

BIOLOGY

Natural Selection &
Evolution of Populations

**How does
urbanization affect
nonhuman
populations, and
how can we minimize
harmful effects?**



HIGH SCHOOL SCIENCE



TEACHER EDITION

How does urbanization affect nonhuman populations, and how can we minimize harmful effects?

Natural Selection & Evolution of Populations: Urbanization

OpenSciEd Unit B.4





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UNIT OVERVIEW

How does urbanization affect nonhuman populations, and how can we minimize harmful effects?

This unit on natural selection and evolution of populations focuses on the phenomenon of increasing urbanization around the world and the impact of that change on nonhuman populations. Students observe nonhuman populations affected by urbanization in their own community and read about three case studies of nonhuman populations that are different in urban and nonurban environments. These initial investigations prompt students to ask what is causing differences they see in these populations.

Students create an initial model of how and why nonhuman populations could change because of urbanization and investigate each case study in more detail to uncover the mechanisms for change. They conduct an investigation of the impact of habitat fragmentation on seed dispersal strategies in hawksbeard plants. Students then investigate how rats in Tokyo could have become resistant to poison, gathering information from a variety of studies to learn how genetic variations affect their physiology and rates of survival. Students also investigate studies of juncos to see if bold behavior is an advantageous trait for living close to people in urban environments. At the end of Lesson Set 1, students synthesize their knowledge to create group models and then a class consensus model explaining how urbanization is a force of change in nonhuman populations—a model that explains evolution by natural selection. Lesson Set 2 focuses on why some nonhuman populations have reduced fitness in urban environments, introducing students to endangered panthers and mountain lions whose populations appear to be harmed by urbanization. Students use a mathematical model to determine how habitat fragmentation impacts fitness and then investigate possible human-engineered solutions to prevent these problems. They develop criteria for how urban areas can grow while maintaining genetically diverse and resilient populations and ecosystems. Finally, students apply their knowledge to evaluate proposed design solutions for Buckeye, Arizona, one of the fastest-growing cities in the United States.

Through these investigations, students will do the following:

- Ask and answer questions about how urbanization may cause changes in nonhuman populations.
- Develop and revise models for how various selection pressures could cause nonhuman populations to evolve.
- Analyze data collected in their own investigations or when reading the work of published scientists and apply this evidence to support their explanations.
- Write and revise explanations for how genetic variations can lead to differential reproductive success and changes in populations.
- Apply their knowledge of evolution by natural selection to explain why small, fragmented populations can be more vulnerable to change than large populations.
- Evaluate and discuss how well proposed designs for the urbanization of a real city meet criteria for protecting biodiversity and the needs of all inhabitants of the area.
- Complete two transfer tasks by applying their knowledge to novel phenomena.

Building Toward NGSS Performance Expectations

HS-ETS1-3:

Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.

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.

HS-LS4-6:

Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

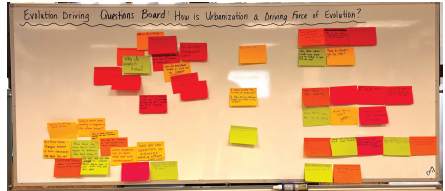
UNIT STORYLINE

Unit Question: How does urbanization affect nonhuman populations, and how can we minimize harmful effects?

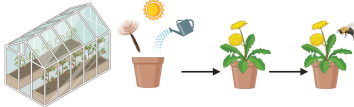
How students will engage with each of the phenomena



Lesson Set 1: How is urbanization a driving force for change?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 1 Lesson Set 1 3 days What is the effect of increasing urbanization on nonhuman populations? Anchoring Phenomenon 	 <i>Students see evidence of increasing urbanization and are introduced to examples of populations impacted by those environments.</i>	We see examples of increasing urbanization around the world. We find and model examples of nonhuman populations affected by urbanization that live in our own community. We read about three populations: hawkbeard, juncos, and rats. We develop an initial consensus model of the effects of urbanization on nonhuman populations. We figure out: • Urbanization is expanding around the globe, and that affects the ability of some nonhuman populations to survive. • Hawksbeard populations in urban areas have a higher proportion of nonfeathery seeds than in non-urban areas. • Some rat populations in urban areas have resistance to poisons. • Some junco populations moved to urban areas and are bolder than those in non-urban areas. • We have questions about the causes of the differences between urban and non-urban nonhuman populations.	

↓ **Navigation to Next Lesson:** We decide to investigate why hawkbeard make fewer feathery seeds in cities.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
LESSON 2 Lesson Set 1 2 days Why does hawksbeard make fewer feathery seeds in cities? Investigation 	 <i>Fragmentation of urban areas impacts seed dispersal strategies in plant populations.</i>	We conduct an investigation of the impact of fragmentation on seed dispersal strategies in hawksbeard and compare our results with published studies. We discuss why common garden experiments are useful in natural selection investigations. We update our consensus model and start a Progress Tracker. We figure out: - Urban areas create physical barriers and habitat fragmentation that prevent hawksbeard seeds from successfully reaching new places to grow. - Hawksbeard plants produce more offspring than can survive and not all of them find a place to grow. - The proportion of two different modes of seed dispersal in hawksbeard is heritable. - Fragmentation causes selection for heritable variations in hawksbeard allowing more seeds without feathers to germinate and have the opportunity to reproduce.	Figure 1. Common garden experiment set-up. - Collect seeds with feathers from 11 locations.  - Raise 30 plants from each location in a greenhouse.  - Count the number of feathery and nonfeathery seeds on two seed heads from each plant.  <i>Illustrations created by OpenSciEd in BioRender, Data source: Cheptou et. al. (2008)</i>

↓ Navigation to Next Lesson: We decide to learn more about how rats developed resistance to poison and whether poison is a selection pressure.

LESSON 3

Lesson Set 1

3 days

Is poison a selection pressure?

Investigation





80% of rats in Tokyo, Japan are resistant to poison.

We investigate how rats in Tokyo became resistant to poison. We discuss ethical decision-making when living things are involved. We investigate a model for how rats developed resistance and write a preliminary explanation. We gather information from studies about genetic variations in rats that affect their physiology and evaluate the impact of new data on our explanations. We revise and self-assess our explanations. We figure out:

- Mutations for poison resistance existed in the rat population before people used poison.
- Rat populations have variations in their mutations.
- Variable expression of mutations affects rat physiology causing different levels of resistance to poison.
- Rats sexually reproduce, which allows for the mixing of genes.
- High reproduction rates allow rats that survive poison to quickly increase in number with offspring resistant to poison.
- Natural selection for resistance happens over generations.

 Rat Poison Explanation

Part 1: Revising Explanation with New Data

Instructions: Write or draw an explanation supported by evidence from the lesson describing how it would be possible for 80% of rats in Tokyo to have resistance to poison today. Make sure your explanation includes why 20% of the rats are not resistant. Use the space below to jot down some notes. Then write and/or draw your explanation below the table or on another page. Your drawing should be supported by labels that explain the mechanism you want to show.

Gotta-Have-It-Checklist	Ideas for Sentence Starters
Your claim about why 80% of Tokyo rats are resistant to poison.	Rat poison is a selection pressure because _____ 80% of rats in Tokyo are resistant to poison because _____ 20% of rats in Tokyo are not resistant because _____ Mutations caused _____ which caused _____ to change in the population.
At least 3 pieces of evidence from different sources. Include the model and readings.	One piece of evidence I have to support my ideas is _____ In our model we found that _____ caused _____ to change. There is variation in _____ which causes _____. When scientists measured _____ they found _____.
Explain how the evidence supports your claim about Tokyo.	I think the situation in Tokyo is similar to what happened in Europe. In Europe they found _____ This likely happened in Tokyo too because _____.

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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↴ **Navigation to Next Lesson:** We figured out that rat poison is a selection pressure for physiological adaptations, which made us wonder what else we need to figure out on our initial class consensus model.

LESSON 4

Lesson Set 1

3 days

What causes populations of city juncos to be bolder than mountain juncos?

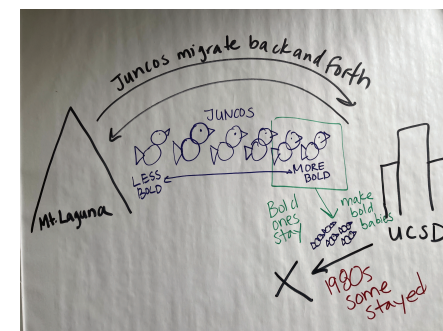
Investigation



Juncos in an urban environment are bolder than juncos in the non-urban mountains.

We investigate juncos to see if bold behavior is an advantageous trait for living in the urban UCSD campus. We figure out that boldness is inherited and we develop initial models to explain how the UCSD juncos came to be bolder. We figure out that a hormone called CORT has a negative relationship with boldness and that there are still some unknown components and mechanisms that would explain this phenomenon. We engage in an electronic exit ticket to check our understanding. We figure out:

- Boldness is a competitive advantage for obtaining food and nesting spaces. This leads to increased survival for birds that are more bold in city environments.
- Juncos have inherited behavioral traits from their parents.
- Elevated corticosterone (CORT) levels correspond to stress levels in Juncos. This then affects how exploratory (bold) those birds are.
- Overtime, juncos that are more bold survive and reproduce causing a greater proportion of juncos living in the city to be more bold.



↴ **Navigation to Next Lesson:** We engage with an electronic exit ticket as a formative check of our understanding.

LESSON 5

Lesson Set 1

2 days

How can we make sense of the way urbanization could have caused changes in hawksbeard, rat, and junco populations?

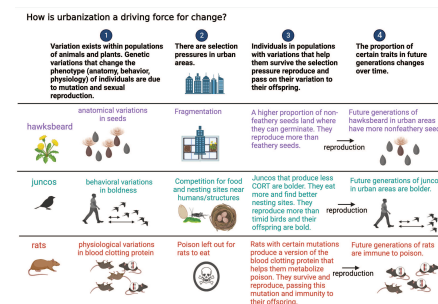
Putting Pieces Together



Urbanization can affect the distribution of traits in multiple species.

We synthesize our knowledge to create group models and then a class consensus model explaining how urbanization is a force of change in nonhuman populations. We read about Lamarck's and Darwin's theories of evolution and recognize that our model supports Darwin's theory of evolution by natural selection. We figure out:

- All populations have heritable variations between individuals.
- There are selection pressures in urban areas.
- Not all individuals in populations survive to reproduce. Those with variations that are better adapted to the environment survive to reproduce more than those that are not well adapted.
- Offspring inherit favorable traits.
- Over many generations, the proportion of favorable traits in a population increases, and the proportion of less favorable traits decreases.
- Our consensus model is similar to Darwin's theory of evolution by natural selection.



Illustrations created by OpenSciEd in BioRender

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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↓ **Navigation to Next Lesson:** We apply our model of evolution by natural selection to a new phenomenon.

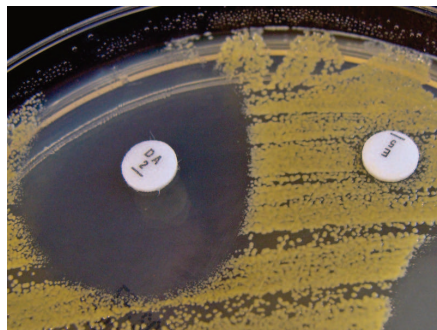
LESSON 6

Lesson Set 1

1 day

Can we apply what we know about evolution by natural selection to another phenomenon?

Putting Pieces Together



Bacteria populations develop resistance to antibiotics.

We apply what we figured out to a new context and complete a transfer task about bacteria that developed resistance to antibiotics. We figure out:

- Some bacteria have traits that keep antibiotics from killing them.
- There is a positive relationship between antibiotic use and antibiotic resistance.
- Natural selection causes an increase in the proportion of bacteria in the population that are resistant to antibiotics.
- If we reduce our use of antibiotics, we will slow the rate at which bacteria develop resistance to antibiotics.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	In this explanation, look for: Student explains how antibiotics cause bacteria with an advantageous heritable trait to differentially survive and reproduce, making all individuals in the population resistant to the antibiotic.	In this explanation, look for: Student explanation is based on evidence for how antibiotics cause bacteria with an advantageous heritable trait to differentially survive and reproduce, changing the proportion of individuals in the population that are resistant to the antibiotic.	In this explanation, look for: Student explanation is based on empirical evidence from a variety of sources for how antibiotics cause only bacteria with an advantageous heritable trait to differentially survive and reproduce, changing the proportion of individuals in the population that are resistant to the antibiotic.

↓ **Navigation to Next Lesson:** We decided to investigate if all populations are helped by natural selection in cities.

Lesson Set 2: How can we use what we know about natural selection to design cities that support resilient populations and ecosystems?

Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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LESSON 7

Lesson Set 2

2 days

What happens when nonhuman populations are harmed by urbanization and what can we do about it?

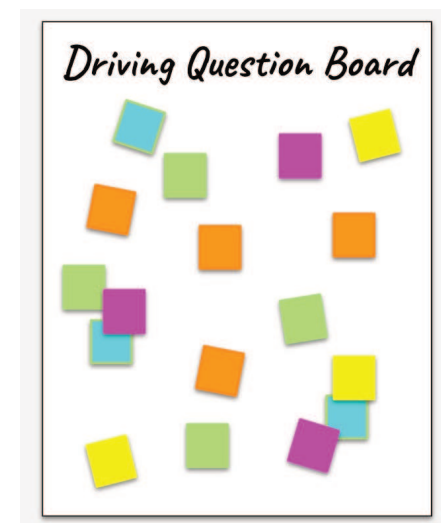
Problematising



Species can be negatively affected by urbanization. New development can plan to reduce negative effects.

We explore a new case of a nonhuman population affected by urbanization, the Florida panther. We use our class consensus model and figure out that it cannot explain what we observe. We hear about a fast-growing urban area in Buckeye, AZ where mountain lions live. We generate questions to help figure out why genetic diversity and fitness are reduced in some nonhuman populations and how the city's growth plan can support resilient populations. We figure out:

- Some populations have reduced fitness in urban environments.
- Our natural selection model cannot fully explain why this happens.
- As cities grow, they can plan for systems that prevent harm to nonhuman populations.



Lesson Question	Phenomena or Design Problem	What we do and figure out	How we represent it
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↓ **Navigation to Next Lesson:** We investigate a new case of the Florida panther and see new urbanization in Buckeye, AZ..

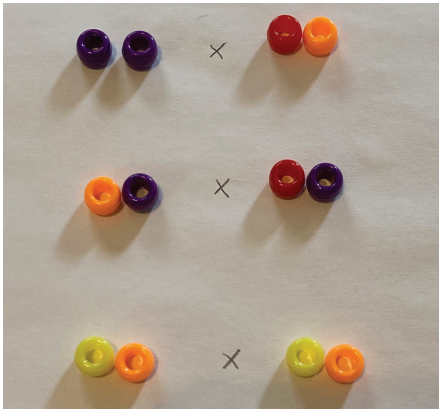
LESSON 8

Lesson Set 2

2 days

How can fragmentation lead to lower genetic diversity?

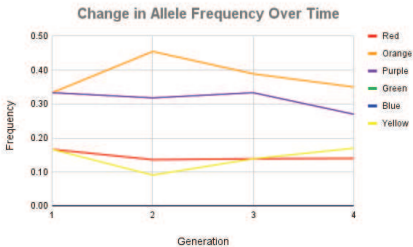
Investigation



Students manipulate a model that simulates the effect of fragmentation on the genetic diversity of an urban population.

We use a mathematical model to explain why nonhuman populations that experience fragmentation have lower genetic diversity. We apply a selection pressure to the model and graph how allele frequencies change over time and then compare results from different groups. We have a consensus discussion to develop an explanation for our lesson question. We wonder about ways to apply this information to areas experiencing urbanization. We figure out:

- Fragmentation can create smaller, isolated populations.
- Fragmented populations become less fit if they lose individuals with alleles that provide a selective advantage.
- Selection pressures and random chance can cause loss of allelic diversity in populations.
- If populations lose genetic diversity they cannot always adapt to a changing environment.



↓ **Navigation to Next Lesson:** We review wonderings that remain about possible solutions for preventing fragmentation and the loss of genetic diversity in urban areas from our Progress Tracker.

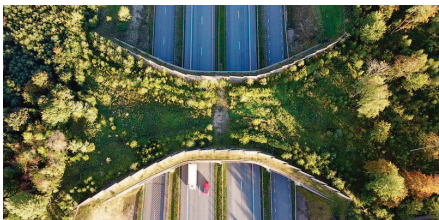
LESSON 9

Lesson Set 2

2 days

How can we plan urban areas to protect genetic diversity in nonhuman populations?

Investigation



Wildlife corridors affect population stability and genetic diversity in nonhuman populations.

We decide to investigate if connecting habitats to make them bigger helps nonhuman populations be more stable and resilient. We discover there are different structures that humans use to connect habitats for nonhuman populations. We apply mathematical and statistical thinking to evaluate how effective these structures are at removing barriers and connecting habitats. We think again about the city of Buckeye and what criteria the community would develop if they were to add these structures. We figure out:

- Selection pressures lead to shifts in trait distribution.
- Reducing fragmentation maintains genetic diversity so populations can adapt to changing conditions.
- People can maintain resilience and genetic diversity in nonhuman populations by creating corridors to connect fragmented populations.
- We can develop criteria for urbanization that sustains biodiversity and benefits both humans and nonhuman populations.

Criteria For Urban Designs	
Class Criteria	Interest Holder's Criteria
• Nonhuman populations do not get fragmented. • Provides good habitat for plants and animals. • Nonhuman populations maintain high fitness and high genetic diversity. • Nonhuman populations have a large protected habitat. • Minimal to no barriers for movement of nonhuman populations. • Put wildlife corridors over or under all roads. • Green roofs, native landscaping • Large protected parks for nonhuman populations	• Housing for all of the people who will live there. • Good schools. • Places to play. • Roads to commute, deliver materials, etc. • Cannot cost too much to build all the protections for animals. • Be safe for people to live there. • Enough water to live. • People need jobs. • Respect the ancestral home of Indigenous people.

↴ Navigation to Next Lesson: We decided we want additional information about Buckeye AZ in order to refine our criteria.

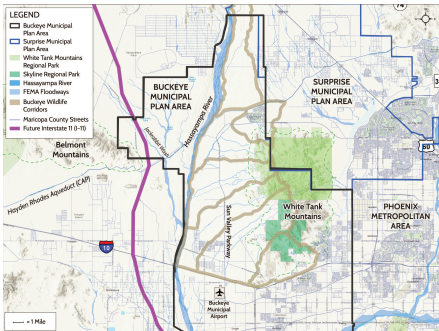
LESSON 10

Lesson Set 2

2 days

How can we use what we know about natural selection to design cities that support resilient populations and ecosystems?

Putting Pieces Together



Evaluate designs proposed for the anticipated growth of the city of Buckeye, AZ.

We investigate the conflicting requirements for protecting biodiversity and providing for the needs of human populations in Buckeye, AZ. We read about the requirements of mountain lions, mule deer and other wildlife. We compare our criteria from Lesson 9 to criteria and constraints developed by citizens of Buckeye. We evaluate two proposed designs for urbanizing Buckeye. We consider how to apply what we learn to areas of concern to us. We figure out:

- Our knowledge of evolution by natural selection helps us evaluate the stability of a proposed urban system for nonhuman populations.
- Urban areas can be designed to prevent fragmentation and allow for gene flow.
- Making decisions involves evaluating the application of science ideas and balancing them with societal impacts.
- Land use decisions are complex, and it may be necessary to prioritize certain criteria over others.

Buckeye Plan Evaluation Tool

Thinking about the long-term stability of nonhuman populations in Buckeye, what should be the goal of the design? What should we see in a design that would help us accomplish that goal?

Use the tables below to help compare and evaluate the competing arguments or different design solutions.

	Design #1	Design #2
Part 1: Summarize the designs		
Summarize the main idea of the design.		

↴ Navigation to Next Lesson: We apply our understanding of evolution by natural selection to a new phenomenon.

LESSON 11

Lesson Set 2

1 day

Can we apply what we know about natural selection and genetic diversity to a novel phenomenon?

Putting Pieces Together



Banana populations are devastated by fungal infections.

We complete a transfer task to apply what we know about natural selection to consider ways to protect banana crops from fungal infections. We figure out:

- There is a pattern of fungal infections attacking banana populations.
- Most banana crops are grown clonally and have no genetic diversity.
- Scientists can create genetically modified bananas with resistance to one fungus.
- As long as farmers grow only one genetic variety of banana, they will be vulnerable to infections.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	In this explanation, look for: Student explains that increased genetic diversity in a population causes an adaptive genetic mutation that provides protection to the plant, increasing chances for survival and therefore that	In this explanation, look for: Student explains that increased genetic diversity in a population causes an increased probability of having an adaptive genetic mutation that provides protection to the plant.	In this explanation, look for: Student explanation is based on the patterns of evidence learned in previous lessons that increased genetic diversity in a population causes an increased probability of having an
	can be passed onto offspring.	increasing chances for survival and therefore that can be passed onto offspring.	adaptive genetic mutation that provides protection to the plant, increasing chances for survival and therefore that can be passed onto offspring.

↴ Navigation to Next Lesson: This is the last lesson in the unit.

LESSONS 1-11

23 days total

TEACHER BACKGROUND KNOWLEDGE

Lab Safety Requirements for Science Investigations

It is important to adopt and follow appropriate safety practices when conducting hands-on science investigations and demonstrations, whether in an instructional space (traditional laboratory or classroom) or in the field. To this end, teachers must be aware of any school or district safety policies, legal safety standards, and better professional safety practices that are applicable to the activities being undertaken.

