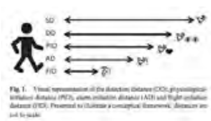
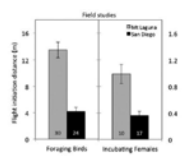
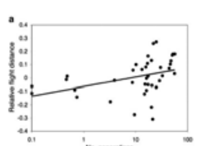
This Lesson....What we are doing now: Students will view a video clip that makes a claim that city juncos are “bolder than their mountain counterparts. They will analyze data sets to determine that one major difference in the behavior can be attributed to how they react to humans that get near them, 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(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L11a: What exactly makes these juncos “city birds”? (1-1.5 periods) S *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 environment. This is really

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			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.**

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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(s)	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.**

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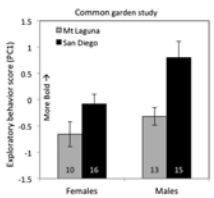
T	**This Lesson....What we are doing now:** Students will figure out what the researchers did to test whether the behavioral differences in the two populations of juncos were due to inheritance or learning in their respective environments by applying sound scientific processes to define the controls 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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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) S *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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			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.**

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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(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L5d: What's happening with our antibiotic experiment? (25 min.) S *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.**

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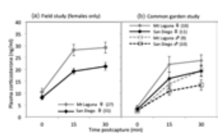
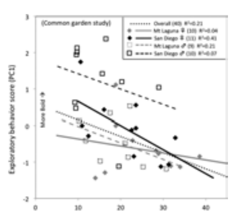
This Lesson....What we are doing now: Students will investigate primary sources using text and graphs to figure out that elevated corticosterone (CORT) levels in birds correspond to how easily birds get stressed which in turn is correlated to boldness levels. Students then develop out a model that accounts 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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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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			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.**

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T	**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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L5e: What's happening with our antibiotic experiment? (1 period) S *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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			○ 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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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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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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			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)?*

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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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	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!

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Why Don't Antibiotics Work Like They Used To? (Bend 3 - Common Ancestry)

NGSS PERFORMANCE EXPECTATIONS BUNDLE

HS. Natural Selection and Evolution	
HS-LS4-1	HS-LS4-4
HS-LS4-2	HS-LS4-5
HS-LS4-3	

Bolded PEs are targeted in Bend **3**

Synopsis: *In this third part of the 3-part unit on evolution, students investigate the juncos further, looking into why the UCSD and mountain juncos don't appear to be having offspring together. Their investigations into other juncos populations across North America lead to discoveries about speciation and mechanisms that contribute to it. Students apply what they figure out back to bacteria to explain how these mechanisms of evolution could help further explain the growing prevalence of antibiotic resistant bacteria and where new strains of bacteria come from.*

What students figure out: *By the end of the unit, students develop ideas about natural selection & evolution including:*

- *Changes in the physical environment, whether naturally occurring or human induced, have thus contributed to the expansion of some species, the emergence of new distinct species as populations diverge under different conditions.*
- *Genetic information provides evidence of evolution; multiple lines of descent can be inferred by comparing the DNA sequences of different organisms.*
- *Natural selection occurs only if there is both (1) variation in the genetic information between organisms in a population and (2) variation in the expression of that genetic information—that is, trait variation—that leads to differences in performance among individuals. The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population. Natural selection leads to adaptation.*
- *Evolution is a consequence of the interaction of four factors: (1) the potential for a species to increase in number, (2) the genetic variation of individuals in a species due to mutation and sexual reproduction, (3) competition for an environment's limited supply of the resources that individuals need in order to survive and reproduce, and (4) the ensuing proliferation of those organisms that are better able to survive and reproduce in that environment.*

Targeted NGSS Performance Expectation(s):
• **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-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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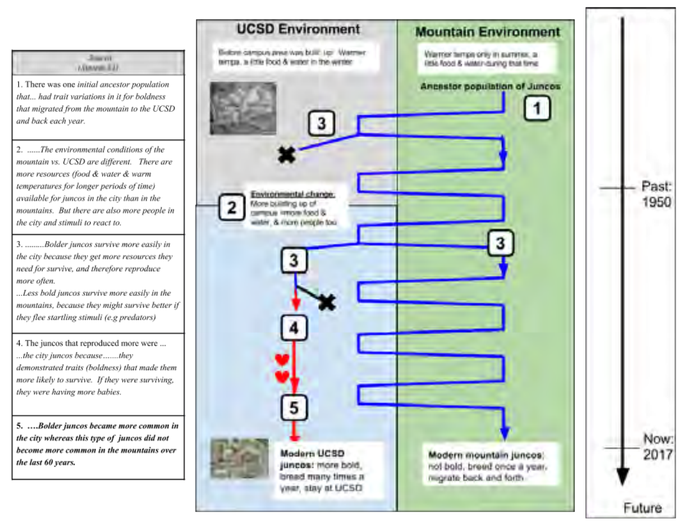
This Lesson...What we are doing now: You will help the class build a consensus model to represent a line of common ancestry for the mountain and UCSD juncos, and use to raise new questions related to gaps in the model, that will motivate future investigations across this last bend of the unit. In this 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 which population a bird belongs to)? (60 min.) *Building toward* *NGSS PEs:* *HS-LS4-1, 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). 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