Science safety practices in instructional spaces require engineering controls and personal protective equipment (e.g., sanitized safety goggles or safety glasses with side shields as appropriate, non-latex aprons and gloves, eyewash/shower station, fume hood, appropriate ventilation, and fire extinguishers). **Science investigations should always be directly supervised by qualified adults, who should review safety procedures annually, and also before initiating any hands-on activities or demonstrations.** Prior to each investigation, students should be reminded of the specific safety procedures they must follow. Each lesson within the OpenSciEd units includes teacher guidelines for applicable safety procedures for setting up and running an investigation, as well as disassembling, disposing of, and storing materials.

Prior to the first investigation of the year, a safety acknowledgement form for students and parents/guardians should be provided and signed. You can access a model safety acknowledgement form for high school activities here: <https://static.nsta.org/pdfs/SafetyAcknowledgmentForm-HighSchool.pdf>

Disclaimer: The safety precautions provided for each activity are based in part on use of the specifically recommended materials and instructions, as well as legal safety standards and better professional safety practices. Be aware that selecting alternative materials or procedures for these activities may affect the activity's level of safety, and is therefore at the user's own risk.

Please follow these lab safety recommendations for any science investigation:

1. Wear sanitized safety goggles (specifically, indirectly vented chemical splash goggles) or safety glasses with side shields, as appropriate, a non-latex apron, and non-latex gloves during the set-up, hands-on investigation, and take-down segments of the activity.
 2. Safety goggles are required when working with liquid biological or chemical hazards (e.g., microbes, acids, bases, etc.). Safety glasses with side shields or safety goggles may be used when working with physical hazards (sharps, springs, glass, projectiles, etc.).
 3. Immediately wipe up any spilled liquid (e.g., water) and/or granules on the floor, as this is a slip-and-fall hazard.
 4. Follow your *Teacher Guide* for instructions on disassembling and storing materials and disposing of waste materials.
 5. Secure loose clothing, remove loose jewelry, wear closed-toe shoes, and tie back long hair.
 6. Wash your hands with soap and water immediately after completing the activity.
 7. Never eat any food items used in a lab activity.
 8. Never taste any substance or chemical in the lab.
 9. Use only GFCI protected circuits when using electrical equipment, and keep away from water sources to prevent shock.
 10. Use caution when working with glassware, which can shatter if dropped and cut skin.
 11. Use caution when using sharp [tools/materials], which can cut or puncture skin.
 12. Never pour chemicals, either used or unused, back into their original container. Dispose of chemicals according to your teacher's instructions.
 13. If you get a hazardous chemical on your clothing or have a clothing fire, use the emergency shower.
 14. If you get a chemical in your eye, use an eyewash station immediately.
 15. Point the test tubes, beakers, or other vessels away from yourself and other people when the vessels contain reactants or other substances.
 16. When diluting acids or bases, the acid or base should be added to water and not water to the acid or base.
 17. Projective trajectory zones must be well defined and free of any obstacles. No participant is to be in the zone during operation of the projectile..
 18. Make sure the ventilation system meets the needs relative to removal of flammable vapors produced. Also make sure there are no active flames or sparks in the work zone.
-  Specific safety precautions are called out within the lesson using this icon and a call-out box.

Where does this unit fall within the OpenSciEd scope and sequence?

This unit is the fourth unit in the OpenSciEd High School Biology course sequence and is designed to build on student ideas about genetic variation, inheritance, change over time, and ecosystem dynamics. In the first unit of the course, *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, students develop ideas about biodiversity, why it is important and how natural and anthropogenic factors affect it. In the unit, *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*, students explore inheritance and variation of traits. They investigate the mechanisms underlying how traits are passed on from parents to offspring including

the role of mutation in genetic variation. In this unit, they will build on those ideas as they look at evidence related to genetic differences between urban and nonurban populations and populations over time. Together with an understanding of ecosystems, they explain how urbanization affects nonhuman populations and how we can minimize harmful effects. In the final unit, *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?* (Speciation Unit), students will explore changes in populations and Earth's systems that cause speciation.

What is the anchoring phenomenon and why was it chosen?

In the anchoring phenomenon, students are introduced to the phenomenon of urbanization and find out that continued urbanization is happening worldwide. They consider what this means for nonhuman populations and make observations about differences in urban populations of hawksbeard, rats, and juncos. They wonder how urbanization could be a driving force for change.

This anchoring phenomenon was chosen from a group of phenomena aligned with the target performance expectations based on the results of a survey administered to students from across the country and in consultation with external advisory panels that include teachers, subject matter experts, and state science administrators. The anchor was chosen for the following reasons:

- Teachers and administrators saw high relevance to students' everyday experiences.
- Explaining how urbanization affects change addresses all the DCIs in the bundle at a high-school level.
- Students have the opportunity to apply their ideas to a real-world scenario that they are likely to encounter in the future.

How is the unit structured?

The unit is organized into two lesson sets. Lesson Set 1 (Lessons 1-6) focuses on how students can make sense of the way urbanization could have caused changes in hawksbeard, rat, and junco populations. This lesson set culminates in a transfer task where students apply what they have figured out so far to explain how bacteria develop resistance to antibiotics. Lesson Set 2 (Lessons 7-11) helps students to use what they know about natural selection to design cities that support resilient populations and ecosystems. At the end of Lesson Set 2, students investigate the conflicting requirements for protecting biodiversity while urbanizing and providing for the needs of human populations in Buckeye, AZ. Students then evaluate two proposed designs for urbanizing Buckeye, AZ, focusing on how to balance the needs of human and nonhuman populations. This unit culminates with a transfer task where they apply all of their understanding about natural selection to consider ways to protect banana crops from fungal infections.

Lesson Set 1: How is urbanization a driving force for change?

Lesson 1

Students investigate how urbanization is rapidly increasing and how it impacts nonhuman populations. They develop initial models based on three case studies about hawksbeard, rats and juncos to explain how urbanization impacts nonhuman populations.

Lessons 2-5

Students investigate each case study and focus on anatomical, physiological, and behavioral changes in nonhuman populations connected to urbanization. They explore selection pressures like fragmentation, poison and competition for food and nesting sites near humans. They analyze data and explain how these selection pressures act on genetic variations in populations and differentially affect the survival and reproduction of some individuals. They develop a revised model of evolution by natural selection.

Lesson 6 Transfer Task

Students apply current understanding of evolution by natural selection to explain how bacteria develop antibiotic resistance.

Lesson Set 2: How can we use what we know about natural selection to design cities that support resilient populations and ecosystems?

Lesson 7

Students investigate why some nonhuman populations affected by urbanization experience reduced genetic diversity and fitness. They investigate the Florida panther and Buckeye, AZ where urbanization is happening quickly, threatening biodiversity in the region. They ask new questions to add to the Driving Question Board.

Lesson 8-10

Students use a model to explain how nonhuman populations lose genetic diversity and fitness when they become small and fragmented. They investigate the effectiveness of solutions that prevent fragmentation and analyze if they help populations maintain genetic diversity. They apply their understanding of evolution by natural selection to develop criteria that protect the biodiversity of populations experiencing the effects of urbanization in Buckeye, AZ and evaluate how well two design proposals for the future urbanization of the region meet the needs of human and nonhuman populations.

Lesson 11 Transfer Task

Students apply ideas about evolution by natural selection to consider ways to protect banana crops from fungal infections.

What elements of the NGSS three dimensions are developed in this unit?

This unit is designed to support students in developing an understanding of **evolution by natural selection** in a relevant context. **Analyzing and interpreting data** is intentionally developed beginning in Lesson 2 as students **compare and contrast self generated and scientific data and evaluate the impact of new data on a working explanation** about the possible **causes and effects** of urbanization on nonhuman populations.. As students work with additional data throughout the unit, they **make directional hypotheses and apply concepts of statistics and probability** to analyze and interpret evidence that can be used to support **explanations** about **cause and effect** of urbanization in nonhuman populations. **Cause and effect** is intentionally developed in this unit. Early in the unit, students use **empirical evidence** to support claims about fragmentation as a **cause** of **natural selection** in urban populations. In later investigations they **examine smaller scale mechanisms**, including genetics, as evidence.

Constructing explanations is intentionally developed throughout the unit. Students' working **explanations are constructed and revised** as their investigations uncover new evidence. They continue to **revise their explanations** as they grapple with disconfirming evidence. Finally they used their ideas about **evolution by natural selection** to develop criteria that could help maintain stable and resilient nonhuman populations as urbanization continues and increases in some locations.

This unit builds toward these performance expectations:

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.~~

HS-LS4-6 Create or revise a simulation to test a solution to mitigate adverse impacts of human activity on biodiversity.

HS-ETS1-3†. Evaluate a solution to a complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics as well as possible social, cultural, and environmental impacts.

* This performance expectation is developed across multiple units.

† This performance expectation is developed across multiple courses.

Science and Engineering Practices	Disciplinary Core Ideas*	Crosscutting Concepts
This unit intentionally develops students' engagement in these practice elements: Analyzing and Interpreting Data - Apply concepts of statistics and probability (including determining function fits to data, slope, intercepts, and correlation coefficients for linear fits) to scientific and engineering questions and problems, using digital tools when feasible. - Compare and contrast various types of data sets (e.g., self-generated, archival) to examine consistency of measurements and observations. - Evaluate the impact of new data on a working explanation and/or model of a proposed process or system. Construction Explanations - Construct and revise 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. 6.3 Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.	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 - 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) - 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	This unit intentionally develops students' engagement in these crosscutting concept elements: Cause and Effect - Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects. - Cause-and-effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller-scale mechanisms within the system. - Systems can be designed to cause a desired effect. - Changes in systems may have various causes that may not have equal effects. The following crosscutting concepts are also key to the sensemaking in this unit: - Patterns - Stability and Change

The following practices are also **key to the sensemaking** in this unit:

- Asking Questions and Defining Problems
- Developing and Using Models
- Planning and Carrying Out Investigations
- Using Mathematics and Computational Thinking
- Engaging in Argument from Evidence

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, HS-LS4-6)
- ~~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)

LS4.D: Biodiversity and Humans

- ~~Biodiversity is increased by the formation of new species (speciation) and decreased by the loss of species (extinction).~~ (secondary) (HS-LS4-7)
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, ~~and climate change.~~ Thus, sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (HS-LS4-6, HS-LS4-7)

ETS1.B: Developing Possible Solutions

- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (secondary) (HS-ETS1-3)
- ~~Both physical models and computers can be used in various ways to aid in the engineering design process. Computers are useful for a variety of purposes, such as running simulations to test different ways of solving a problem or to see which one is most efficient or economical; and in making a persuasive presentation to a client about how a given design will meet his or her needs.~~ (secondary) (HS-LS4-6)

*“Disciplinary Core Ideas” are reproduced verbatim from *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. DOI: <https://doi.org/10.17226/13165>. National Research Council; Division of Behavioral and Social Sciences and Education; Board on Science Education; Committee on a Conceptual Framework for New K-12 Science Education Standards. National Academies Press, Washington, DC. This material may be reproduced and used by other parties with this attribution. If the original material is altered in any way, the attribution must state that the material is adapted from the original.

Connections to the Nature of Science (NOS) and Engineering, Technology, and Applications of Science (ETS)

Connections to the Nature of Science (NOS)	
Which elements of NOS are developed in the unit?	How are they developed?
Scientific Investigations Use a Variety of Methods. Science investigations use diverse methods and do not always use the same set of procedures to obtain data.	In Lessons 2-4 students investigate data from studies that use different methods to collect evidence of natural selection in nonhuman populations.
Scientific Knowledge is Based on Empirical Evidence. Science knowledge is based on empirical evidence.	Students engage with empirical evidence in the form of multiple studies throughout the unit and use that empirical evidence to support claims about the cause of differences between populations.
Scientific Knowledge is Open to Revision in Light of New Evidence. Most scientific knowledge is quite durable but is, in principle, subject to change based on new evidence and/or reinterpretation of existing evidence.	In Lesson 5, students use their understanding of evolution by natural selection to compare the model they developed to Lamarck and Darwin's theories .
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.	In Lesson 10, students evaluate proposals for growth in the city of Buckeye, AZ that take into account the nonhuman populations that live there. Their evaluation is based on the assumption that evolution by natural selection will continue to happen in the future as it did in the past.

Connections to Engineering, Technology, and Applications of Science (ETS)	
Which elements of ETS are developed in the unit?	How are they developed?
Influence of Engineering, Technology, and Science on Society and the Natural World. New technologies can have deep impacts on society and the environment, including some that were not anticipated.	In Lesson 9 students investigate data from a student of the implementation of a fish ladder. The fish ladder was designed to allow fish of all sizes to pass upstream but had the unintended consequence of limiting passage to fish of certain sizes.
Influence of Engineering, Technology, and Science on Society and the Natural World. New technologies can have deep impacts on society and the environment, including some that were not anticipated. Analysis of costs and benefits is a critical aspect of decisions about technology.	In Lesson 10, students use their understanding of human-created wildlife corridors to compare criteria and constraints developed by citizens of Buckeye and with those they develop themselves in Lesson 9. They evaluate two proposed designs for urbanizing Buckeye, AZ, focusing on how to balance the needs of the human and nonhuman populations.

How does the unit build three-dimensional progressions across the course and the program?

OpenSciEd units support students in integrated development and use of the three dimensions. No one dimension can be developed in isolation from the others, as reflected in three-dimensional Lesson-Level Performance Expectations (LLPEs) which detail the specific dimensions and elements used and assessed in each lesson. However, some practices and crosscutting concepts are more productive for investigating particular anchoring phenomena, so focal practices and crosscutting concepts are articulated in each unit. All 46 SEP and 29 CCC elements are developed at some point in the high school OpenSciEd program, so all elements of a given SEP or CCC may not be present even in a unit that emphasizes developing that SEP or CCC.

This unit uses and builds upon **disciplinary core ideas (DCIs)** and other science ideas that students should have previously developed in OpenSciEd High School Biology and OpenSciEd Middle School.

- All cells contain genetic information in the form of DNA molecules. Genes are regions in the DNA that contain the instructions that code for the formation of proteins, which carry out most of the work of cells. (*OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*)
- Animals engage in characteristic behaviors that increase the odds of reproduction. (*OpenSciEd Unit 8.6: How could things living today be connected to the things that lived long ago? (Penguins Unit)*, *OpenSciEd Unit 8.5: Why are living things different from one another? (Muscles Unit)*)
- Ecosystems are dynamic in nature; their characteristics can vary over time. Disruptions to any physical or biological component of an ecosystem can lead to shifts in all its populations. (*OpenSciEd Unit 7.5: How does changing an ecosystem affect what lives there? (Palm Oil Unit)*)
- Biodiversity describes the variety of species found in Earth's terrestrial and oceanic ecosystems. (*Palm Oil Unit*)
- A complex set of interactions within an ecosystem can keep its numbers and types of organisms relatively constant over long periods of time under stable conditions. If a modest biological or physical disturbance to an ecosystem occurs, it may return to its more or less original status (i.e., the ecosystem is resilient). (*Serengeti Unit*)
- Anthropogenic changes (induced by human activity) in the environment—including habitat destruction, pollution, introduction of invasive species, overexploitation, can disrupt an ecosystem and threaten the survival of some species. (*Serengeti Unit*)
- Each chromosome consists of a single very long DNA molecule, and each gene on the chromosome is a particular segment of that DNA. The instructions for forming species' characteristics are carried in DNA. All cells in an organism have the same genetic content, but the genes used (expressed) by the cell may be regulated in different ways. (*Cancer Unit*)
- Although DNA replication is tightly regulated and remarkably accurate, errors do occur and result in mutations, which are also a source of genetic variation. Environmental factors can also cause mutations in genes, and viable mutations are inherited. (*Cancer Unit*)
- Environmental factors affect expression of traits, and hence affect the probability of occurrences of traits in a population. Thus, the variation and distribution of traits observed depends on both genetic and environmental factors. (*Cancer Unit*)
- Natural selection leads to the predominance of certain traits in a population and the suppression of others. (*Penguins Unit*)
- Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common, and those that do not become less common. Thus, the distribution of traits in a population changes. (*Penguins Unit*)
- Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value. (*Serengeti Unit*)
- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (*Cancer Unit*)

This unit begins the development of **disciplinary core ideas (DCIs)** and other science ideas that students will utilize and continue building in subsequent units in the OpenSciEd Biology and Chemistry courses:

- 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. (*OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes? (Speciation Unit)*)
- 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. (*Speciation Unit*)
- 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. 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. (*Speciation Unit*)
- When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (*OpenSciEd Unit C.4: Why are oysters dying, and how can we use chemistry to protect them? (Oysters Unit)*, *OpenSciEd Unit C.5: How can chemistry help us evaluate fuels and transportation options to benefit the Earth and our communities? (Fuels Unit)*)

This unit uses and builds upon high school level **Science and Engineering Practices (SEPs)** and **Crosscutting Concepts (CCCs)** that students should have previously developed in **OpenSciEd High School Biology** and will continue to build in future units in **OpenSciEd High School Chemistry and Physics**. The progression of these practices and concepts across the program are as follows:

	Questions	Models	Investigations	Data	Math	Explanation	Argument	Obtaining
Biology	Cancer Unit	Serengeti Unit, Fires Unit	Fires Unit, Natural Selection Unit	Natural Selection Unit, Cancer Unit	Serengeti Unit	Fires Unit, Cancer Unit, Natural Selection Unit	Speciation Unit	Cancer Unit, Speciation Unit
Chemistry	Polar Ice Unit, Oysters Unit	Electrostatics Unit, Space Survival Unit	Polar Ice Unit	Fuels Unit	Polar Ice Unit, Oysters Unit	Fuels Unit	Fuels Unit	Electrostatics Unit, Space Survival Unit
Physics	Electricity Unit, Cosmology Unit	Electricity Unit, Microwave Unit	Microwave Unit	Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit, Meteors Unit	Vehicle Collisions Unit, Meteors Unit	Electricity Unit, Earth's Interior Unit, Vehicle Collisions Unit	Vehicle Collisions Unit	Cosmology Unit, Microwave Unit

	Patterns	Cause/Effect	Scale	Systems/Models	Energy/Matter	Structure/Function	Stability/Change
Biology	Natural Selection Unit, Speciation Unit	Cancer Unit, Natural Selection Unit, Speciation Unit, Serengeti Unit	Serengeti Unit	Fires Unit, Cancer Unit, Serengeti Unit	Fires Unit, Serengeti Unit	Cancer Unit	Speciation Unit, Serengeti Unit
Chemistry	Electrostatics Unit, Space Survival Unit	Oysters Unit, Fuels Unit	Electrostatics Unit, Oysters Unit	Polar Ice Unit	Polar Ice Unit, Fuels Unit	Space Survival Unit	Oysters Unit
Physics	Cosmology Unit, Vehicle Collisions Unit, Earth's Interior Unit	Vehicle Collisions Unit, Earth's Interior Unit	Meteors Unit, Earth's Interior Unit	Electricity Unit, Vehicle Collisions Unit, Microwave Unit	Electricity Unit, Earth's Interior Unit	Earth's Interior Unit, Vehicle Collisions Unit	Electricity Unit, Cosmology Unit

What are some common ideas that students might have?

Students will come into the unit with many ideas about urbanization and change derived from previous classroom experiences, intuitive understandings of the way the world works, everyday experiences with nature, and the conversations they have had with parents, friends, and family members.

- Changes in a population occur through a gradual change in all members of a population, not from the survival of a few individuals that preferentially reproduce (Brumby, 1979; Bishop & Anderson, 1990; Anderson et al., 2002; Stern & Roseman, 2004).
- Change occurs in the inherited characteristics of a population of organisms over time because of the use or disuse of a particular characteristic (Bishop & Anderson, 1990).
- Sudden environmental change is required for evolution to occur (Nehm & Reilly, 2007).
- Individual organisms can deliberately develop new heritable traits because they need them for survival (Bishop & Anderson 1990; Passmore et al., 2002; Stern & Roseman, 2004).
- Evolution happens when individual organisms acclimate or "get used to" new conditions gradually (Bishop & Anderson, 1990).
- Natural selection involves organisms trying to adapt (UC Museum of Paleontology at Berkeley, 2012).
- All individuals within a population of organisms are the same. Differences among them are trivial and unimportant. All members of a population are nearly identical (Greene, 1990; Passmore & Stewart 2004; Anderson et al. 2002; Shtulman, 2006).
- Natural selection gives organisms what they need (UC Museum of Paleontology at Berkeley, 2012).
- Humans cannot negatively impact ecosystems because species will just evolve what they need to survive (UC Museum of Paleontology at Berkeley, 2012).

- The fittest organisms in a population are those that are strongest, healthiest, fastest, and/or largest (UC Museum of Paleontology at Berkeley, 2012).
- Natural selection produces organisms perfectly suited to their environments (UC Museum of Paleontology at Berkeley, 2012).
- All traits of organisms are adaptations (UC Museum of Paleontology at Berkeley, 2012).

It is valuable to think of ideas like these not as misconceptions that need to be replaced but as productive ideas that we can use to build understanding. Not only does this help some students feel more comfortable talking about science and build a scientific identity, it improves science learning across the board.

How will I need to modify the unit if taught out of sequence?

This is the fourth unit of the High School Biology Course in the OpenSciEd Scope and Sequence. Given this placement, several modifications would need to be made if teaching this earlier in the year. These include the following adjustments:

- If taught before *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, supplemental teaching of biodiversity, resilience, group behavior, and carrying capacity will be required. Additionally, students will need additional scaffolding for transfer tasks and the practices of asking questions and defining problems, developing and using models, and using mathematics and computational thinking.
- If taught before *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*, supplemental scaffolding of the practice of constructing explanations and Crosscutting Concepts of cause and effect will be helpful.
- If taught before *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*, supplemental teaching of inheritance, variation, and mutation will be required.

How do I shorten or condense the unit if needed? How can I extend the unit if needed?

The following are example options to shorten or condense parts of the unit without eliminating important sensemaking for students:

- Lesson 1: Instead of taking students outside to look for examples of the effect of urbanization on nonhuman populations, do a virtual walk in another city.
- Lesson 2: Model and collect all field/non-urban data together, as a class and then send students to complete the urban investigation in groups.
- Lesson 4: Instead of having the students visit both locations in pairs using Google Earth, have the teacher do it as a demonstration that students watch and record what they see.
- Lesson 10: Remove the future transportation map from *Buckeye Development Designs* so there is less material for students to consider as they evaluate designs.

To extend or enhance the unit, consider the following:

- Lesson 2: Ask students to make a logical quantitative prediction for the change in the proportion of the outcome of the investigation. Ask students: What would happen in the next generation of plants? How could you model it?
- Lesson 2: As an extension, challenge students to think about the role bees play in determining the (genetic) makeup of the next generation of plants. In the common garden experiment, bees pollinated ALL plants regardless of their origin. In a natural setting, a single bee would not be able to visit flowers located 30 km apart. Students could investigate how far bumblebees normally fly and think about which populations might be able to cross-pollinate and which would not impact the differential survival and reproduction of traits in the population. This impact of fragmentation will be brought up in Lesson Set 2.
- Lesson 8: For students interested in an extension about genetic drift and how population size influences allele fixation, direct them to experiment with changing allele frequency parameters and population sizes in the computer Population Genetics simulation at https://www.radford.edu/~rsheehy/Gen_flash/popgen/.
- Lesson 8: Evodots, <http://faculty.washington.edu/herronjc/SoftwareFolder/EvoDots.html/>, is a virtual alternative for investigation. It can also be used as an extension if students benefit from more time and another modality for processing ideas.
- Lesson 8: As an extension, instruct students how to create their preferred graph using a computer spreadsheet program or CODAP to produce graphs similar to those shown in *Model Instructions/Key*. Explain how to organize data in the spreadsheet, make simple calculations, and cut and paste repeated formulas.
- Lesson 9: Students can use CODAP to analyze data spread using r^2 and *Statistics Extension*.
- Lesson 10: Criteria and constraints in this lesson were distilled from the Imagine Buckeye: General Plan 2040 Update. As an extension to DCI: ETS1.B.1, students could pursue answers to specific questions about Buckeye in this document.

What mathematics concepts will students engage with in the unit?

This unit requires students to develop mathematical models, calculate proportions and allele frequency, identify relationships between variables, and interpret standard deviations and correlation coefficients. Making mathematical models is a Standard for Mathematical Practice, and specific modeling standards appear throughout the high school standards.

This unit does not assume students are fluent with the mathematical practices listed below but that students develop these practices as part of the sensemaking. Thus, these standards are not so much prerequisites as co-requisites. If students are simultaneously developing the skills and vocabulary in math class, you can help by making explicit connections to the mathematical standards below.

Talk with the math teacher(s) to identify the strategies students are familiar with for calculating proportions and frequencies, working with statistics and probability, and constructing graphical representations of data.

Category	Code	Domain and Heading	Standard	Lesson
n/a	CCSS.MATH.PRACTICE.MP2	Mathematical Practice	Reason abstractly and quantitatively.	1, 2, 3, 4, 8, 9, 10
n/a	CCSS.MATH.PRACTICE.MP4	Mathematical Practice	Model with mathematics.	8
Statistics and Probability	CCSS.MATH.CONTENT.HS.S-IC.B.3	Making Inferences and Justifying Conclusions: Make inferences and justify conclusions from sample surveys, experiments, and observational studies.	Recognize the purposes of and differences among sample surveys, experiments, and observational studies; explain how randomization relates to each.	2, 8
Interpreting Categorical and Quantitative Data	CCSS.MATH.CONTENT.S.ID	Interpret differences in shape, center, and spread in the context of the data sets, accounting for possible effects of extreme data points (outliers).	Represent data on two quantitative variables on a scatter plot and describe how the variables are related.	9

What strategies are available to support equitable science learning in this unit?

OpenSciEd units are designed to promote equitable access to high-quality science learning experiences for all students. Each unit includes strategies, which are integrated throughout the OpenSciEd routines and are intended to increase relevance and provide access to science learning for all students. OpenSciEd units support these equity goals through several specific strategies, such as: 1) integrating Universal Design for Learning (UDL) Principles during the unit design process to reduce potential barriers and increase accessibility for students to engage in learning experiences; 2) developing and supporting classroom agreements that encourage a safe learning culture; 3) supporting classroom discourse to promote students in developing, sharing, and revising their ideas; and 4) specific strategies for supporting emerging multilingual students in science classrooms.

Many of these strategies are highlighted in the teacher guides in sidebar callout boxes with the headings of:

- Attending to Equity
- Supporting Emerging Multilingual Learners
- Supporting Universal Design for Learning
- Additional Guidance
- Alternate Activity
- Key Ideas
- Discussion Callouts

The example callout below highlights how an activity can be modified to support a wider variety of learners.

*** ATTENDING TO EQUITY- Universal Design for Learning:** If it is something familiar to your students or part of their education plans, consider allowing students to use a digital graphing tool such as a graphing calculator or spreadsheet software to help them create their graphs. Students can take the data table and enter it into graphing software. Allowing alternatives for use of tools such as a calculator can remove barriers for students in *expressing* their understanding by keeping the focus on the learning goal. Use of such tools can help provide a match between a student's abilities and the demands of the task.

What are recommended adult-level learning resources for the science concepts in this unit?

The OpenSciEd instructional model focuses on the teacher being a member of the classroom community, supporting students in figuring out scientific ideas motivated by their questions about phenomena. Students iteratively build their understanding of phenomena as the unit unfolds. To match the incremental build of a full scientific explanation across the unit, the science content background necessary for you to teach individual lessons incrementally builds too. Throughout the unit, we provide just-in-time science content background for you that is specific to the Disciplinary Core Ideas (DCIs) that will be figured out in a lesson. Places to look for this guidance include the “Where we are going” and “Where we are not going” sections for each lesson. Also, the expected student responses, keys, and rubrics illustrate important science ideas that should be developed in each lesson. The K-12 Science Framework is another great resource to learn more about the DCIs in this unit (**LS4.B: Natural Selection, LS4.C: Adaptation, LS4.D: Biodiversity and Humans, and ETS1.B: Developing Possible Solutions**), including what students have learned previously and where they are headed in high school. In addition to the science content background information embedded in the lesson resources, we provide recommended resources below that can help build your understanding of phenomena and Performance Expectations bundle for this unit:

Atwell, J. W., Cardoso, G. C., Whittaker, D. J., Campbell-Nelson, S., Robertson, K. W., & Ketterson, E. D. (2012). Boldness behavior and Stress Physiology in a novel urban environment suggest rapid correlated evolutionary adaptation. *Behavioral Ecology*, 23(5), 960–969. <https://doi.org/10.1093/beheco/ars059>

Buckeye, AZ General Plan <https://www.buckeyeaz.gov/business/development-services/planning-zoning/general-plan>

Buckeye Wildlife Corridors Best Practices Guide <https://www.buckeyeaz.gov/business/development-services/planning-zoning/general-plan/wildlife-corridors>

Cheptou, P. O., Carrue, O., Rouifed, S., & Cantarel, A. (2008). Rapid evolution of seed dispersal in an urban environment in the weed *Crepis sancta*. *Proceedings of the National Academy of Sciences*, 105(10), 3796–3799.

Fergus, C. (1991). The Florida Panther Verges on Extinction. *Science*, 251(4998), 1178–1180.

Furtak, E. M. (2012). Linking a Learning Progression for Natural Selection to Teachers' Enactment of Formative Assessment. *Journal of Research in Science Teaching*, 49(9), 1181–1210.

Google Earth Time Urban Expansion Lapse Investigations <https://earth.google.com/web/@36.15660736,-114.97474849,635.68508203a,133270d,35y,25h,52t,Or/data=Ci8SLRIgMGM5NzE2MWMONjk4MTFIYUJMTMyZGUyNWlyYWZmNjkiCWxhcyl2ZWdhcw>

Grandemange A, Kohn HM, Lasseur R, Longin-Sauvageon C, Berny P and Benoit E, Consequences of the Y139F Vkorc1 mutation on resistance to AVKs—in vivo investigation in a 7th generation of congenic Y139F strain of rats. *Pharmacog Genom* (2009). DOI: 10.1097/FPC.0b013e32832ee55b.

Haugen, T. O., Aass, P., Stenseth, N. C., & Vøllestad, L. A. (2008). Changes in selection and evolutionary responses in migratory brown trout following the construction of a fish ladder. *Evolutionary Applications*, 1(2), 319–335. <https://doi.org/10.1111/j.1752-4571.2008.00031.x>

Knaepkens, G., Bervoets, L., Verheyen, E., & Eens, M. (2003). Relationship between population size and genetic diversity in endangered populations of the European bullhead (*Cottus Gobio*): Implications for conservation. *Biological Conservation*, 115(3), 403–410. [https://doi.org/10.1016/s0006-3207\(03\)00156-3](https://doi.org/10.1016/s0006-3207(03)00156-3)

Learning in Places Collaborative. (2020). Framework: Ethical Deliberation and Decision-Making in Socio-Ecological Systems. Bothell, Seattle, WA & Evanston, IL: Learning in Places.

Pelz, H. J., Rost, S., Hünnerberg, M., Fregin, A., Heiberg, A. C., Baert, K., MacNicol, A. D., Prescott, C. V., Walker, A. S., Oldenburg, J., & Müller, C. R. (2005). The genetic basis of resistance to anticoagulants in rodents. *Genetics*, 170(4), 1839–1847.

White Tank Mountains Regional Connectivity Initiative Storyline <https://storymaps.arcgis.com/collections/6af114926f624c03a5ae89dfc69b9579?item=1>

How do I support students' emotional needs?

In this unit, students explore the challenges associated with ethics of experimentation with animals and the impact of urbanization. These raise issues concerning the ethical treatment of animals, land ownership, decision-making, and animal welfare. Students may have emotional needs related to three main issues:

- Trauma associated with poisoning animals as animal control or for running scientific investigations;
- History of colonization and the process of urbanization. Students may feel guilt for living in an urbanized area;
- Strong beliefs about animal well-being, such as protecting animals and their habitat from human use.

Before beginning this unit, make sure to reach out to the counselor at your school for student-specific support and strategies that might be needed in regard to the students in your classroom. Consider asking the counselor to join you in the classroom at key moments, such as the discussion on the ethics of poisoning rats in **Lesson 3**. Also consider planning follow-up check-ins with the counselor in regard to any students who may need additional emotional support.

Educate yourself about standards for the ethical treatment of animals for research by reading the modern papers cited for rat and junco research, or contact your local university to learn the standards used by the review board that approves investigations involving animals. Learn more about local initiatives to create wildlife corridors, create pollinator gardens, or other related initiatives. Plan ahead with ways to scaffold justice-oriented teaching. Consider the following website:

- Resource: Learning for Justice: Critical Practices: <https://www.learningforjustice.org/frameworks/critical-practices>

Reach out to students' support systems at home before the unit using *Pre-Unit Letter Home*. This letter is a way to communicate with trusted adults and make them aware of the content of the unit. The letter also provides an opportunity for trusted adults to share important context with you about students' experiences and background that might be relevant.

Be aware that students who are struggling may demonstrate a variety of behaviors, including but not limited to: fidgeting, withdrawal, disruption or distraction, rapid breathing, holding their breath, and change in body language or tonation. If you notice a student might be struggling, share what you are observing and ask if they need some help.

Often in science classrooms, we are focused on evidence and data. When addressing a phenomenon or design solution that straddles the nature-cultural divide, like this one, supporting students in using an empathy or socio-emotional lens will also be important. Make space for students to process and validate their feelings and reactions. These opportunities were built in throughout the unit.

Furthermore, an important part of addressing controversial histories is that there has been change in how we approach these issues and there is hope. The examples of wildlife corridors described in Lesson 9 and design plans evaluated in Lesson 10 provide examples of actionable ideas that can be used to protect nonhuman populations from the effects of fragmentation in any community.

What is the Learning in Places Nature-Culture Relations framework?

This unit is informed by educational approaches and frameworks developed by Learning in Places. When students go outside, the Observations and Data Collection for Making Sense of Phenomena Framework is mentioned as a resource. This framework involves systematic observations of phenomena over time that can lead to a deeper understanding of phenomena in the world. When coupled with other forms of data, these will contribute to ethical deliberations and decision-making about socio-ecological phenomena (Learning in Places Collaborative, 2020). Lesson 9 references the Nature-Culture Relations Framework. Nature-culture relations help us think about how our unique cultures impact the decisions we make about human relations and the natural world.

Read more about *Learning in Places Collaborative. (2020). Learning in Places Collaborative. (2021). Framework: Nature-Culture Relations. Bothell, Seattle, WA & Evanston, IL: Learning in Places* at: http://learninginplaces.org/wp-content/uploads/2021/10/framework_Nature_Culture_Relations_rev101321.pdf

Guidance for Developing Your Personal Glossaries

This unit refers to two categories of academic language (i.e., vocabulary). Most often in this unit, students will have experiences with and discussions about science ideas before they know the specific vocabulary word that names that idea. After students have developed a deep understanding of a science idea through these experiences, and sometimes because they are looking for a more efficient way to express that idea, they have co-developed that definition and can add the specific term to a personal glossary at the back of their notebooks. These “definitions we co-develop” should be recorded using the students’ own words whenever possible. On the other hand, “definitions we encounter” are “given” to students in the course of a reading, video, or other activity, often with a definition clearly stated in the text. Sometimes definitions we encounter are helpful just in that lesson and need not be recorded in students’ personal glossaries. However, if a word we encounter will be frequently referred to throughout the unit, it should be added.

It is best for students if you create consensus definitions in the moment, using phrases and pictorial representations that the class develops together as they discuss their experiences in the lesson. When they co-create the meaning of the word, students “own” the word—it honors their use of language and connects their specific experiences to the vocabulary of science beyond their classroom. It is especially important for emergent multilingual students to have a reference for this important vocabulary, which includes an accessible definition and visual support. Sometimes defining a word is a challenge. The *Teacher Guide* provides a suggested definition for each term to support you in helping your class develop a student-friendly definition that is also scientifically accurate.

The definitions we co-construct and encounter in this unit are listed in this document and in each lesson to help prepare and to avoid introducing a word before students have earned it. They are not intended as a vocabulary list for students to study before a lesson, as that would undermine the authentic and lasting connection students can make with these words when they are allowed to experience them first as ideas they're trying to figure out.

Lesson	Definitions we co-construct	Definitions we encounter
L1		urban, urbanization
L2	adaptation**, natural selection**, selection pressure	fragmentation, hypothesis, common garden experiment
L3	physiological adaptation	allele*
L4	behavioral adaptation, fitness	trait**
L5	evolution	theory
L6		
L7	biodiversity*, resilience*	
L8	fitness (revised)	gene pool, allele frequency
L9	standard deviation	correlation coefficient, r^2 value (extension)
L10		washes, floodways
L11		

*Co-constructed or encountered in a previous OpenSciEd High School unit.

**Co-constructed or encountered in the middle school grade band of NGSS/OpenSciEd Middle School.

HOME COMMUNICATION

Dear Parents, Guardians, and Caregivers,

Your child's high school biology class is starting a unit called *How does urbanization affect nonhuman populations, and how can we minimize harmful effects?* as part of the OpenSciEd high school science curriculum. This unit is anchored by observations of time lapse images showing the growth of cities over time. Students will also explore case studies of three animal and plant populations that develop different traits when they live in urban areas.

The first half of the unit investigates these case studies in depth, allowing students to discover how and why nonhuman populations change over time due to pressures caused by cities. Each case study focuses on a different aspect of natural selection; students will learn about selection pressures that cause anatomical, physiological, and behavioral changes in populations. They will analyze data showing how genetic variations in populations provide opportunities for some individuals to outcompete others, reproduce more, and pass on favorable genes to the next generation. The second half of the unit presents students with an opportunity to apply their understanding of natural selection to an engineering design problem. They learn about the rapid growth of Buckeye, Arizona, a suburb of Phoenix, and the potential threats to biodiversity and ecosystems in the region should human development expand as predicted. Students will learn more about the effect of habitat fragmentation on the genetic diversity of populations and examine possible solutions to prevent that fragmentation. They will then use that knowledge to evaluate two design proposals for the future expansion of this metropolitan area.

In this unit, students explore the challenges associated with ethics of experimentation with animals and the impact of urbanization. These raise issues concerning the ethical treatment of animals, land ownership, decision-making, and animal welfare. Students may have emotional needs related to three main issues:

- Trauma associated with poisoning animals as animal control or for running scientific investigations;
- History of colonization and the process of urbanization. Students may feel guilt for living in an urbanized area,
- Strong beliefs about animal well-being, such as protecting animals and their habitat from human use.

If you anticipate your child may find these topics challenging, please contact me at _____ if you are comfortable doing so. You can also contact the school counselor at _____. By knowing about these challenges in advance, we can be sensitive to students' needs and provide support for students if they experience any strong emotions during this unit.

Adolescents will sometimes develop difficult behaviors after a traumatic experience. It is important for trusted adults to understand that these behaviors and emotions are common when children experience trauma. Students may be more aggressive or withdrawn and go through periods of sadness, anger, or emotional "numbing." Contact a counselor if you see any of the following behaviors in your child:

- problems sleeping, nightmares,
- changes in school performance,
- truancy,
- risk-taking behavior,
- conflicts with peers,
- new or increasing psychosomatic complaints, including stomachaches and headaches,
- depression or suicidal thoughts.

Being able to talk to someone who is removed from the situation is often helpful to both adults and children after a traumatic event. After experiencing trauma, children are best supported when their parents or trusted caregivers accept their feelings and are open to listen and talk. Let your child come to you. Do not overwhelm your child if they are not ready to talk. Respect your child's need to take breaks.

If you have any questions about the content of this unit or would like to discuss anything further, I encourage you to reach out to me at _____.

Best,

Your name or signature here

Estimados padres, tutores y cuidadores:

La clase de biología de la escuela secundaria de su hijo está comenzando una unidad llamada *¿Cómo afecta la urbanización a las poblaciones no humanas y cómo podemos minimizar los efectos dañinos?* como parte del plan de estudios de ciencias de la escuela secundaria de OpenSciEd. Esta unidad se basa en observaciones de imágenes en intervalos de tiempo que muestran el crecimiento de las ciudades a lo largo del tiempo. Los estudiantes también explorarán estudios de casos de tres poblaciones de animales y plantas que desarrollan diferentes rasgos cuando viven en áreas urbanas.

La primera mitad de la unidad investiga estos estudios de caso en profundidad, lo que permite a los estudiantes descubrir cómo y por qué las poblaciones no humanas cambian con el tiempo debido a las presiones causadas por las ciudades. Cada estudio de caso se centra en un aspecto diferente de la selección natural: Los estudiantes aprenderán sobre las presiones de selección que causan cambios anatómicos, fisiológicos y de comportamiento en las poblaciones. Analizarán datos que muestran cómo las variaciones genéticas en las poblaciones brindan oportunidades para que algunos individuos superen a otros, se reproduzcan más y transmitan genes favorables a la siguiente generación. La segunda mitad de la unidad presenta a los estudiantes la oportunidad de aplicar su comprensión de la selección natural a un problema de diseño de ingeniería. Aprenden sobre el rápido crecimiento de Buckeye, Arizona, un suburbio de Phoenix, y las amenazas potenciales a la biodiversidad y los ecosistemas en la región si el desarrollo humano se expande según lo previsto. Los estudiantes aprenderán más sobre el efecto de la fragmentación del hábitat en la diversidad genética de las poblaciones y examinarán posibles soluciones para prevenir esa fragmentación. Luego utilizarán ese conocimiento para evaluar dos propuestas de diseño para la futura expansión de esta área metropolitana.

En esta unidad, los estudiantes exploran los desafíos asociados con la ética de la experimentación con animales y el impacto de la urbanización. Estos plantean cuestiones relativas al trato ético de los animales, la propiedad de la tierra, la toma de decisiones y el bienestar animal. Los estudiantes pueden tener necesidades emocionales relacionadas con tres cuestiones principales:

- Trauma asociado con el envenenamiento de animales como control animal o para realizar investigaciones científicas;
- Historia de la colonización y el proceso de urbanización. Los estudiantes pueden sentirse culpables por vivir en una zona urbanizada;
- Creencias sólidas sobre el bienestar animal, como la protección de los animales y su hábitat del uso humano.

Si anticipa que estos temas le resultarán desafiantes a su hijo, comuníquese conmigo al _____. Si se siente cómodo haciéndolo, También puede comunicarse con el consejero escolar al _____. Al conocer estos desafíos de antemano, podemos ser sensibles a las necesidades de los estudiantes y brindarles apoyo si experimentan emociones fuertes durante esta unidad.