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		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).*	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..**

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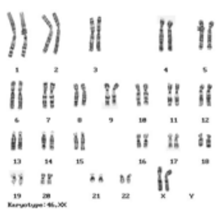
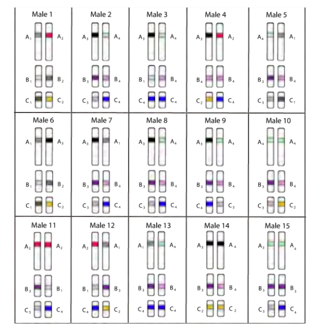
This Lesson...What we are doing now: Students gather information about how much DNA is unique between different people and apply what they figure out to a karyotype-based model for patterns of inheritance between offspring and parents that could help identify who the dad of a child is.

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? (55-60 min) *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 information that is different than what the parents had (50% + 50% ≠ 100%)?*	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 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).**

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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 which populations an individual junco belongs too? (45 min) *Building toward* *<u>NGSS PEs:</u>* *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 it has been since they shared a common ancestor.*	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. 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.

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			• 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?"**

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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.

Lesson Question	Phenomena	Lesson Performance Expectation(s)	What We Figure Out (CCCs & DCIs), *New Questions* and **Next Steps**
L18: What alleles are found in both populations? 40 min *Building toward* *NGSS PEs:* *HS-LS4-1, HS-LS4-2, HS-LS4-3, HS-LS4-4, & HS-LS4-5*	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.	**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.*	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.**

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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 and 12:38-13:23 and 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.**

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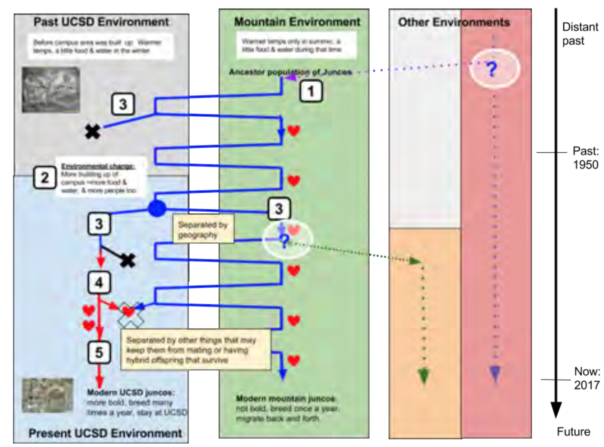
This Lesson...What we are doing now: Students will analyze data from scientists' investigations on the role of plumage and vocalization on mating behaviors in birds. They will use this evidence to argue that such interactions would lead birds to having preferences for mates that look and act like their 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.) *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 done on this and reported out our discoveries (there is evidence that birds really do decide who to breed with based on feather color and song of potential mates). We used this to argue that these differences (in song and plumage) between UCSD and mountain juncos may be helping to keep them from interbreeding. We wondered if the UCSD juncos should be considered a new species, since we learned that when scientists are thinking 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.**

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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. S *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).**

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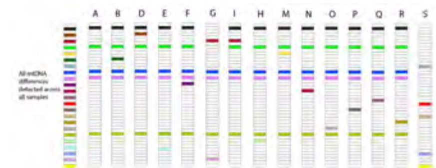
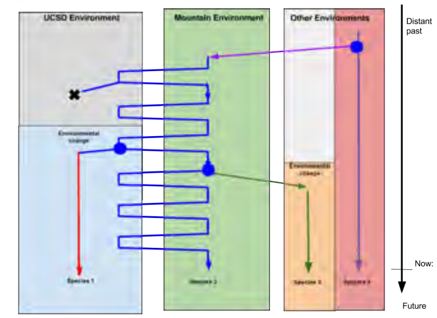
This Lesson...What we are doing now: Students will analyze data on the mutations found in mtDNA from juncos found across N. America to support arguments for which juncos are more closely related to each other than others. They will gather information from two video clips (field observations and conclusions) 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: 6 minutes of Diversification 1: The Dark Eyed-Junco Video and 8 minutes of Diversification 2: The Dark Eyed-Junco Video provide additional information from 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?”**

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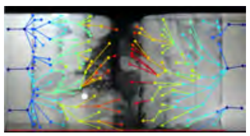
This Lesson...What we are doing now: Students will investigate the role of mutation in the evolution of bacteria through three information sources (a video clip, a New York Times article, and an article from Nature). Then you will help them summarize all the evidence they have from the entire unit for 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 would these mechanisms affect the evolution of bacteria over time? (95 min) + Optional 30 min. extension S *Building toward* *NGSS PEs:* *HS-LS4-1,* *HS-LS4-2,* *HS-LS4-3,* *HS-LS4-4,* *& HS-LS4-5*	A timelapse video from Harvard Medical School shows patterns in lines of descent 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 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 a 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.**

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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* *<u>NGSS PEs:</u>* *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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