En ocasiones, los adolescentes desarrollan comportamientos difíciles después de una experiencia traumática. Es importante que los adultos de confianza comprendan que estos comportamientos y emociones son comunes cuando los niños experimentan un trauma. Los estudiantes pueden ser más agresivos o retraídos y pasar por periodos de tristeza, ira o "adormecimiento" emocional.

Comuníquese con un consejero si observa alguno de los siguientes comportamientos en su hijo:

- problemas para dormir, pesadillas,
- cambios en el rendimiento escolar,
- ausentismo escolar,
- comportamiento de riesgo,
- conflictos con sus compañeros,
- quejas psicosomáticas nuevas o crecientes, incluidos dolores de estómago y de cabeza,
- depresión o pensamientos suicidas.

Poder hablar con alguien que está alejado de la situación suele ser útil tanto para adultos como para niños después de un evento traumático. Después de experimentar un trauma, los niños reciben mejor apoyo cuando sus padres o cuidadores de confianza aceptan sus sentimientos y están abiertos a escuchar y hablar. Deje que su hijo venga a usted. No abruma a su hijo si no está listo para hablar. Respete la necesidad de su hijo de tomar descansos.

Si tiene alguna pregunta sobre el contenido de esta unidad o desea discutir algo más, le invito a que se comuniquen conmigo al _____.

Sinceramente,

Su nombre o firma aquí

LESSON 1: What is the effect of increasing urbanization on nonhuman populations?

PREVIOUS LESSON *There is no previous lesson.*

THIS LESSON

ANCHORING PHENOMENON

3 days



Nita Knott

We investigate the continuing expansion of cities and discuss and observe examples of nonhuman populations that have adapted to cities. We define the terms urban and urbanization and model the impact of increasing urbanization on nonhuman populations. We read about three examples of populations (hawksbeard, juncos, and rats) impacted by urbanization and use information from these examples to revise our models and come up with a class model. We are curious to learn more about the mechanisms of urbanization that impact nonhuman populations.

NEXT LESSON *We will conduct an investigation of the impact of fragmentation on seed dispersal strategies in hawksbeard and compare our results with published studies.*

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

1.A Ask questions based on observations about potential effects of urbanization on the survival of nonhuman populations. (SEP: 1.1; DCI: LS4.C.4; CCC: 2.4)

1.B Develop and revise models to illustrate the cause and effect relationship between increasing urbanization and survival of nonhuman populations. (SEP 2.3; DCI: LS4.B.2; CCC: 2.2)

1.C Ask and refine questions about the cause and effect of increasing urbanization on the survival of nonhuman populations that can be investigated with available resources. (SEP 1.6; DCI: LS4.C.4; CCC: 2.2)

WHAT STUDENTS WILL FIGURE OUT

- Urbanization is expanding around the globe, and that affects the ability of some nonhuman populations to survive.
- Many plants and animals live in cities with humans.
- Some urban nonhuman populations have trait variations that differ from non-urban populations.
- Hawksbeard populations in urban areas have a higher proportion of nonfeathery seeds than in non-urban areas.
- Some rat populations in urban areas have resistance to poisons.
- Some junco populations moved to urban areas and are bolder than those in non-urban areas.
- We have questions about the mechanisms that impact nonhuman populations living in urban areas.

Lesson 1 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	10 min		INTRODUCE TIME LAPSE SATELLITE IMAGERY Organize pairs of students to investigate time lapse satellite imagery of growing cities in different locations around the world.	A-C	internet-connect device
2	5 min		DETERMINING IMPACTS ON NONHUMAN POPULATIONS Facilitate students in sharing ideas in a three-column chart about the impact of growing cities on nonhuman populations.	D-G	chart paper, chart paper markers
3	5 min		CREATE A LIST OF URBAN ENVIRONMENTAL COMPONENTS AND INTERACTIONS Create a list of components and interactions in cities that influence the success of nonhuman populations.	H	three-column chart
4	20 min		FIND EXAMPLES OF URBAN-DWELLING POPULATIONS Take students outside to look for nonhuman populations that live in urban environments.	I	
5	5 min		NAVIGATE: HOME LEARNING Share a home learning opportunity with students.	K	
<i>End of day 1</i>					
6	6 min		NAVIGATE: SHARE HOME LEARNING Students share information they learned in the community.	L-M	self-documentation photos, 3x3 sticky notes, three-column chart
7	8 min		DEVELOP INITIAL MODELS Support students to individually develop models of how the survival of one nonhuman population is affected by urbanization.	N	three-column chart
8	9 min		SHARE AND COMPARE INITIAL MODELS Revisit Community Agreements and facilitate a gallery walk.	O-Q	individual models
9	14 min		INVESTIGATE CASE STUDIES Organize a jigsaw of case studies of three nonhuman populations that are affected by urban environments.	R-S	<i>Case Study: Hawksbeard, Case Study: Juncos, Case Study: Rats</i> , internet connected device for groups that read about juncos
10	5 min		REVISE INITIAL MODELS Facilitate revision of individual models.	T	individual models
11	3 min		NAVIGATE Students add a cause and effect question to their revised models and turn them in.	U	individual models
<i>End of day 2</i>					

Part	Duration		Summary	Slide	Materials
12	5 min		NAVIGATE Ask students to compare their individual models with another student.	V	initial models
13	15 min		DEVELOP INITIAL CONSENSUS MODEL Build an initial class consensus model explaining how nonhuman populations might be affected by urbanization.	W	three-column chart
14	15 min		DRIVING QUESTION BOARD Ask students to write individual questions and then build a Driving Question Board.	X-Y	3x3 sticky notes, chart paper, colored markers
15	5 min		IDEAS FOR INVESTIGATION Help students generate and share specific investigative ideas for addressing questions about the mechanisms of change.	Z	
16	5 min		NAVIGATE Facilitate an exit ticket for what to investigate next.	AA	

End of day 3

Lesson 1 • Materials List

	per student	per group	per class
Lesson materials	- science notebook - self-documentation photos 3x3 sticky notes - individual models - initial models	- internet-connect device <i>Case Study: Hawksbeard</i> <i>Case Study: Juncos</i> <i>Case Study: Rats</i> - internet connected device for groups that read about juncos	- chart paper - chart paper markers - three-column chart - colored markers

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Day 1:

- Provide devices with internet access to pairs of students.
- Gather chart paper and markers or equivalent.
- For the outdoor observation activity, do the following advance prep:
 - Identify the space you want your students to observe and potential nonhuman populations students may see.
 - Identify the boundaries of this space.
 - Talk with your school administration about the students going outdoors and discuss safety precautions to take.
 - If a water feature (e.g., pond) is located nearby, recruit a teacher aide or parent volunteer to be present and supervise that area for the duration of the activity.



Follow these additional safety guidelines, along with any safety guidance from your school:

- Inspect the area where students will complete observations.
- Identify any species that could be an issue for participants (e.g., poisonous plants, such as mold/mildew, or harmful animals, such as mosquitos, ticks, reptiles).
- Identify any standing water, such as ponds, that could pose a safety hazard.
- Set the boundary to avoid this area or have adequate adult supervision present if students will visit the area.
- Inspect the site for accessible options to accommodate students with physical limitations.
- Review safety rules and permissions for taking students outside.

Day 2:

- Create groups of three students, or let students choose groups based on the difficulty of the case studies.
- Copy and three-hole punch case studies for groups of three students. Each group needs one copy of *Case Study: Hawksbeard*, *Case Study: Juncos*, *Case Study: Rats*.

Day 3:

- Gather chart paper, 3x3 sticky notes, and markers for the Driving Question Board.

Lesson 1 • Where We Are Going and NOT Going

Where We Are Going

This unit builds on concepts of adaptation and natural selection from *OpenSciEd Unit 8.6: How could things living today be connected to the things that lived long ago? (Penguins Unit)*, and the following NGSS middle school disciplinary core ideas:

- MS LS4.B: Natural selection leads to the predominance of certain traits in a population and the suppression of others.
- MS LS4.C: Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes.

The unit also revisits topics covered in high school units *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)*. Students may use what they recall about resilient ecosystems and populations as well as what they know about genetics and inheritance to inform ideas and models created in this lesson.

Students are building toward a complete understanding of the following DCIs:

- HS LS4.B.2 The traits that positively affect survival are more likely to be reproduced, and thus are more common in the population.
- HS LS4C.4 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),(HS-LS4-6)~~

To do this, they will be identifying traits associated with survival in urban and non-urban populations. In Lesson 2, they will continue to build toward this element by predicting what will happen in future generations.

Students use elements of the science practices of *Asking Questions and Defining Problems*, and *Developing and Using Models* to identify the potential problems caused by urbanization on nonhuman populations and then develop and revise a model based on evidence to illustrate and/or predict the relationships between components of the system.

Students use elements of the crosscutting concept *Cause and Effect* to suggest and predict how complex urban systems may have various causes that may not have equal effects on nonhuman populations.

In this lesson, students will encounter the terms *urban* and *urbanization*, which they should add to their personal glossaries.

Where We Are NOT Going

Students will engage with their communities outside of the classroom to bring some relevant cultural experiences to the classroom that may support the class with figuring out the phenomenon. We are not, however, going to be investigating all of the species students and their communities have experience with and might be interested in.

The lesson does not address why urbanization is increasing and why people are moving to cities. The focus instead is on acknowledging the trend and thinking about the potential long-term evolutionary impacts on nonhuman populations.

LEARNING PLAN for LESSON 1

1 · INTRODUCE TIME LAPSE SATELLITE IMAGERY

10 min

MATERIALS: science notebook, internet-connect device

Observe imagery of urbanization. Say, *I found these interesting clips showing how the Earth is changing. I think you should see them.* Display slide A and direct students to draw a Notice and Wonder chart on a piece of loose-leaf paper in their science notebooks. Display slide B and play <https://youtu.be/9nAeOwM9bWs> to focus students on how to use the website and choose their cities. To conduct the investigation they should go to Google Earth, click “layers” (lower left of screen) and then choose “time lapse.” Change the speed of the time lapse if necessary (upper right of screen), then type in the location of the city they want to investigate (upper left of screen). Have students work in pairs for 5 minutes to observe the time lapse from two cities and to record what they notice and wonder. Encourage them to use the pause button as needed and to watch the timelapse of each city multiple times.

ALTERNATE ACTIVITY

If Google Earth is not available for students to use, show <https://youtu.be/ONl4LiHP330>. Alternatively, NASA has similar images of Baltimore at <https://svs.gsfc.nasa.gov/99> and Las Vegas at <https://svs.gsfc.nasa.gov/30215>.

ADDITIONAL GUIDANCE

If this is the students’ first Notice and Wonder chart, you may want to model for students a “notice” or observation and a “wonder” or question by projecting the time lapse from one city to the whole class. Modeling an example will help students focus their noticings and wonderings on the phenomenon and not on distracting details. Ask two or three students to share one thing they noticed and/or wondered about and write that on the board as an example of a noticing or wondering. Ask students if they understand what to record on each side of the chart.

SCIENCE NOTEBOOK



If your students have not set up their notebooks yet, ask them to set up a section of their binders for the current unit where they will keep all of their handouts and notes for the unit organized. They should have dividers to keep materials from each unit separate and loose-leaf paper to use throughout the unit. The handouts you provide to students will be three-hole-punched and should be placed in the section of their binder they have designated for the unit. If they have not already established a section in their notebooks for the personal glossaries, take a moment to have them set it up so they will be ready to add important scientific terminology as the unit progresses.

Share noticings and wonderings. Display slide C. Bring the whole class back together and ask them to share what they noticed and wondered with each other, adding to their chart any new ideas they hear from other students. *

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

This lesson is intended to raise initial questions about a phenomenon with the intention of clarifying what is known and seeking information about what is not known. Often, there are more questions than answers when scientists begin their investigations. Develop a safe and supportive space for students’ uncertainty and focus on the need to ask and answer questions in order to address the uncertainty that may require the entire unit to resolve. Encourage students to keep track in their science notebooks of questions that arise at any time. Those that are not answered can be added to the Driving Question Board on day 3.

Suggested prompt	Sample student response
What did you notice?	Cities are expanding. Cities expanded differently depending on where there is open space to fill. People are building houses along waterways but not in the hills. Green space disappeared. New structures appeared in the water. Not all cities expanded in the same direction. Some grow taller and some grow out. One city merged into another one.
What did you wonder?	What did the different colors mean? What were they building out into the water? How can there be such a big city in a desert? Why are cities expanding? What happened to the plants and animals that used to be where the cities are going? Whose ancestral home is this? Who helped build these cities?
ADDITIONAL GUIDANCE	If students do not ask <i>Whose ancestral home is this?</i> and <i>Who helped build these cities?</i>, add your own wonderings to those posed by students. As students investigate the urbanization of different lands throughout this unit, it is important to note and acknowledge the Indigenous past, present, and future of areas undergoing urbanization. It is also important to acknowledge the histories of oppression and inequality that often facilitate the expansion of cities. While humans have been building cities for thousands of years and many ancient cities were buried long ago, this unit focuses on the modern-day accelerated pace of urbanization.

2 · DETERMINING IMPACTS ON NONHUMAN POPULATIONS

5 min

MATERIALS: chart paper, chart paper markers



Connect to ideas about ecological resilience. Say, *Some of you were concerned about plants and animals that might be impacted by growing cities. Let's think more about what lives in those areas where cities are growing.* Let students know that you will be using the term *nonhuman populations* to refer to all the groups of organisms affected by urbanization. Display **slide D**. Ask students to write down their ideas

about the question on the slide in their notebooks. After two minutes, ask them to share some of their ideas.

Suggested prompt	Sample student response
<i>What questions do you have about the effects of urbanization on nonhuman populations?</i>	Do some populations move away? Will some populations go extinct? Will some populations grow? Will some animals change to use the resources in the city? Could some animals have more food to eat if they like people's food? What plants and animals are losing their habitat? Will ecosystems lose some of their important interactions if populations die or move?

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Questions (SEP 1.1) related to:

- Unequal changes to the survival rates of some nonhuman populations. (CCC: 2.4; DCI: LS4.C.4)
- Examples of changes to nonhuman populations based on changes in cities. (CCC: 2.4; DCI: LS4.C.4)

What to do: Use the following questions:

- Are all nonhuman populations affected in the same way?
- What are the effects on nonhuman animals if the environment changes?
- How could urbanization help or harm nonhuman populations?

Building toward 1.A Ask questions based on observations about potential effects of urbanization on the survival of nonhuman populations. (SEP: 1.1; DCI: LS4.C.4; CCC: 2.4)

Brainstorm nonhuman populations that survive well in cities. Display slide E. Facilitate a Think, Pair, Share about the questions on the slide. Create a three-column chart and label the first column *nonhuman populations*. In that column, fill in student ideas about nonhuman populations that survive well in cities.

Suggested prompt	Sample student response
<i>What nonhuman populations do you know that survive well in cities? Why do they do well?</i>	Squirrels eat out of bird feeders. Rabbits eat food out of the garden. Birds nest in the gutters and under bridges. Rats eat garbage. Cockroaches live in my kitchen. Peregrine falcons dive off of tall buildings. Weeds grow in sidewalk cracks. Prairie dogs live in abandoned lots. Pigeons and ducks eat popcorn people give them.

ADDITIONAL GUIDANCE

At some point on day 1, a student is likely to use the word *adapt* when talking about how nonhuman organisms respond to environmental changes. When that happens, ask students to define what they mean. This will help the class start thinking about how *adapt* is used in everyday language versus how it is used in science. In science, *adapting* is not a decision an individual makes to adjust to a changing situation. We will co-construct and refine this definition throughout the first lesson set, beginning in Lesson 2, to include adaptive traits or characteristics that increase a population's chance of survival, considering elements of genetics and reproduction. It may be helpful to use synonyms of “adapt” (like *well-suited for*, *change*, or *acclimate*) until the class has co-constructed the scientific definition.

Share data on urbanization. Display slide F. Say, *After I looked at Google Earth, I found some additional data about how much cities are growing and found out that what we saw on the time lapse is expected to continue.* Ask students to share what they notice about the graph. Listen for ideas such as:

- There used to be more people living in rural areas.
- In about 2005, more people were living in urban areas.
- The rural population growth flattened, while urban population kept growing.
- The urban population is predicted to keep growing.

Define urban and urbanization. Display slide G. Say, *We are starting to encounter and use the term urban. I want to be sure we all are using this term in the same way.* Facilitate a discussion to define the term and ask students to add it to their personal glossaries.

ADDITIONAL GUIDANCE

Students' entries may look like this: *Urban means in a city, a place where thousands or millions of people live close together and buildings and roads are close together. It is the opposite of rural, where people's houses are spread far apart and there are big open green spaces with very few or no structures built by people.*

Say, *Researchers looking at growth in cities use the term urbanization to describe the process we have been talking about.* Facilitate the development of a shared understanding of this term.

ADDITIONAL GUIDANCE

It is important to construct a broad definition of urbanization to help all students, especially those who may not live in large city centers, make personal connections throughout the unit. Urbanization can happen as cities expand as well as in rural areas. If you live in a rural or suburban area, think of recent construction, road-building, or industry that moved into your area. Look for the changes to the rural/urban interface where human population expansion is happening. This unit will use the term *non-urban* to refer to rural and suburban areas.

Students' entries may look like this: *urbanization is the process of turning into a city, a city getting bigger, or land being transformed with human-made structures. There is more and more concrete, more roads, more buildings, and more people living and working close together.*

ADDITIONAL GUIDANCE

Throughout the course, students will learn a lot of new vocabulary. A *definition we co-construct* is one students work together to understand through investigation and collaborative sensemaking. They should celebrate their growing understanding of the word by adding it to their personal glossaries. A *definition we encounter* may be encountered through text, media, or teacher suggestion. The instructions encourage students to add these words to their glossaries as they are central to understanding, but this can be left up to the individual student to add them or not based on their own needs. Students can, however, add any other words and terms they find useful to have to their personal glossaries.

3 · CREATE A LIST OF URBAN ENVIRONMENTAL COMPONENTS AND INTERACTIONS

5 min

MATERIALS: three-column chart

Create a list of components and interactions in cities. Display slide H. Say, *Let's return to the list we created of nonhuman populations that do well in urban areas. What components in urban areas affect how well they do? Why do they do well when others do not?* Add the term *components* to the top of the second column of the three-column chart started in the previous activity. If necessary, ask someone to remind the class what components are. Listen for them to explain that components are the parts of a system. As part of the conversation, ask students to describe how they think nonhuman populations interact with those components. Add those ideas to the third column of the chart, labeled *interactions*. Save this list for days 2 and 3.

Suggested prompt	Sample student response
<i>What components in urban areas affect how well nonhuman populations survive?</i>	Food, water, and shelter Temperature Tall buildings, concrete, and human-made things Cars People Predators Pollution or poison

Suggested prompt	Sample student response
<i>What types of interactions determine how well they survive?</i>	Animals find food, water, and places to live. The animals might like people or be scared of them. People like them and do not kill them, or they might think they are pests and want to get rid of them. If they can find a place to hide from people. If they have enough space to sleep, eat, raise their young. They might be affected by pollution from cars, loud noises, and other sources. There might be danger like being hit by cars.
ADDITIONAL GUIDANCE	Consider the following prompts to elicit more responses as needed: • What kinds of living and nonliving things are found in a city ecosystem? • What behaviors might occur? • What types of relationships might you see between nonhuman populations in a city? • What relationships might be missing because of a city? Why? • How might humans interact with nonhuman populations differently in cities?

4 · FIND EXAMPLES OF URBAN-DWELLING POPULATIONS

20 min

MATERIALS: science notebook



Suggest an outdoor exploration. Say, *What would be a good way for us to investigate the components on this list to figure out how they interact with nonhuman populations? Is there a way we could do that right now?* Listen for students to suggest that the class go outside or explore the local area. Display **slide I**. Explain that the class will be going outside to observe nonhuman populations living in urban or urban-like environments. They should keep track of their noticings and wonderings in their science notebooks using the questions on the slide as a guide.

SAFETY PRECAUTIONS

Discuss expectations for safety when going outside. Describe the boundaries of your investigation and point out any hazards to avoid. See materials preparation for additional safety guidance.



ADDITIONAL GUIDANCE

Field-based observations and data collection engage students in multisensory socio-ecological sensemaking (Learning in Places Collaborative, 2020.) Even schools located in rural and suburban environments will have blacktop areas, sidewalks, driveways, and other urban-like areas to observe. Prepare for this activity by walking around your schoolyard in advance to plan your route. Look for plants growing in cracks or in gutters, animals seen running through urban areas, evidence of burrows or nests, spider webs on buildings and parked cars, lichen on rocks and trees, bird droppings on windshields, moldy food, listen for bird calls, etc.

For further support in taking students outside investigate:

- Learning in Places: Observation and Data Collection Framework <http://learninginplaces.org/framework/s/observations-and-data-collection-for-making-sense-of-phenomena-framework/>
- Activity sheet for taking a focused walk together: <http://learninginplaces.org/for-families/le-3-a-taking-a-focused-walk-together-species-kinds-and-behaviors/>

Learning in Places Collaborative. (2020). Framework: Observations and Data Collection for Making Sense of Phenomena. Bothell, Seattle, WA & Evanston, IL: Learning in Places.

Find examples of nonhuman populations in urbanized areas. Allow students to do a free walk for the first few minutes and then bring them together to share what they noticed. As needed, redirect them to look more closely at places plants, animals, or other nonhuman populations might live, such as sidewalk cracks, in trees, or under building eaves. Suggest they look for evidence that animals may have visited the area even if they cannot see them now. Ask them to pay attention to the interactions they see with different abiotic factors in the environment.

ALTERNATE ACTIVITY

If going outside is not an option, allow students to explore virtual walking tours of different cities around the world. Make sure they look at cities in different climates, at different times of year, and in different regions to see a variety of components and interactions. Direct them to focus on where they see plants and animals or where they expect animals would live. It can be difficult to see animals in the virtual tours. Samples sites include:

- Virtual Vacations: <https://virtualvacation.us/walk>
- City Walks: <https://citywalks.live/>

ADDITIONAL GUIDANCE

Throughout the unit, students will consider urbanization in different locations around the world. For each location, consider briefly discussing *How long have humans lived here?*, *On whose ancestral home are humans living?*, or *Who are the tribal neighbors here?* If you have not done so previously in your class, we recommend making a land acknowledgement for where your school sits before beginning the outdoor activity as a way to answer these questions using the information at: <https://native-land.ca/>. While making a land acknowledgment is good practice, it is only a first step in acknowledging the damage done to communities by settlers. These words are empty without tough conversations and action. Learn more about making Indigenous land acknowledgements here: <https://nativegov.org/news/a-guide-to-indigenous-land-acknowledgment/>

Write about possible impacts of increasing urbanization. After students come inside, display **slide J** and ask them to respond in writing to the question on the slide. They will return to these ideas in the next class.

5 · NAVIGATE: HOME LEARNING

5 min

MATERIALS: science notebook

Share home learning with students. Say, *We found some interesting examples of how urbanization can affect nonhuman populations at our school. Let's look for more examples before we come back to class tomorrow.* Display **slide K** and talk through the two options presented. This is an opportunity for self-documentation where students can take photos of what they observe, learn from community members, and share that information with the class. *

* ATTENDING TO EQUITY

The home learning includes an opportunity for self-documentation, an OpenSciEd instructional routine that can be used to help students see how focal science ideas relate to everyday phenomena in their lives. This routine can be a powerful way to support students in forging connections between their identity outside of the classroom and the science ideas they engage with inside the classroom.

End of day 1

6 · NAVIGATE: SHARE HOME LEARNING

6 min

MATERIALS: science notebook, self-documentation photos, 3x3 sticky notes, three-column chart

Share home learning. Display **slide L**. Ask students to turn and talk to their neighbors to share what they observed and learned from the home learning.

Update lists of components and interactions and populations. After a few minutes, bring the whole class together. Make sure the three-column chart from day 1 is visible and accessible to students. Display **slide M** and pass out sticky notes. Ask students to update the lists as instructed on the slide and choose a few volunteers to share significant findings from the home learning to the whole class. Show appreciation for the contributions from community members that help us understand the effects of increasing urbanization on nonhuman populations. *

* ATTENDING TO EQUITY

Framing students' families and communities as legitimate sources of knowledge can serve multiple purposes. It can 1) help students feel like they belong in the science classroom by framing their family/community knowledge as productive for science, 2) engage students' families in conversations about what is happening in the classroom, and 3) help students make connections between the science classroom and their everyday lives.

7 · DEVELOP INITIAL MODELS

8 min

MATERIALS: science notebook, three-column chart



Develop initial models. Say, *We have been trying to understand the impact of increasing urbanization on nonhuman populations. We have a great list of nonhuman populations that live in cities, as well as components and interactions that could influence how well they survive in urban areas. What else do we need to include in our models?* Listen for students to say mechanisms and mention how that is the one item we are missing and still need to figure out. If necessary, ask students to refresh their memories about mechanisms as the *cause, how or why*, that explains interactions. Ask students to each silently choose one population from the three-column chart (or another of interest to them) that

* SUPPORTING STUDENTS IN ENGAGING IN DEVELOPING AND USING MODELS

they will develop a model for, explaining how its survival is or will be affected by urbanization. Display **slide N** and read through the instructions for developing a model. Allow time for students to develop their models in their science notebooks using pictures, symbols, and/or words. *

ADDITIONAL GUIDANCE

Emphasize that students have two options, looking at the past or the future. For either option, they should consider a way to show the predicted effects of urbanization over time, perhaps using two or three panels. Also emphasize that they are modeling populations, which are groups of organisms, not just one individual. The models should show how population survival is affected by urbanization over time.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: As students **develop and then revise their models** (SEP 2.3) throughout day two, look for:

- **Effects of urbanization over time** indicating **increased survival and/or reproduction of some individuals**. (DCI: LS4.B.2)
- Addition of or questions about **mechanisms that cause change in survival and/or reproduction of some individuals**. (CCC: 2.2; DCI: LS4.B.2)
- **Description of how urbanization causes change in nonhuman populations**. (SEP 2.3; CCC: 2.2)

What to do: Use the following questions to support student thinking:

- Can you say more about how the urban component they chose might affect nonhuman populations?
- How did other student models from the gallery walk represent the effects of urbanization?
- Do all individuals in the population survive the effects of the urban component they chose? Why or why not?
- What additional information do you need to more accurately describe the effects of urbanization in the population?
- What smaller scale mechanisms might affect survival in populations?

Building toward 1.B.1 Develop and revise models to illustrate the **cause and effect relationship between increasing urbanization and survival of nonhuman populations**. (SEP 2.3; DCI: LS4.B.2; CCC: 2.2)

As this is the first modeling activity of a new unit, emphasize to students that they use models for a purpose. Models are dynamic and can change as new information is learned, and models need to be *applied* to be useful. Models are not used to describe something, but rather students should learn to use them to develop an explanation. In this case, the goal of the lesson set is to explain mechanisms of urbanization that drive change in nonhuman populations.

Encourage students to identify places in their models where they do not have enough information or need to know more. Consider asking them to add question marks as a way to keep track of what they need to figure out.

8 • SHARE AND COMPARE INITIAL MODELS

9 min

MATERIALS: individual models, science notebook

Revisit classroom agreements. Thank students for developing individual models. Acknowledge that this may have been difficult, but you noticed that there are many interesting interpretations of how urbanization affects population survival that it would be worth everyone looking at. Before facilitating a gallery walk, display **slide O** and revisit your Community Agreements. In particular, focus on the value of everyone's ideas and how diverse ideas can help us move forward with our science thinking together. *

Facilitate a gallery walk. Display **slide P** and ask students to create a T-chart to record similarities and differences they see as they do the gallery walk. Distribute the initial models around the classroom and provide time for students to walk around the room and record observations.

Facilitate a discussion of the models. Bring the class back together and display **slide Q**. Facilitate a discussion of the similarities and differences they saw. Ask students to share some of their questions as well. Recommend students add additional similarities and differences from their peers to their notebooks.

* ATTENDING TO EQUITY

Building classroom culture: It is important to use this classroom culture-building time to continue to cultivate an equitable learning community that promotes trusting and caring relationships. The Community Agreements should reinforce to students the value of (1) the diversity of thought among all community members in pushing our learning forward and (2) providing a safe learning environment that ensures fair participation. In addition, the Community Agreements should interrupt cultural norms or stereotypes that could make science

How/ Why do non-human populations change over time?

Similarities

- many people said "before" and "after"
- Sea gulls changed what they ate from "natural" food to people food
- animals started living in human-made structures
- there are more buildings and electronics "after" than "before"
- people were part of the model

Differences

- different plants and animals
- some sea gulls ate french fries, others ate trash "after"
- some lived inside, some outside houses
- some animals found new places to live, others lost places to live
- people don't like all of the populations that live in cities

experiences feel uncomfortable for some students (e.g., a student stereotyped as being someone who is not intelligent enough to think like a scientist, who cannot share their thinking). See an example in Case Study: Hawksbeard.

To reduce some students' anxiety about sharing their initial models with the class, consider keeping them anonymous during the gallery walk.

9 · INVESTIGATE CASE STUDIES

14 min

MATERIALS: science notebook, *Case Study: Hawksbeard*, *Case Study: Juncos*, *Case Study: Rats*, internet connected device for groups that read about juncos

Introduce case studies. Say, *We have initial models, but we also still have a lot of questions about the effect of urbanization on nonhuman populations. How can we answer our questions?* Students will generate a variety of ideas. Listen for ideas related to looking for examples in nature that are documented in some way (video, reading, scientific data, etc.). Display **slide R**. Say, *I have three case studies that might help us start to better understand how nonhuman populations change due to urbanization.* Explain that you will be putting them in groups of 3 and that each student in the group will read a different case study. As they read, they should focus on the questions on the slide, record their ideas in their science notebooks, and be prepared to share what they learn about their case with the other members of their groups when they finish reading.

Small groups read and discuss case studies. Provide each group with a copy of *Case Study: Hawksbeard*, *Case Study: Juncos*, *Case Study: Rats*. Give students 5-7 minutes to read and then ask them to share what they learned and what questions they have with their group members. See sample student ideas in the table below.*

Case Study	Sample Ideas	Sample Questions
Hawksbeard	Urban plants have a higher proportion of seeds without feathery tufts compared to non-urban plants. The mechanism is unknown (students may speculate), but the proportion of each trait seems to be inherited.	Why would plants produce two types of seeds? Is the seed type inherited?
Junco	Urban birds are bolder than non-urban/mountain-dwelling birds; they let humans approach them more closely before flying away. The mechanism is unknown (students may speculate).	Why are bird populations bolder in cities?
Rats	Some rats in the population are resistant to common poisons. The mechanism is related to mutations that change the enzyme for blood clotting. We do not know how the rats get the mutation.	Are all rats resistant? Have they always been resistant? How did they become resistant? Does this only happen in cities?

ADDITIONAL GUIDANCE

Many people have strong feelings about rats, and the case study may bring up conversations about why some animals are considered “pests” and whether poison should be used on animals.

The article also mentions that the word “rat” is used to reference the two most common rat species found in cities: Norway rats (*Rattus norvegicus*) and black rats (*Rattus rattus*). Both species are very common, and most informal writing and city health departments do not distinguish between the two. Be aware that using the common names for specific rats: Norway (or brown rats) and black rats may also raise questions about colorism and discrimination against species of a particular color or national origin.

* ATTENDING TO EQUITY

Universal Design for Learning. You may wish to allow students to select readings based on interest before dividing them into groups. Or for this activity, students can choose which text to read based on difficulty. *Case Study: Juncos* is most accessible, while *Case Study: Rats* is at the highest reading level. You can read more about Universal Design for Learning features and text-specific differentiation suggestions in *UDL for Jigsaw Readings*.

Connect readings to initial models. Display **slide S**. Keep students in their groups and ask them to look at their initial models and discuss how the mechanisms and other information in the case studies might connect. Encourage students to discuss both their own models and to help other group members consider connections.

10 • REVISE INITIAL MODELS

5 min

MATERIALS: individual models



Revise initial models. Display **slide T**. Say, *Now that you have seen other students' models, learned about the junco, rat, and hawksbeard, and talked about how they might connect to your models, let's update our models. Think about ways to express your ideas more clearly based on what you saw or read. If you have new ideas for mechanisms that cause change, add those. Also, add any new questions you have about how urbanization affected your chosen population.*

ADDITIONAL GUIDANCE

One important difference between the models students developed and the case studies is that the models are predicting change over time with increasing urbanization, and the case studies compare urban and non-urban environments. Data that monitors nonhuman populations as urbanization increases can be difficult to find. The comparison in the case studies makes the assumption that the non-urban population can serve as an example of a population before urbanization.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: As students **draw and then revise their models (SEP 2.3)** throughout day 2, look for:

- Effects over time indicating **increased survival and/or reproduction of some individuals. (DCI: LS4.B.2)**
- Questions about **mechanisms that cause change in survival and/or reproduction of some individuals. (CCC: 2.2; DCI: LS4.B.2)**
- **Description of how urbanization affects nonhuman populations. (SEP 2.3; CCC: 2.2)**

What to do: Collect student models and use the following questions to support their thinking:

- Can you say more about how the urban component they chose might help or harm certain nonhuman populations?
- How did other student models from the gallery walk represent the effects of urbanization?
- Can the mechanisms from the three case studies apply to your model?
- Do all individuals in the population survive the urban component they chose? Why or why not?
- What additional information do you need to more accurately describe the effects of urbanization on the population?

Building toward 1.B.2 **Develop and revise models to illustrate the cause and effect relationship between increasing urbanization and increased survival of nonhuman populations. (SEP 2.3; DCI: LS4.B.2; CCC: 2.2)**

11 · NAVIGATE

3 min

MATERIALS: individual models

Collect individual models. Display **slide U**. Let students know that they have been using the crosscutting concept *cause and effect* throughout the lesson. Ask them to review their models and add a cause and effect question if they do not have one. Collect individual models from each student. Use the assessment guidance to provide feedback on student models before returning them on day 3.

* SUPPORTING STUDENTS IN DEVELOPING AND USING CAUSE AND EFFECT

Support students in recognizing the *cause and effect* relationship between environments and living organisms. Reinforce the idea that scientists often ask questions related to cause and effect relationships in order to gather data to help explain observed phenomena, like we are. Emphasize the relationship between *cause* and *mechanism* to help students recognize that the mechanism can explain what causes an observed effect. If students have trouble thinking about how to word questions related to cause and effect, provide examples such as: *What is the effect of water pollution on the ability of trout to get oxygen in the local stream? Does eating french fries out of the garbage cause rats to have heart problems? What causes pigeons to become so tame they eat out of your hand?*

End of day 2

12 · NAVIGATE

5 min

MATERIALS: initial models

Compare models. Pass back the individual models from the previous class. Display **slide V** and give students time to read comments you left and compare their models with their elbow partners', focusing on the questions on the slide.

13 · DEVELOP INITIAL CONSENSUS MODEL

15 min

MATERIALS: science notebook, three-column chart

Gather in a Scientists Circle for an Initial Ideas Discussion. Display **slide W**. Ask students to form a Scientists Circle, a horseshoe shape oriented toward the three-column chart students built on days 1 and 2, and to bring their science notebooks with them.

SCIENTISTS CIRCLE

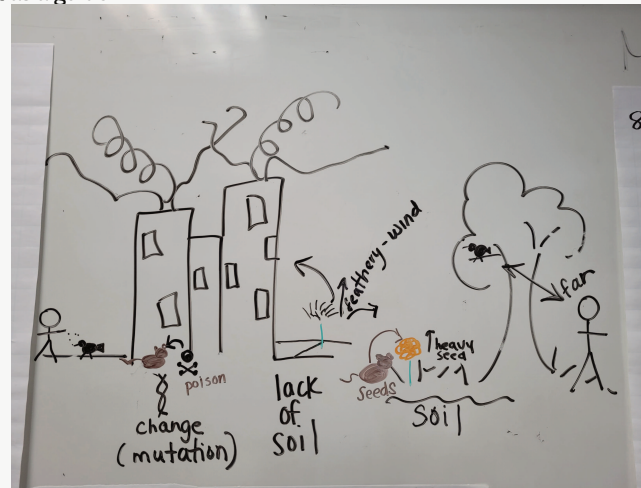
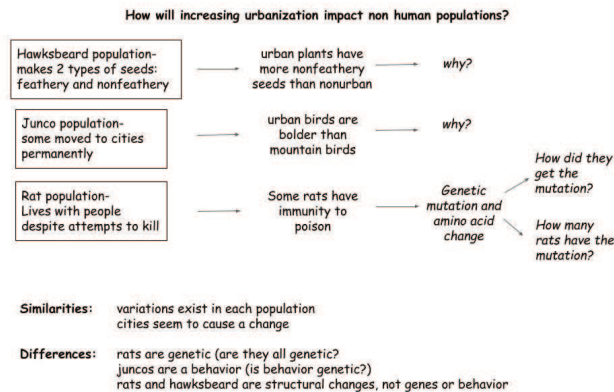


Your students may be familiar with the Scientists Circle from a previous unit. You will form a Scientists Circle in this lesson and many future lessons. Setting up the Community Agreements and logistics for forming, equitably participating in, and breaking down that space is important to do now if this is your first time forming such a space. Having students sit in a circle so they can see and face one another can help build a sense of shared mission and a community of learners working together. Returning to this Scientists Circle throughout the course of the unit to take stock of what the class has figured out and where they need to go next will be an important routine to help students take on greater agency in steering the direction of their learning. This circle will also help students build a sense of pride in their work. You may want to inform students that professional scientists collaborate with one another to brainstorm, discuss, and review their work also.

Debrief similarities and differences of initial models. Ask students to share anything new they learned from comparing their models to their elbow partners'. Students should update the similarities and differences T-chart in their science notebooks as the peers share.

Review case studies. Review the question students have focused on for the last two days: What is the effect of increasing urbanization on nonhuman populations? Say, *During the last class you read about three case studies but we did not have a chance to discuss them as a class. What did you learn that might help us answer our lesson question?* Facilitate the creation of a written summary of each case study on a clean piece of chart paper or the whiteboard. Begin to build an organized comparison of the three case studies similar to the examples below.

Summarize similarities and differences in the case studies and ask questions. Facilitate a conversation about the similarities and differences between the case studies, using information from the three-column chart and individual student models to find patterns and raise additional questions. Add these ideas below the chart using the example on the left as a guide.



Illustrations created by OpenSciEd in BioRender

14 · DRIVING QUESTION BOARD

15 min

MATERIALS: 3x3 sticky notes, chart paper, colored markers



Write initial questions for the Driving Question Board. Display slide X. Pass out three sticky notes and a marker to each student. Say, *Over the last three days you have raised a lot of great questions about how urbanization could affect nonhuman populations. Let's gather them all and create our Driving Question Board (DQB).* Let students know that the DQB will help keep the class organized and keep track of what we want to know and what we figure out throughout the unit. Instruct them to write up to three questions each, one per sticky note. Remind students to reference *Supporting Questioning* to evaluate their questions. They should revise them based on criteria developed throughout the year and what they know to be possible in the classroom. *

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- Evaluation and revision of questions that can be answered with available resources through cause and effect investigations. (SEP 1.6; CCC: 2.2)
- Questions clustering around the cause and effect of urbanization on the survival of nonhuman populations living in cities. (SEP 1.6; CCC: 2.2; DCI: LS4.C.4)
- Questions that focus on the mechanisms that affect nonhuman populations. (SEP 1.6; CCC: 2.2; DCI: LS4.C.4)

What to do:

- Guide students to questions they wrote in their science notebooks throughout the lesson.
- Remind students to reference *Supporting Questioning* to evaluate their questions.
- Guide students to the class model to help them make sense of how their questions would support developing that model as an explanatory tool for this phenomenon that explains the effect of urbanization on nonhuman populations.
- Ask students what questions arose related to mechanisms in the hawksbeard, junco, and rat case studies.
- Ask if the same mechanisms account for all cases.
- Encourage students to ask cause and effect questions that begin:
 - Why does that happen?
 - How does that happen?
 - What causes. . .?
 - What would the impact be if. . .?

Building toward 1.C Ask and refine questions about the cause and effect of increasing urbanization on the survival of nonhuman populations that can be investigated with available resources. (SEP 1.6; DCI: LS4.C.4; CCC: 2.2)

Build a Driving Question Board. Display slide Y. Explain to the class that you would like for them to take responsibility for creating the DQB and that the process for doing so is described on the slide. You might want to choose the first volunteer to begin the process and then step back. Step in when necessary to point students to some of the class norms to encourage equitable participation. *

* SUPPORTING STUDENTS IN ENGAGING IN ASKING QUESTIONS AND DEFINING PROBLEMS

At this point in the year, students should be able to evaluate whether their question is testable and relevant. They should also recognize which questions can be investigated in the scope of the classroom either through access to multimedia or testing with available resources.

* ATTENDING TO EQUITY

Students' questions are vital to drive their thinking forward. The Driving Question Board underscores the importance of questions and the crucial role they have in the work of the class. Students will return to the DQB throughout the unit to add questions and identify questions that they have already answered through investigations and sensemaking. Ensure that the Driving Question Board is accessible for future use, and promote it as a product that represents students' thinking, rather than as a mere "hook" for the unit.

Suggested prompt

What questions do we have about the effects of urbanization on nonhuman populations?

Sample student response

Can new food sources in a city change populations?
How do rats get mutations?

Suggested prompt	Sample student response
	Do humans cause mutations in other animals? Do gene mutations help with adapting to eating trash? How do rats get used to poison in cities? What causes juncos to be bolder? Are they used to people? Does DNA determine behavior? Why did juncos decide to stay in San Diego all year? How long does it take animals to adapt to their new lifestyle? How does a fluffy seed become non-fluffy? Why do flowers make heavy seeds? Why does the same flower make two types of seed? If everyone will live in the city someday, what will happen to plants and animals? Do non-urban populations change too? Why does urbanization benefit some animals but not others? Are the nonhuman populations smaller in urban areas than in rural areas? Where do the changes happen in an animal's body? In its genes? Somewhere else? Are the organisms learning to do things differently? Are there other animals that have had DNA mutations to help adapt to living in urban areas? Is it the pollution of a city that changes animals? Are there more protected places in a city for animals to live? Are there not as many predators in the city? How long does it take for animals' DNA to mutate and have resistance to certain things?

15 · IDEAS FOR INVESTIGATION

5 min

MATERIALS: science notebook

Generate ideas for investigation. Congratulate students on generating a productive board full of great questions. Let them know that the next step is to brainstorm ideas that will help us figure out how to answer those questions. If this is a new practice for students, ask them to focus on questions related to the mechanisms (causes) of change. They should focus on one question at a time and generate ideas for how they could go about answering each question. Their first instinct may be to do research. Prompt them to be more specific and answer questions about what specific data they would need to answer each question. Consider modeling an example to get them started.

Display **slide Z**. Give students two minutes to generate ideas for investigation in their science notebooks before sharing their ideas with the class. Encourage students to think about how we might generate the evidence we need to answer the questions that we asked. If students asked generalized questions, such as *How long does it take the animals to adapt to their new lifestyle?*, ask them to consider what else we could investigate about the case study populations to get at their question. Record student ideas on the board titled *Ideas for Investigation*.

Suggested prompt	Sample student response
<i>What kind of investigations could we do?</i>	We could grow hawksbeard plants and look at their seeds. We could poison rats. We could compare rat DNA from different cities or compare urban and rural rats. We could run animal behavior labs. We could feed animals different kinds of food from cities or natural areas. We could visit cities and observe animals. We could watch documentaries or videos. We could read some scientific articles. We could interview researchers.
<i>How would these investigations help us answer our questions?</i>	We need to know what is happening to the DNA of populations. We need to know what causes mutations. We need to know why animal behaviors change. We need to know what the different kinds of seeds are for. We need to know what causes populations to change. We want to know how fast populations change.

MATERIALS: None

Students prioritize what question(s) to answer next. Display slide AA. Say, *We have a lot of questions that we want to try and find the answers to over the next several weeks. We also have a great list of ideas for how to investigate those questions.* Introduce the class to the Unit Question, *How is urbanization a driving force of change?* Ask them to review the DQB and their initial ideas for investigations with that Driving Question in mind. After a minute, ask students to share what question they think the class should investigate next. As students identify specific questions or groups of questions, keep a record of which questions the class thinks should be answered next. Prompt the class to consider what aspects of the class model are most incomplete and which questions might be easier to answer as they prioritize.

ADDITIONAL GUIDANCE

As the class is increasingly motivated to understand the mechanisms better, listen for students identifying questions related to a deeper investigation into one of the case studies (hawksbeard, juncos, or rats). Ask students to identify how answering particular questions might help them develop the class model to explain how urbanization could affect nonhuman populations. The mechanism for the hawksbeard, which is where the storyline goes next, is an anatomical difference, which is easier to model and explain compared to genetic mechanisms or behavior.

Ask students to complete an exit ticket. Display slide BB. Ask students to tear out a half sheet of loose-leaf paper and, based on the DQB and ideas for investigation everyone just shared, write down their ideas for what the class should investigate next and why.

Additional Lesson 1 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research.

RST.11-12.2 Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

Students read one of three case studies and summarize and paraphrase the contents for their peers. Their summary uses evidence from the text to determine the change in the population described and how urbanization causes that change.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively.

In this lesson, students use quantitative data presented in case study readings to recognize changes in urban and non-urban populations. This information is used to elicit questions about the mechanisms that cause those differences.

LESSON 2: Why does hawksbeard make fewer feathery seeds in cities?

PREVIOUS LESSON We investigated the impact of increasing urbanization on nonhuman populations. We read about three examples of populations (hawksbeard, juncos, and rats) impacted by urbanization. We discussed similarities and differences between all of our models to develop a class consensus model and developed questions and ideas for further investigation.

THIS LESSON

INVESTIGATION

2 days



cheptou

We learn that people build fragmented plots of soil in urban areas where hawksbeard plants can grow. We carry out an investigation to simulate the impact of fragmentation on the survival rates of different hawksbeard seeds. We compare our new explanation of the mechanism for change to common garden experiments conducted on hawksbeard populations from France. We determine that the proportion of seed dispersal forms is inherited and that fragmentation causes a change in the proportion of seeds of each type in a population. We wonder how scientists investigate the genetics of populations as they change.

NEXT LESSON We will investigate a model for how rats developed resistance and write a preliminary explanation. We will gather additional information and evaluate the impact of new data on our explanations. We will revise and self-assess our explanations for rat poison as a selection pressure that caused a change in the distribution of resistant traits.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

- 2.A** Make a directional hypothesis to explain how fragmentation could cause the proportion of traits related to seed dispersal to change in hawksbeard populations. (SEP: 3.5; DCI: LS4.B.2; CCC: 2.1)
- 2.B** Incorporate new data into an explanation of how different traits could become more common in fragmented hawksbeard populations, increasing the chance of survival and opportunity for reproduction. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1)
- 2.C** Compare and contrast how self-generated and published data support the claim that differential survival and opportunity to pass on heritable traits could lead to adaptation in hawksbeard seed dispersal traits. (SEP: 4.4; DCI: LS4.C.2; CCC: 2.1)

WHAT STUDENTS WILL FIGURE OUT

- In fragmented urban environments, certain types of hawksbeard seeds have an advantage.
- Those seeds that are nonfeathery are more likely to land in a place they can germinate.
- If seed type is heritable, over time, the proportion of nonfeathery seeds in the population will increase and the proportion of feathery seeds will decrease.
- Common garden experiments can provide empirical data to support explanations by controlling variables.

Lesson 2 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Review what students figured out about hawksbeard and their ideas about what could cause the differences in seed structure in urban and non-urban environments.	A	<i>Case Study: Hawksbeard</i> for students assigned this reading in Lesson 1, Lesson 1 class consensus model
2	5 min		DISCUSS SEED DISPERSAL STRATEGIES Review student knowledge about seeds. Discuss why one plant would make both feathery and nonfeathery seeds.	B-E	Lesson 1 class consensus model, feathers (variety pack), paper clips (#2 size or 1 1/8 inch)
3	6 min		ANALYZE WHERE HAWKSBEARD GROWS Share photos of areas where hawksbeard grows and facilitate discussion about fragmentation.	F-G	
4	9 min		INTRODUCE SEED DISPERSAL INVESTIGATION AND WRITE A HYPOTHESIS Introduce students to an investigation and support them in writing a hypothesis.	H-K	<i>Seed Dispersal Investigation</i> , terry cloth washcloths, feathers (variety pack), paper clips (#2 size or 1 1/8 inch), ruler, <i>Seed Investigation Protocol</i> , large terry cloth beach towel, large adjustable fan
5	15 min		RUN SEED DISPERSAL INVESTIGATION Support students as they conduct investigations.	J	<i>Seed Dispersal Investigation</i> , terry cloth washcloths, feathers (variety pack), paper clips (#2 size or 1 1/8 inch), large terry cloth beach towel, large adjustable fan
6	5 min		COMPLETE EXIT TICKET Ask students to review their explanations and make revisions before turning in as an exit ticket.	L	<i>Seed Dispersal Investigation</i>
<i>End of day 1</i>					
7	5 min		NAVIGATE Have students compare results from their group investigations.	M	<i>Seed Dispersal Investigation</i>
8	9 min		DISCUSS INITIAL EXPLANATIONS Facilitate the development of a collective explanation of the impact of fragmentation on seed type in hawksbeard populations.	N-P	<i>Seed Dispersal Investigation</i>
9	9 min		COMPARE RESULTS TO PUBLISHED STUDIES Organize groups of students to read about common garden experiments done by researchers.	Q	<i>Hawksbeard Garden Experiment</i>
10	10 min		BUILDING UNDERSTANDINGS DISCUSSION ABOUT THE EFFECTS OF FRAGMENTATION Facilitate a discussion focused on what evidence is gained through common garden experiments with hawksbeard plants.	R-S	<i>Hawksbeard Garden Experiment</i> , <i>Garden Experiment Key</i>

Part	Duration		Summary	Slide	Materials
11	5 min		UPDATE THE CONSENSUS MODEL Add fragmentation as a selection pressure on hawksbeard populations to the consensus model.	T	Lesson 1 class consensus model
12	7 min		NAVIGATE: INTRODUCE PROGRESS TRACKER AND COMPLETE A ROW Introduce the Progress Tracker and provide time for students to record what they learned.	U-V	<i>Progress Tracker</i>

End of day 2

Lesson 2 • Materials List

	per student	per group	per class
Lesson materials	• <i>Case Study: Hawksbeard</i> for students assigned this reading in Lesson 1 • science notebook • <i>Seed Dispersal Investigation</i> • <i>Hawksbeard Garden Experiment</i> • <i>Progress Tracker</i>	• terry cloth washcloths • feathers (variety pack) • paper clips (#2 size or 1 1/8 inch) • ruler	• Lesson 1 class consensus model • feathers (variety pack) • paper clips (#2 size or 1 1/8 inch) • <i>Seed Investigation Protocol</i> • large terry cloth beach towel • large adjustable fan • <i>Garden Experiment Key</i>

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Day 1: Seed Investigation

- **Group size:** 4-5 students.
- **Setup:** Use a large terry cloth beach towel and two terry cloth washcloths to represent unfragmented and fragmented plots of soil. (If using alternative material, it should be soft so paper clips do not all bounce off and also a bit rough to catch feathers in a light wind. Sort the feathers so each group will get 8 feathers of a unique color (8 red or 8 blue, etc). Test out the position of the fan in the classroom in advance to choose the best location and setting for all students to experience wind that will move feathers off of the small washcloths without moving the feathers closest to the fan too far away. The wind should be light enough that most feathers land on the large beach towel, representing the field.
- **Safety:** Use caution with fans. Instruct students to use the fans only for the intended purpose.

Lesson 2 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students build on the following middle school ideas about natural selection:

MS LS4.B: *Natural selection leads to the predominance of certain traits in a population and the suppression of others.*

MS LS4.C: *Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes.*

Specifically, they build on the idea that certain anatomical structures in seeds are likely to increase in proportion over time while others are likely to decrease in proportion over time toward the high school DCI:

The evidence from this lesson works towards High School DCIs below:

HS LS4.C.2 *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.*

Students use elements of the science practices of *Planning and Carrying Out Investigations* to write a predictive hypothesis of the outcome of an investigation and then *analyzing and interpreting data* to interpret the results.

Students use elements of the crosscutting concept *cause and effect* as they identify fragmentation as a selection pressure on hawksbeard populations and grapple with ways to collect empirical evidence to show the impacts of that force. Students may use their middle school understanding of *Structure and Function* to deduce how plants use different seed shapes as seed dispersal strategies.

Students encounter the terms hypothesis, anatomical, fragmentation and common garden experiment. They also revisit their middle school level understanding of adaptation by natural selection. They co-construct a definition for selection pressure.

Where We Are NOT Going

In this lesson, the data set students investigate does not include a genetic mechanism for the inheritance of seed type in hawksbeard. Lessons 2-4 focus intentionally on building from concrete, visible anatomical traits (hawksbeard) to more abstract, less visible physiological, genetic (rats), and behavioral mechanisms (juncos) to allow students to build the elements of adaptation by natural selection.

Students make predictions about reproduction and generational change, but do not completely explain it. Lesson 3 will provide additional evidence for these ideas. The lesson may bring up questions about problems that may arise in populations isolated by fragmentation, but does not address the loss of genetic diversity in the population. This idea will be picked up again in the second lesson set.

This lesson does not directly discuss the connections of sexual reproduction to natural selection. Although bees are mentioned as pollinators on hawksbeard, allowing sexual reproduction to occur, it may be confusing for students that the external structures of the seeds being studied are determined by the parental generation, while the internal structures of the seed (not being investigated directly) are part of the F1 generation. The focus in this lesson is on the structure and function of the seed and how it improves the chance the seed will find a place to germinate, which grows the next generation of the plant. Lesson 3 will include sexual reproduction and the connection to natural selection. Lesson Set 2 will connect habitat fragmentation to reduced gene flow and reduced genetic diversity.

LEARNING PLAN for LESSON 2

1 · NAVIGATE

5 min

MATERIALS: *Case Study: Hawksbeard* for students assigned this reading in Lesson 1, Lesson 1 class consensus model

Acknowledge exit ticket ideas. Say, *Reading your exit tickets from last class, we have interest in learning more about hawksbeard, juncos and rats. We will definitely return to your questions and investigation ideas for all three populations, but it seems like learning more about hawksbeard is the easiest place for us to start learning more about how urbanization is a driving force for change in nonhuman populations.*

Review the hawksbeard case study from Lesson 1. Display **slide A**. Post the class consensus model from Lesson 1 where everyone can see it. Say, *Can someone remind us what ideas we had about the differences in hawksbeard plants in urban and non-urban environments?* Ask students assigned to this reading during Lesson 1 to take out *Case Study: Hawksbeard* to review. Students who did not read *Case Study: Hawksbeard* may need time to make sense of the graph. Listen for ideas such as:

- They had two types of seeds and there were more nonfeathery ones in urban areas.
- We wanted to know why there is a higher proportion of nonfeathery seeds in urban areas.

2 · DISCUSS SEED DISPERSAL STRATEGIES

5 min

MATERIALS: science notebook, Lesson 1 class consensus model, feathers (variety pack), paper clips (#2 size or 1 1/8 inch)

Elicit prior knowledge about seeds. Say, *You all already know alot about plants. Let's figure out what we already know about the basic function of seeds and how they are formed.* Display **slide B**. Facilitate a brief discussion using the prompts below.

Suggested prompt	Sample student response
Why are seeds important to a plant?	Seeds are how plants reproduce. Seeds are embryos for a plant. Because they are the plant's babies.
How are seeds formed?	Pollen from one plant fertilizes the eggs of another plant and the eggs develop into seeds. In plants, like babies in humans. Bees have something to do with it.

ADDITIONAL GUIDANCE	This brief review of sexual reproduction in plants is important as part of the foundation of adaptation by natural selection. If students are unfamiliar with the function of seeds and how flowers reproduce review <i>OpenSciEd Unit 8.5: Why are living things different from one another? (Muscles Unit)</i>, Lesson 13: <i>How do plants reproduce?</i> This idea is part of the NGSS DCI MSLS1.B: Organisms reproduce either sexually or asexually, and transfer their genetic information onto their offspring.
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* ATTENDING TO EQUITY

Supporting emergent multilinguals: When encountering new vocabulary, like *dispersal*, strategies that may benefit emergent multilingual learners are to use student-friendly definitions, make connections to cognate words when possible, and include a visual representation of the word, like the feather being blown downwind. Use these strategies throughout the unit for both *definitions we co-construct* and *definitions we encounter*.

Discuss seed dispersal strategies. Say, *Let's make sure everyone is familiar with feathery seeds and how they move around. Many of you may have experience with flowers like hawksbeard.* Show the video <https://youtu.be/OwovtvnYquM>, on **slide C** of dandelion seed dispersal, which is similar to the hawksbeard. Ask, *How is the plant moving its seeds? Where will the seeds end up?* Listen for students to say wind carries the feathery seeds to new locations to grow.

Demonstrate dispersal of seed types. Say, *Scientists use the terms disperse and dispersal to talk about the way seeds move and spread out. So every hawkweed plant makes some seeds with anatomical structures like this* (hold up a feather and blow on it) *that move in the wind, but it also makes a few seeds without those feathery tufts. They are more like these paper clips that just fall off the plant* (hold up a paper clip and drop it). Display **slide D**. Discuss possible reasons for different dispersal strategies. Accept all ideas in this discussion, but press for reasoning. *

Suggested prompt	Sample student response
<i>Why do plants disperse their seeds?</i> <i>In hawksbeard, one plant makes different kinds of seeds. What ideas do you all have for why there is variation in the types of seeds plants make?</i>	They might germinate better if they fall away from their parent plant where there is more space. If they are all in the same spot, they are probably taking each others' resources. Adult plants cannot move. When they are spread out there is more sun, soil and water available. Maybe some kinds survive in different places so it is good to have both. Sometimes there is no wind and sometimes there is wind so if they have both they will land in more places. It might be beneficial to keep some offspring nearby so they make the paperclip kind. It is harder to make the feathers.
ADDITIONAL GUIDANCE	The term <i>anatomical</i> is intentionally used when revoicing the students' description of hawksbeard seeds as the focus in this lesson is on anatomical adaptations. Lessons 3 and 4 will introduce physiological and behavioral examples to create a complete understanding of HS-LS4.C. The term <i>anatomical</i> is part of the middle school grade band of the NGSS (MS-LS4.A). If students experienced OpenSciEd Middle School, <i>anatomical</i> was co-constructed in <i>OpenSciEd Unit 8.5: Why are living things different from one another? (Muscles Unit)</i>. If students describe <i>anatomical</i> using other terms, such as structures or parts, support them in using these more familiar terms.

ADDITIONAL GUIDANCE

When reasoning about natural selection some students may have ideas that organisms can change because they *need* to change when the environment changes. These need-based ideas have been documented in the research literature and are common novice ideas based on “intuitive common sense thinking” (Furtak, 2012). To support students as they build on these ideas toward a more sophisticated understanding of natural selection, avoid language such as “The seeds needed to disperse to survive”. Focus on describing the traits that exist and how they provide an advantage or disadvantage for survival and reproduction. For example, “Seed dispersal increases the potential that seeds will germinate.” For more resources related to common student ideas see *Teacher Background Knowledge*.

Consider additional information needed. Say, *To summarize what we know: we have ideas about why a hawkbeard plant might make two different kinds of seeds that disperse differently, but we are still looking for evidence that could explain why hawkbeard produce a higher proportion of nonfeathery seeds in urban areas compared to non-urban areas.* Display **slide E** and discuss the question on the slide.

Suggested prompt

What additional information would help us figure out why the proportion of feathery seeds is different in urban and non-urban environments?

Sample student response

Find out where plants are growing in urban areas and outside of urban areas.

Find out what it looks like where they grow.

Examine the different seed types.

Try growing the seeds in each location.

Find out what is different about where hawkbeard grows in both environments.

3 · ANALYZE WHERE HAWKSBEARD GROWS

6 min

MATERIALS: None

Examine photos of where hawkbeard grows. Say, *I was able to find some photos of the places scientists collected hawkbeard seeds for the investigations some of you read about.* Display **slide F**, which includes views of two places where hawkbeard grows: a non-urban field where grapes are grown and an urban street in Montpellier, France. Give students a minute to turn and talk with their neighbor about what they notice. Then ask students to share their observations with the whole class.

Suggested prompt	Sample student response
<i>What do you notice?</i>	The field is large and open with lots of space, just plants growing. Plants grow in square plots in the city with a tree in the middle. City plot has squares of trees every few feet with concrete in between. In the city there are lots of tall buildings along the street. There are a lot more hawksbeard plants in the field than the sidewalk plots.
Discuss the relationship between seed type and environment. Say, <i>You noticed that there were broken up plots of soil in the urban environment. This is called fragmentation. Fragmentation is something that happens a lot in urban environments.</i> Facilitate a think, pair, share for the question on slide G.	
Suggested prompt	Sample student response
<i>How might fragmented plots of soil impact the next generation of hawksbeard plants?</i>	There are fewer places for seeds to land and grow. Seeds might get stuck on buildings or sidewalks. If seeds do not land on soil, they will not grow because they will not have the resources they need.
<i>How could we test our ideas?</i>	Find places where hawksbeard plants live in cities and observe them when the seeds fall. Try growing hawksbeard seeds on concrete and in soil and see if they germinate and grow. Grow some hawksbeard plants in a greenhouse and take them to a city when they are ready to disperse seeds and watch where they land.
ADDITIONAL GUIDANCE	Encourage students to add <i>fragmentation</i> to their personal glossary as a definition they encounter. Fragmentation will be discussed in multiple lessons in this unit. Student definitions may sound like: <i>Fragmentation is when a large habitat is broken up into smaller pieces that are not connected. It creates barriers for plants (or animals) to move. It happens in places where there is urbanization.</i>

4 · INTRODUCE SEED DISPERSAL INVESTIGATION AND WRITE A HYPOTHESIS

9 min

MATERIALS: *Seed Dispersal Investigation*, terry cloth washcloths, feathers (variety pack), paper clips (#2 size or 1 1/8 inch), ruler, *Seed Investigation Protocol*, large terry cloth beach towel, large adjustable fan

Introduce an investigation. Say, *Good ideas! I have some supplies that I think can help us model some of your ideas so we can figure out what causes differences in the proportion of seed types in urban and non-urban environments.* Display **slide H**. Distribute *Seed Dispersal Investigation* to each student and describe the basic investigation set up by following the protocol on *Seed Investigation Protocol*.



Write a hypothesis. Display **slide I**. Direct students to complete questions 1 and 2 on *Seed Dispersal Investigation* on their own and then share what they predicted in question 2 with an elbow partner.

ADDITIONAL GUIDANCE

Here, students encounter the term *hypothesis*. They likely have ideas about what it means from their prior experiences. Students commonly come to high school with a definition of a hypothesis as an educated guess. Discuss with students that when scientists develop a hypothesis they are working on a tentative explanation based on observation and evidence, rather than guessing. Students should add *hypothesis* to their personal glossary with a definition such as *a possible scientific explanation that predicts an outcome*.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment:

- Identification of the **proportion of surviving nonfeathery and feathery seeds** as the **dependent variable or effect** of fragmentation. (SEP: 3.5; DCI: LS4.B.2; CCC: 2.1)
- Identification of **fragmented or unfragmented plots** as the **independent variable** as the **cause for change**. (SEP: 3.5; CCC: 2.1)
- A logical **prediction that the proportion of each seed type will increase or decrease as a result of fragmentation**. (SEP: 3.5; DCI: LS4.B.2; CCC: 2.1)

What to do:

- Ask students to identify the cause and effect seen in the investigation and connect those to the independent and dependent variables.
- Refer students back to their investigations on cellular respiration and photosynthesis from *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)* when they identified independent and dependent variables.
- Extension: Ask students to make a logical quantitative prediction for the change in proportion of the outcome of the investigation.

Building toward 2.A **Make a directional hypothesis to explain how fragmentation could cause the proportion of traits related to seed dispersal to change in hawksbeard populations.** (SEP: 3.5; DCI: LS4.B.2; CCC: 2.1)

ALTERNATE ACTIVITY

- To save time and/or space, model and collect all field/non-urban data together as a class, then send students to complete the urban investigation in groups.
- Allow students who ask to simulate trees or buildings using water bottles or other tall cylinders, books or boxes.
- If students are more familiar with calculating percentages, those are also appropriate for analysis.

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

Over the course of this first lesson set, students will engage several times in planning and carrying out investigations (SEP) to find cause and effect (CCC) to derive the elements of adaptation by natural selection (DCI). In this initial investigation students will quickly figure out fragmentation as a mechanism (CCC) that drives selection (DCI) because it is easy to see. The protocol is provided to allow the SEP focus to support students in developing directional hypotheses, which is a new use of the practice. The model used in the investigation is simple, but will be a powerful reference for students later in the unit when they learn about more abstract mechanisms of selection they cannot easily see. The hypothesis they develop on day 1 (SEP) guides their thinking about cause and effect (CCC). They will then compare their self-generated data to the published results on day 2 to deepen their thinking about the need for capturing empirical causal evidence (CCC) for natural selection and adaptation (DCI).

Finish reviewing instructions. Display **slide J**. Briefly review the protocol one more time. Use **slide K** to explain how to calculate the proportions. Divide the students into groups of 4 or 5. Assign half of the groups to start with the urban plots and half to begin with the shared non-urban field plot.

5 • RUN SEED DISPERSAL INVESTIGATION

15 min

MATERIALS: *Seed Dispersal Investigation*, terry cloth washcloths, feathers (variety pack), paper clips (#2 size or 1 1/8 inch), large terry cloth beach towel, large adjustable fan



Provide time to complete the investigation. Repost **slide J** with instructions to support students while they carry out the investigation. Provide students with 10 minutes to run the investigation. As they finish collecting data, circulate to each group to facilitate data analysis and explanation writing. Students in each group should also work together to write an explanation of what they learned for question 5 in *Seed Dispersal Investigation*. *

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- The **collection of data** related to the **proportion of feathery and nonfeathery seeds with the potential to survive**. (SEP: 4.5; DCI: LS4.B2)
- Discussion and writing of **explanations** about the **higher potential for survival and germination of nonfeathery seeds** in **small fragmented plots compared to large ones**. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1)
- Discussion and writing about how the **new data supports or refutes** hypotheses about the **effect of urbanization on hawksbeard seed type**. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1)
- Discussion and writing of **explanations** of how **fragmentation causes fewer feathery seeds to land on soil**. (SEP: 4.5; DCI: LS4.B2; CCC: 2.1)
- Questions about the **changes in proportion of seed type over generations of plants**. (SEP: 4.5; DCI: LS4.B2)

What to do:

- Ask students to identify the cause and effect seen in the investigation.
- Ask: How did the environment the seeds were placed in affect the outcome?
- Remind students to use evidence to support their explanations.
- As an extension, ask: What would happen in the next generation of plants? How could you model it?

2.B Incorporate **new data into an explanation of how different traits could become more common** in **fragmented hawksbeard populations, increasing the chance of survival, and opportunity for reproduction**. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1)

6 • COMPLETE EXIT TICKET

5 min

MATERIALS: *Seed Dispersal Investigation*

Complete an exit ticket. Display **slide L** and ask students to review and revise the explanation at the bottom of *Seed Dispersal Investigation* and turn it in to you as they leave.

ADDITIONAL GUIDANCE

Review student responses to question 5 (explanations) and exit tickets to look for overall comprehension of the mechanism of fragmentation before collaboratively writing a whole-class scientific explanation on day 2. Provide feedback prompts as suggested in the *what to do* section of the assessment callout box. If it appears that students did not understand what happened, take time to review their investigation data in class and develop the mechanism together.

End of day 1

7 • NAVIGATE

5 min

MATERIALS: *Seed Dispersal Investigation*

Review findings. Display **slide M**. Return *Seed Dispersal Investigation*. Ask a student to recap what we did in the last class. Then ask students to turn and compare the results of their group's investigation with someone who was not in their group yesterday. After a minute, bring the class together and lead a discussion. Record the major noticings on the white board.

Suggested prompts	Sample student responses	Follow-up questions
<i>What similarities did you notice?</i>	Not all seeds landed in a place they can germinate. In the field both the clips and feathers landed in big numbers. A larger proportion of clips (nonfeathery seeds) had the potential to survive in the non-urban area. In the urban, fragmented areas, a lot of clips landed on the cloth, but feathers did not. In the urban areas feathers landed in places they could not germinate.	<i>What happened to the proportion of different seed types in the non-urban environment?</i> <i>What will happen to seeds that do/do not land on soil?</i> <i>Why does a plant make so many seeds if many of them do not have the potential to germinate?</i>
<i>What differences did you notice?</i>	The person I compared with had a higher/lower survival rate for feathers than we did. People whose set-up was closer to the fan had a lower feather survival rate than those farther away.	<i>What do you think caused those differences?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>How well did our model replicate the real world?</i>	We were not working with real seeds in a real city with real soil. We only had two fragmented plots. In a city, there would be many more places for seeds to land and grow. We did not have obstacles like trees and bikes in the way like there would be in the city or animals to eat the seeds. Wind speed and direction varies more in real life. We do not know if seeds will germinate, we are assuming they will.	<i>What was missing from our investigations?</i> <i>How reliable are our results?</i> <i>How would we run the investigation differently if we were using real plants?</i>
<i>What do you predict would happen to the proportion of nonfeathery seeds in future generations of urban hawksbeard?</i>	Over time more of them would be nonfeathery in the urban environment and less of them would be feathery.	<i>What conditions would make it more likely for the hawksbeard to survive and reproduce?</i>

8 · DISCUSS INITIAL EXPLANATIONS

9 min

MATERIALS: *Seed Dispersal Investigation*

Compare initial explanations. Say, *Even recognizing these differences and limitations, all groups observed fairly consistent results when comparing the modeled fragmented urban area with the unfragmented non-urban one. Let's discuss how you wrote your explanations about what caused the differences in proportion of seed types in urban versus non-urban environments. Before we do that, let's briefly revisit our Community Agreements.* Display **slide N** or display your Community Agreements, pointing out categories related to supporting one another and moving their science forward. Remind students that writing explanations can be challenging. Throughout this unit they will develop this practice. Work to develop a supportive space where students feel comfortable making mistakes, receiving feedback and working to improve their explanations.

Display **slide O**. Ask one volunteer to share their groups' explanation from *Seed Dispersal Investigation* using a document projector or by reading out loud. Ask a few other students to suggest refinements to the statement. Sentence starters for constructive feedback are provided on the bottom of the slide.

ADDITIONAL GUIDANCE

A possible explanation could be: Fragmented soil plots in urban areas make it less likely that feathery seeds will land in a place with the soil nutrients, water and sunlight they need to germinate. Feathery seeds may float away and get stuck on a building, street or sidewalk and never grow into a new plant. Seeds without feathers land next to the parent plant where there is already soil, so they can grow. Plants that produce a higher proportion of nonfeathery seeds likely have more offspring germinate in cities. In the nonurban environment there was no difference in the proportion of seed types.

Prompts for writing the explanation may include:

- What was the change in the hawksbeard population?
- What caused the change?
- Could both seed types survive?

Introduce or review the terms adaptation and natural selection. Display **slide P**. Say, *What I hear you saying is that nonfeathery seeds may be better suited for the urban environment because they are more likely to survive and reproduce. Scientists call this an **adaptation**. Over time the organisms that are better suited are selected for by the environment. Scientists call this **natural selection**.* Facilitate a discussion to co-construct definitions to add to their personal glossaries. Explain that these definitions will be refined later in the unit so they should leave space for revision.

ADDITIONAL GUIDANCE

Discuss adaptation and natural selection whenever your students raise the idea in this lesson. If adaptation did not come up in Lesson 1, it is important to establish the difference between the way *adapt* and *adaptation* are used in everyday language versus biology. Students may be building on middle school level understanding of adaptation and natural selection such as:

- Natural selection leads to the predominance of certain traits in the population and the suppression of others (MS LS4.B).
- Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. (MS LS 4.C).

9 · COMPARE RESULTS TO PUBLISHED STUDIES

9 min

MATERIALS: *Hawksbeard Garden Experiment*

Compare class results to the results from scientific literature. Say, *Ok, so we have an initial explanation about what could cause differences in the proportion of seed types in urban and non-urban environments based on our classroom investigations with a model of the system. How do we know that our results model what happens in the real world?* Listen for answers such as: look at scientific studies, review actual data, or see what scientists have figured out. Say, *I have more information for you to look at from the original investigation.* Display **slide Q** and distribute *Hawksbeard Garden Experiment*. Return students to their groups from the previous class to read and discuss the experiments described. Each student should complete the questions on the handout. *

ADDITIONAL GUIDANCE

Encourage students to add *common garden experiment* to their personal glossary as a definition they encounter. Thinking about experimental design to show cause and effect with natural selection is challenging and these types of experiments will be discussed again in Lesson 4. They can use the explanation from *Hawksbeard Garden Experiment* or describe the term in their own words.

* ATTENDING TO EQUITY

Universal design for learning. The diagrams in this reading provide multiple forms of *representation* of the ideas in the text to support students who struggle with reading and to support Emergent Multilingual Learners. Point out this image to those individuals who would benefit from focusing on the image first and then doing the reading. Encourage students to annotate the reading by highlighting or underlining key results and other ideas.

10 · BUILDING UNDERSTANDINGS DISCUSSION ABOUT THE EFFECTS OF FRAGMENTATION

10 min

MATERIALS: *Hawksbeard Garden Experiment, Garden Experiment Key*



Discuss results of the common garden experiments. Display **slide R**. Facilitate a discussion of questions 1–5 from *Hawksbeard Garden Experiment* using *Garden Experiment Key* as a guide. *

KEY IDEAS

Purpose of this discussion: The goal for this discussion is to conceptualize fragmentation as a selection pressure that could act on variation in the proportion of seed type in urban and nonurban populations of hawksbeard over generations.

Listen for these ideas:

- Common garden experiments allow scientists to control most variables so they can see cause and effect.
- Collecting large amounts of data helps scientists be more certain when patterns emerge.
- The scientist's results supported ours.
- Variations in seed structure increase the chance of survival and germination in different environments.
- Not all offspring will germinate. Having more dispersal strategies increases the chance some seeds will have an opportunity to germinate and eventually reproduce.
- The proportion of feathery and nonfeathery seeds is likely inherited.
- Hawksbeard with variations that produce even higher proportions of nonfeathery seeds could become more common in future generations because more of their seeds would germinate.
- Fragmentation causes an increase in the proportion of nonfeathery seeds in hawksbeard populations in urban areas.

Co-construct a definition for selection pressure. After the discussion of question 5, when students discuss future generations of hawksbeard, introduce the term selection pressure. Say, *You all described how you think fragmentation could cause differences in the proportion of seed types in future generations. Scientists call this a **selection pressure**.* Display **slide S**. Facilitate the co-construction of the term selection pressure and ask students to add it to their personal glossary.

ADDITIONAL GUIDANCE

Student definitions for *selection pressure* may sound like: things in the environment that make it harder or easier for some individuals in a population to survive and reproduce.

* ATTENDING TO EQUITY

Differentiation. As an extension, challenge students to think about the role bees play in determining the (genetic) makeup of the next generation of plants. In the common garden experiment, bees pollinated ALL plants regardless of their origin. In a natural setting, a single bee would not be able to visit flowers located 30 km apart. Students could investigate how far bumblebees normally fly and think about which populations might be able to cross pollinate and which would not, impacting the differential survival and reproduction of traits in the population. This impact of fragmentation will be brought up in Lesson Set 2.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Students comparing the results of their investigation to the investigation described in *Hawksbeard Garden Experiment* to build their explanation (SEP 4.4) including:

- Evidence from both investigations that not all hawksbeard seeds will land in a place where they have a chance to germinate. (SEP: 4.4; DCI: LS4.C2)
- Evidence from both investigations that nonfeathery seeds are anatomically suited to survive and likely to germinate in fragmented places. (SEP: 4.4; DCI: LS4.C2)
- Evidence from both investigations that fragmentation may be a selection pressure that causes a change in the proportion of different seed types that have the potential to survive and germinate. (SEP: 4.4; DCI: LS4.C2; CCC 2.1)
- The proportion of nonfeathery and feathery seeds produced in hawksbeard is likely to be inherited. (DCI: LS4.C2)
- The common garden experiments generated empirical data that more closely models the natural system to illustrate the effect of fragmentation on hawksbeard. (SEP: 4.4; CCC 2.1)
- Discussion of how common garden experiments control variables allowing them to eliminate other variables that might have an effect on the variables. (CCC: 2.1)

What to do:

- Ask students if they think seed dispersal structures are inherited. Why?
- Revisit the importance of controlled experiments to reveal cause and effect.
- Facilitate the invention of a scenario showing the proportion of unfeathered seeds increasing over generations in urban areas.
- Ask students what would happen in (un)fragmented environments if hawksbeard plants only made one type of seed.
- Refer to the answers in *Garden Experiment Key*.

2.C Compare and contrast how self-generated and published data support the claim that differential survival and opportunity to pass on heritable traits could lead to adaptation in hawksbeard seed dispersal traits. (SEP: 4.4; DCI: LS4.C.2; CCC: 2.1)

11 · UPDATE THE CONSENSUS MODEL

5 min

MATERIALS: science notebook, Lesson 1 class consensus model

Update the class consensus model. Display slide T. Say, *So I hear you saying we have evidence from multiple sources that fragmentation could be a selection pressure that acts on variations in the hawksbeard populations to change the proportion of nonfeathery seeds. Say, Can we update our model from Lesson 1 now?* Ask students for suggestions for how to represent fragmentation as a selection pressure in the model. Encourage students to build on each other's ideas.

Identify missing pieces in our model. Say, *You all identified a missing piece that we would need to understand if we were going to fully explain our predictions about what we think will happen to hawksbeard in the future. What is missing here?* Listen for students to identify inheritance patterns in the hawksbeard in the seed dispersal type as the missing piece.

12 · NAVIGATE: INTRODUCE PROGRESS TRACKER AND COMPLETE A ROW

7 min

MATERIALS: *Progress Tracker*

Propose starting a Progress Tracker to keep track of ideas. Display slide U. Say, *The consensus model does not provide us with a lot of space to write down everything we learned about the impact of urbanization on the hawksbeard and fragmentation as a selection pressure. If we had a place to keep track of all the ideas and patterns that we might eventually use as evidence to support our claims, that would be really helpful.* Distribute *Progress Tracker*. Have students add the unit question, *How is urbanization a driving force for change?*, to the top of the page. Explain that the Progress Tracker can also help make sure the investigations they do in each lesson connect back to what they want to figure out about the impact of urbanization on nonhuman populations. Give students a few minutes to write and draw what they learned as in the example below. *

Record remaining questions in the Progress Tracker. Display slide V. Encourage students to record the questions they still have. Remind them of the missing pieces related to genetics that they identified. Prompt them to think about the unit question and what other features of urbanization might act as selection pressures on nonhuman populations. Remind them of the additional case studies they investigated in Lesson 1 with rats and juncos.

Lesson number	Lesson Question	What I Figured Out in Words, Pictures and/or Symbols	Questions I Have
2	Why do hawksbeard make fewer feathery seeds in cities?	- Fragmentation happens in cities and is a selection pressure that makes it difficult for feathery seeds to land in a place they can germinate. - More non-feathery seeds probably survive to germinate because they land next to their parent. - We predict that over time the proportion of plants with nonfeathery seeds will increase in urban areas.	- How do the genetics work for hawksbeard? - Do plants from feathery and nonfeathery seeds always make the same proportion of seed types? - What other things can be selection pressure in urban environments?

ADDITIONAL GUIDANCE

The Progress Tracker is intended as a way for students to track their own learning and understanding and should not be assessed for a grade. However, it can be used as a formative assessment tool for each lesson in which it is used. For this lesson, check for the way students use terms such as selection pressure and fragmentation to support explanations of natural selection. If students do not incorporate key vocabulary terms, leave prompts that ask if there are scientific terms that can be applied to this explanation. Lesson 3 will focus on writing scientific explanations, therefore, reviewing the Progress Tracker will provide an idea of how individual students write at this time, allowing you to adjust or remove the scaffolds provided in the following lesson.

* ATTENDING TO EQUITY

Supporting emergent multilinguals: Allow and encourage students to use both content-specific and everyday registers when expressing their ideas. Switching back and forth between different registers is especially important for emerging multilingual students because it helps them draw on their full range of meaning-making resources. Students who are learning English also benefit from redundancy of content and vocabulary.

The options for written and/or graphic descriptions of what students learned on the Progress Tracker provide two modalities for students to express and represent their understanding. Sometimes it is easier to draw or use symbols to show their understanding until they find the words to express their ideas. Encourage students to use both. Often a picture or symbol is a better memory trigger than writing.

Additional Lesson 2 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

RST-11.12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

As students read a modified version of published scientific research they evaluate how the study was conducted and the data they collected. They compare this information to self-generated data they produced themselves the day before and discuss how the results agree or disagree. They also discuss the important distinctions in quality of data collected by researchers compared with what they collect themselves.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively.

CCSS.MATH.CONTENT.S.IC.B.3 Make inferences and justify conclusions from ~~sample surveys~~, experiments, and observational studies.

Recognize the purposes of and differences among ~~sample surveys~~, experiments, and observational studies; ~~explain how randomization relates to each.~~

Students collect data and calculate survival rates for two forms of hawksbeard seed. They compare their own quantitative results to formal results from published studies and discuss the advantages of collecting data using different techniques, including common garden experiments, which control for more variables.

LESSON 3: Is poison a selection pressure?

PREVIOUS LESSON We investigated the impact of fragmentation on the proportion of hawkbeard seeds with feather and nonfeathery seeds by conducting our own investigation and comparing the results to common garden experiments published by scientists. We determined that the proportion of seed dispersal forms is inherited and that fragmentation causes a change in the proportion of seeds of each type in a population. We wondered how scientists investigate the genetics of populations as they change.

THIS LESSON

INVESTIGATION

3 days



Denitsa Kireva, Pexels

We hear that 80% of rats in Tokyo are resistant to poison and decide to investigate. We investigate a model for how rats developed resistance and write a preliminary explanation. We gather additional information from multiple studies about genetic variations in rats that affect their physiology and evaluate the impact of new data on our explanations. We revise and self-assess our explanations for rat poison as a selection pressure that caused a change in the distribution of resistant traits.

NEXT LESSON We will investigate the inheritance of boldness to figure out how the UCSD juncos came to be bolder than the juncos in Mt. Laguana.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

3.A Construct an explanation based on patterns of evidence at the genetic and population scale for rat poison as a selection pressure that causes some rats with particular variations to survive better and therefore reproduce when exposed to poison. (SEP: 6.2; DCI: LS4.B.1; CCC: 1.1)

3.B. Construct and revise an explanation based on evidence from a variety of sources that suggests how individual genetic mutations cause physiological advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to differential reproduction and an increased number of rats in the entire population that carry adaptive genetic variations. (SEP: 6.2; DCI: LS4.B.1, LS4.C.1; CCC: 2.2)

WHAT STUDENTS WILL FIGURE OUT

- Mutations for poison resistance existed in the rat population before people used poison.
- Rat populations have variations in their mutations.
- Variable expression of mutations affects rat physiology, causing different levels of resistance to poison.
- Rats sexually reproduce, which allows for the mixing of genes.
- High reproduction rates allow rats that survive poison to quickly increase in number with offspring resistant to poison.
- Natural selection for poison resistance happens over generations.

Lesson 3 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Turn and talk to recall what students know and want to figure out about selection pressures in urban areas.	A-B	<i>Progress Tracker</i> , class consensus model
2	8 min		MOTIVATE RAT INVESTIGATIONS Motivate students to ask questions about how rats in Tokyo developed high resistance to poison and read a historical study.	C-D	<i>Historical Rat Study</i>
3	8 min		CONSIDER ETHICAL DECISIONS FOR INVESTIGATIONS As a class, discuss ways to investigate living things ethically.	E-G	
4	5 min		INTRODUCE RAT MODELING ACTIVITY Review how to set up the rat model.	H	<i>Rat Modeling Investigation</i> , pony beads (red), pony beads (blue)
5	15 min		CONDUCT RAT INVESTIGATION Groups of students develop a model to collect data showing what happens to the percentage of a particular mutation in the population before and after the introduction of a selection pressure.	I	<i>Rat Modeling Investigation</i> , calculator, pony beads (red), pony beads (blue), <i>Rat Cross Model Key</i>
6	4 min		NAVIGATE Students stop and jot about limitations in the model.	J	
<i>End of day 1</i>					
7	5 min		NAVIGATE: REVIEW RESULTS OF RAT MODEL Facilitate a review of what students learned from the rat model.	K	<i>Rat Modeling Investigation</i>
8	15 min		BUILDING UNDERSTANDINGS Facilitate a Building Understandings Discussion of the mechanism learned in the model. Discuss the assumptions made that require additional evidence.	L	<i>Rat Modeling Investigation</i>
9	20 min		READ ABOUT RATS Students learn about rat reproduction and work in pairs to investigate data from studies about variations in mutations in rats for poison resistance.	M-O	<i>Rat Genetic Variation</i>
10	5 min		NAVIGATE Facilitate reflective writing on which questions related to Tokyo rats students can now answer and with what evidence.	P	<i>Rat Genetic Variation</i>
<i>End of day 2</i>					
11	5 min		NAVIGATE Facilitate a reflection on how student thinking has changed.	Q	<i>Rat Modeling Investigation</i>

Part	Duration		Summary	Slide	Materials
12	20 min		BUILDING UNDERSTANDINGS DISCUSSION FOR RAT POISON AS A SELECTION PRESSURE Gather students in a Scientists Circle to discuss how the new data support or refute an explanation for how Tokyo rats developed resistance to poison.	R-T	<i>Rat Modeling Investigation, Rat Genetic Variation</i>
13	15 min		REVISE RAT POISON EXPLANATIONS USING NEW DATA Individually revise final explanations for rat poison as a selection pressure in Tokyo. Students complete a self-assessment on how they wrote explanations.	U-V	<i>Rat Poison Explanation, Rat Modeling Investigation, Rat Genetic Variation</i>
14	5 min		NAVIGATE Turn and talk to celebrate what students have figured out in this lesson.	W	

End of day 3

Lesson 3 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Progress Tracker</i> <i>Historical Rat Study</i> <i>Rat Modeling Investigation</i> - calculator <i>Rat Genetic Variation</i> <i>Rat Poison Explanation</i>	- pony beads (red) - pony beads (blue)	- class consensus model - pony beads (red) - pony beads (blue) <i>Rat Cross Model Key</i>

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.
Prepare bags of 50 red and 50 blue beads for each student group.

Lesson 3 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students investigate how genetic variations are passed from generation to generation in rats, focusing on poison as a selection pressure. Students see how populations of rats, which are prolific reproducers, can recover even if most of the population is susceptible to poison as long as a small number of individuals carry an adaptive variation. Students begin by manipulating a simple model to introduce genetic variation to their middle school understanding of natural selection and then add increasing complexity to their understanding as they read about scientific studies that investigate variations in multiple mutations that cause resistance.

This lesson builds on middle school DCI's:

LS4.B.1: Natural Selection

- Natural selection leads to the predominance of certain traits in a population, and the suppression of others. (MS-LS4-4)

LS4.C: Adaptation

- Adaptation by natural selection acting over generations is one important process by which species change over time in response to changes in environmental conditions. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common. Thus, the distribution of traits in a population changes.

In this lesson, students continue to build understanding of the following HS DCIs:

- LS4.B.1: 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.
- LS4.C.1: 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)

Students use elements of the science practice of *Constructing Explanations and Designing Solutions* when they use self-generated data from group models to construct explanations and then later revise explanations using data from published studies. Students receive teacher feedback and specific scaffolding to support their explanations in this lesson before encountering it independently in the Lesson 6 transfer task, *Antibiotic Resistance Transfer Task*.

Students use elements of the crosscutting concept of *Patterns* and *Cause and Effect* when they examine patterns from genetic data from rats exposed to poison and apply it to physiological changes measured in individual rats and larger changes in urban rat populations.

Students will co-construct a definition for *physiological adaptation*. They will encounter the word *allele*.

Where We Are NOT Going

There are many different pest control techniques used by humans to control rat populations. This lesson focuses only on anticoagulant poison and the mechanisms of resistance that have evolved in rat populations.

Although fragmentation is part of the story for why different rat populations have different mutations, it is not the main emphasis of the lesson. Instead, students build a case for poison as an additional selection pressure for nonhuman populations in urban areas. Some students will be able to integrate both selection pressures into their explanations, but it is not required.

LEARNING PLAN for LESSON 3

1 · NAVIGATE

5 min

MATERIALS: science notebook, *Progress Tracker*, class consensus model

Recall what we figured out in our last lesson. Display **slide A** and direct students to look at *Progress Tracker*. Use the following prompts as a guide.

Suggested prompt	Sample student response
<i>What did we figure out about hawksbeard in the last lesson?</i>	We think that fragmentation is a selection pressure.
<i>What questions did we still have?</i>	How does the inheritance of seed shape work? How are genetics part of natural selection? What are some other selection pressures in urban environments?
<i>How can our class consensus model help us answer our questions?</i>	The rats had some information about genetics.

Motivate interest in learning about rats. Explain that we do not have data that helps us explain the genetics or inheritance of seed shape in hawksbeard. However, it might be possible to learn more about these mechanisms by investigating a different population. Display **slide B**. Discuss what they remember about rats and what questions they still have.

Suggested prompt	Sample student response
<i>What do you remember about rats and poison from Lesson 1?</i>	Some rats in the population have resistance to common poisons. People try to control the size of the rat population by tightly closing food and garbage containers, cleaning out nesting areas, trapping, and poisoning. Rats can cause property damage, spoil food, and transfer diseases to people. Rats seem to prefer living near people and take advantage of the food and resources people provide. The mechanism of resistance is related to mutations that change the protein for blood clotting. We do not know how the rats get the mutation.

Suggested prompt	Sample student response
<i>What questions do we have about how rat poison affects the rat population?</i>	Are all rats resistant? Have they always been resistant? How did they become resistant? Does this only happen in cities? Is poison a selection pressure in rats?
<i>How could we figure out if poison is a selection pressure in urban environments like fragmentation was for the hawksbeard?</i>	We could look at investigations other people have done of rats and poison. We could poison rats and see what happens but that seems like it could hurt the rats.

2 · MOTIVATE RAT INVESTIGATIONS

8 min

MATERIALS: *Historical Rat Study*

Introduce resistant rats in Tokyo. Say, *I hear you saying we want to investigate what caused rats to be resistant to poison in urban areas. After we read about rats in Lesson 1, I came across an article that mentioned rats in Tokyo, Japan. Tokyo was the largest city in the world in 2023 with over 37 million people.* Display **slide C**. Ask students to turn and talk about the statistics on the slide. After a minute, ask students to share their wonderings. Listen for:

- students to recognize that 80% is a high percentage,
- questions about why it is 80%, not higher or lower,
- wonderings about how that happened,
- wonderings about how this information compares to other cities.

Say, *Good questions! We cannot go back in time easily to figure out how rats in Japan developed resistance to poison. How could scientists doing research today figure out what happened in the past?* Listen for suggestions like: look at fossils, talk to people who lived a long time ago, read historical records. Say, *I also wondered how long people have known about rat resistance to poison and where else in the world this is happening. I found what I think is the first published study about resistance to poison in rats. Let's take a look at it.*

Display **slide D** and distribute *Historical Rat Study*. Provide 2 minutes to read the study independently. Then ask students to turn and talk about their noticings and wonderings. Facilitate a brief discussion using prompts similar to those below. If no one asks about ethics, ask what they thought about the way they tested the effect of poison on rats.

Suggested prompt	Sample student response
<i>What did you notice?</i>	84% of farm rats did not die; they were resistant. That is close to what happened in Japan. 67% of control rats died, so not all rats are resistant. They poisoned rats on purpose!
<i>What did you wonder?</i>	Are farm rats in Scotland the same as city rats in Japan? How could they poison rats as part of an experiment? That seems cruel.

3 · CONSIDER ETHICAL DECISIONS FOR INVESTIGATIONS

8 min

MATERIALS: science notebook

Acknowledge students' ethical concerns and revisit the Community Agreements. Say, *I hear some of you wondering about how scientists in the past conducted their experiments. Let's take a few minutes to revisit our Community Agreements and decision-making framework from earlier units before we explore more about the history of rats in urban areas.* Display **slide E**. Ask students to think about which of the Community Agreements we might want to focus on as we discuss a potentially emotionally sensitive topic like poisoning and therefore harming rats. Students may share ideas about how focusing on the *respectful* and *committed to our community* agreements might help us when discussing difficult topics. Ask students to suggest specific ways they might draw on these Community Agreements to support difficult conversations. Let students know that when the class discusses topics that feel emotionally challenging, they should feel comfortable asking to step out of the room. *

Discuss ethical concerns. Display **slide F**. After providing a minute of think time about the question on the slide, facilitate a brief discussion using the prompts below and on **slide G** as a guide.

Suggested prompts	Sample student responses	Follow-up questions
<i>Why is it such a high priority for people to study poison resistance in rats?</i>	Rats live with us and eat our food and make us sick. Many people want to get rid of them.	<i>Does everyone agree that we should control rat populations?</i>
<i>Who makes decisions about whether to use poison in cities or scientific investigations?</i>	Animal control Individual homeowners and renters Scientists Ethics boards at universities (today)	<i>What values should inform our decision?</i>

* ATTENDING TO EQUITY

Universal Design for Learning: It is important to use this community agreement-building to revisit how to cultivate an equitable learning community that promotes trusting and caring relationships that foster student *engagement*. The Community Agreements should remind students to value the diversity of classroom community members and equity in the sensemaking work they will do together this school year. It is critical that the Community Agreements support safe and fair participation and interrupt cultural community agreements or stereotypes that could make science experiences feel uncomfortable to students.

Suggested prompts	Sample student responses	Follow-up questions
<i>We will not be conducting investigations with rats in class. How else could we learn if poison is a selection pressure in rats?</i>	We could look at results from old experiments. We could look at the genes of living rats. We could use a simulation. We could research more about rats' lives.	<i>What are the potential limitations to the options that we are considering?</i>
ADDITIONAL GUIDANCE	Researchers today go through a review board before receiving permission to experiment on animals. Strict guidelines exist for conducting experiments on animals. Despite these guidelines, debate still exists about what, if any, experimentation on animals is ethical. Validate students' personal and community beliefs and explain that the studies that will be discussed going forward met the guidelines of the institutions where research was conducted. Descriptions of these studies will not focus on the methods that were used for collecting and sampling rats, but citations are available if students want to investigate the methods further.	

4 · INTRODUCE RAT MODELING ACTIVITY

5 min

MATERIALS: *Rat Modeling Investigation*, pony beads (red), pony beads (blue)

Motivate using a model to determine a mechanism. Say, *I heard some good suggestions for using a simulation of some type to investigate the genetics and reproduction in rats. At the beginning of this lesson, we reviewed that resistance is caused by a mutation, so we know it is genetic. Let's use another model, like we did with hawksbeard, to see if we can collect evidence to support a logical explanation for what may have happened to cause 80% of rats in Tokyo to become resistant to poison.* Distribute *Rat Modeling Investigation* and display **slide H**. Read through the instruction steps 1-4 with students. Use the following prompts to check for student understanding.

Suggested prompt	Sample student response
<i>What question are we trying to answer?</i>	What caused rats in Tokyo to be resistant to poison?
<i>How can the data help us answer our question?</i>	Changes to the percentage of rats carrying the red allele may help us determine if poison is a selection pressure that causes adaptations in rat populations.
ADDITIONAL GUIDANCE	Students will encounter the term <i>allele</i> in <i>Rat Modeling Investigation</i>. They previously co-constructed a definition for allele in <i>OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)</i>. Pause to revisit this definition which may be similar to <i>different versions of a gene</i>.

ALTERNATE ACTIVITY

Students with strong math skills may not require colored beads to make the calculations necessary in this model. Allow students to use other methods, such as drawing Punnett squares and colored dots as shown in *Rat Cross Model Key*. Encourage students who quickly calculate the outcome of the model to calculate alternative mating scenarios from the one they originally chose in generations 2 and 3 to share with the class how the outcomes can vary.

5 • CONDUCT RAT INVESTIGATION

15 min

MATERIALS: *Rat Modeling Investigation*, calculator, pony beads (red), pony beads (blue), *Rat Cross Model Key*



Work in groups to model the development of resistance to poison. Display slide I. Divide students into groups of 4-5 and provide time for them to complete the model and answer the questions on *Rat Modeling Investigation*. After students collect their data, encourage them to write the explanation at the end of *Rat Modeling Investigation* individually. Collect *Rat Modeling Investigation*.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: When students **write or draw an explanation (SEP 6.2)** to explain the results from *Rat Modeling Investigation*, look/listen for:

- See *Rat Cross Model Key*.
- **Changes in the dominance pattern of red vs. blue alleles before and after the introduction of poison.** (DCI: LS4.B.1; CCC: 1.1)
- **Changes in the percentage of rats carrying the red allele before and after the introduction of poison.** (SEP: 6.2; DCI: LS4.B.1; CCC: 1.1)
- **Explanation of poison as a cause of differential survival and reproduction for some rats.** (SEP: 6.2; DCI: LS4.B.1; CCC: 1.1)

What to do: Review student responses and provide feedback according to the assessment guidance below before returning the explanations to students on day 2.

- Remind students to add evidence, such as percentages, to their response.
- Ask if the red allele provides an advantage, disadvantage, or is neutral if there is no selection pressure.
- Ask why some of the rats with blue-blue alleles would still be found even if there is poison in the environment.
- Ask what happened at individual genetic and population scales.

Building toward 3.A Construct an explanation based on patterns of evidence at the genetic and population scale for rat poison as a cause for some rats with particular variations to survive better and therefore reproduce when exposed to poison. (SEP: 6.2; DCI: LS4.B.1; CCC: 1.1)

6 • NAVIGATE

4 min

MATERIALS: science notebook

Write about limitations of the model. Say, *I heard some great discussions about how to write an explanation for this model, along with some insightful questions. Many of you recognized that while we have some information that helps us write an explanation, we are still missing pieces of the puzzle.* Display slide J and ask students to stop and jot some of these ideas in their notebooks to discuss in the next class.

End of day 1

7 · NAVIGATE: REVIEW RESULTS OF RAT MODEL

5 min

MATERIALS: *Rat Modeling Investigation*, science notebook

Recall where we left off. Display **slide K**. Return *Rat Modeling Investigation* with your feedback to students as they enter the room. Provide time for students to turn and talk about the prompts on the slide.

8 · BUILDING UNDERSTANDINGS

15 min

MATERIALS: *Rat Modeling Investigation*, science notebook

Facilitate a Building Understandings Discussion about rat poison as a selection pressure. Display **slide L**. Gather the class in a Scientists Circle with *Rat Modeling Investigation* and their science notebooks. Discuss the key ideas described in the callout box below. Draw on the limitations students wrote in their notebooks at the end of day 1 to elicit questions for further investigation. Write student questions on the board. If necessary, ask students what additional evidence they need to explain how the genetic variations in the rat impact the situation in Tokyo. Explain that students will have a chance to revise their explanation from *Rat Modeling Investigation* after we collect additional information to address these limitations. *

KEY IDEAS

Purpose of this discussion: There are two goals for this discussion: 1. To establish poison as a selection pressure that causes differential reproduction and the proliferation of rats who carry a genetic mutation for resistance in Tokyo. 2. To motivate questions about the differences/variations between the different mutations that cause resistance in rats.

Listen for these ideas:

- Rats reproduce and shuffle their genes.
- The red and blue alleles were passed from generation to generation even when they did not affect survival rates. When the environment changed and poison became a selection pressure, many rats had the red allele even though it started with one rat.
- Natural selection leads to an increased proportion of rats with resistance in the population over generations.
- Questions about how quickly rats actually reproduce.
- Questions about whether all mutation variations function in the same way.
- Questions about the level of resistance a rat has based on the number of copies of the red (resistant) allele they carry.

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Be explicit with students about your role in this discussion, which is to press students for evidence when they bring up ideas for what was happening to the rats over generations. Tell students explicitly, *My role in this discussion is to press for evidence. You might hear me ask, "Where did you see that?" It is my job to push us as a class to articulate the evidence we have to support our ideas.*

9 · READ ABOUT RATS

20 min

MATERIALS: science notebook, *Rat Genetic Variation*

Provide information about rat reproduction. Say, *These are important questions. Let's see what information we can find to answer them.* Display the information on **slide M** and ask students to turn and talk about how this new information might impact the outcome of the model. Facilitate a brief discussion of these ideas using the prompts below. Suggest students take notes in their science notebooks with information that will inform the revision of their explanation.

Suggested prompt	Sample student response
How could this additional information impact the outcome of our model?	If rats reproduce 5 times/year and have up to 8 babies each year, the percentages of the red allele could change very quickly after poison is introduced. The population size can grow from just a few rats back to a large population very quickly. If rats are confined to one neighborhood, there may be some neighborhoods where no rats have a red allele and none are resistant. If rats only mate with rats in their own neighborhood, then the red allele could spread very quickly and protect rats that live in that neighborhood. Fragmentation may be a selection pressure in rats too if city streets are barriers.
Introduce a reading with additional rat resistance studies. Say, <i>I found another reading that may answer some of our questions related to genetics and how the different mutations function.</i> Display slide N and remind students that they learned about mutations to the VKOR gene in Lesson 1. Point out the Y139F mutation along with the other mutation names, which they will see in the reading. Read and analyze data with a partner. Display slide O. Distribute <i>Rat Genetic Variation</i> to each student. Give student pairs time to read and answer the questions on the slide in their science notebooks.	

10 • NAVIGATE

5 min

MATERIALS: science notebook, *Rat Genetic Variation*

 **Facilitate a reflection.** Ask students to return their attention to the list of questions they wrote on the board after their Building Understandings Discussion. Display **slide P** and ask them to stop and jot the answer to the questions. Remind them that they will use this information to revise their explanations in the next class.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: As students stop and jot about how the new evidence supports the revision of their explanations (SEP 6.2), look for/listen for:

- Rats reproduce often and in large numbers, so if even a small number survive poison, they grow to a big population quickly. (DCI: LS4.B.1, LS4.C.1; CCC: 2.2)
- Different mutations exist in different parts of Europe. There are multiple ways (different proteins) rats can be resistant to poison. (DCI: LS4.B.1, LS4.C.1; CCC: 2.2)
- Each mutation causes the VKOR gene to be expressed differently and provides resistance to a different amount of poison. (DCI: LS4.B.1, LS4.C.1; CCC: 2.2)
- Having two mutated alleles can make more protein that provide resistance compared to just one allele. (DCI: LS4.B.1, LS4.C.1, CCC: 2.2)

What to do:

- Refer students to the class question board and *Rat Genetic Variation* to make connections for which part of the reading answers a particular question.
- Refer students to your comments on *Rat Modeling Investigation*, where you suggested more data to support a particular claim.

Building toward 3.B.1 Construct and revise an explanation based on evidence from a variety of sources that suggests how individual genetic mutations cause physiological advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to differential reproduction and an increased number of rats in the entire population that carry adaptive genetic variations. (SEP: 6.2; DCI: LS4.B.1, LS4.C.1; CCC: 2.2)

End of day 2

11 · NAVIGATE

5 min

MATERIALS: *Rat Modeling Investigation*, science notebook

Provide individual think time to prepare for a whole-class discussion. Display slide Q. Direct students to look back at the explanations they wrote on *Rat Modeling Investigation* on day 1 as well as what they wrote in their notebooks about what they learned at the end of the last class in the Stop and Jot. Ask students to take a moment and complete the prompt on the slide on their own in their science notebooks or in their heads. *

* ATTENDING TO EQUITY

Universal Design for Learning: Sentence stems like this one can help learners engage in the process of reflection and self regulation. Give students time to consider how their thinking has changed over time to help them recognize their own progress.

12 · BUILDING UNDERSTANDINGS DISCUSSION FOR RAT POISON AS A SELECTION PRESSURE

20 min

MATERIALS: *Rat Modeling Investigation*, *Rat Genetic Variation*, science notebook

Facilitate a Building Understandings Discussion about rat poison as a selection pressure. Navigate into the sensemaking discussion by saying, *I think some of our thinking has changed since the beginning of the lesson. Let's take a moment to see how all of the patterns in the data we saw could explain how poison could act as a selection pressure, causing 80% of rats in Tokyo to develop resistance.* Display **slide R**. Gather the class in a Scientists Circle with *Rat Modeling Investigation* and *Rat Genetic Variation*. Facilitate a discussion of the data presented in *Rat Genetic Variation* and help students connect what they learned from the reading to the two prompts on the slide. Display **slide S** as needed to discuss the results from the reading. *

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Asking students to restate what another student has said helps students listen carefully to each other so that they can work with others' ideas. It will also make writing the revised explanation easier because more students will practice articulating what they know, and they will hear ideas phrased in multiple ways. This move can feel odd to students at first, so it will help if you let them know ahead of time that you will be asking this.

Suggested prompts	Sample student responses	Follow-up questions
<i>What did we learn about what caused resistance in rats from the reading?</i>	Rats all over Europe have different variations of the poison resistance gene. Different mutations have different amounts of VKOR protein activity (resistance) to warfarin compared to wildtype. Some mutations provide higher levels of resistance than others. Rats with certain variations can eat more poison than others without dying. Rats with the Y139F mutation have resistance to more than one type of poison. Two copies of the Y139F mutation provide more resistance to a rat than just one.	<i>How does this genetic evidence help us explain what happened to rat populations in Tokyo?</i>
<i>Is it possible to use poison to control rat populations?</i>	The poison selects for the more resistant rats. The most resistant ones survive and pass on their genes. This means it would be hard to use poison to get rid of some rats in urban areas because if you miss one rat, they could breed and come back. We are never going to design a poison to contain rats. As long as there are mutations out there, it will be a back-and-forth war with resistance.	<i>What do you predict would happen if we had data over many, many generations?</i> <i>How can a small change in an organism's body have a big effect on populations?</i>

KEY IDEAS

Purpose of this discussion: To establish the factors needed to explain how poison could act as a selection pressure, causing 80% of rats in Tokyo to develop resistance.

Listen for these ideas:

- There is variation in mutations in different rat populations.
- There is physiological variation in the expression of those mutations.
- Rats reproduce rapidly and shuffle their genes.
- Some alleles can stay “hidden” in individuals and be inherited by offspring, causing some offspring to be susceptible to poison.
- Natural selection leads to an increased proportion of rats with resistance in the population over generations.

Co-construct physiological adaptations. At an appropriate time in the consensus discussion, say, *What you all just described is what scientists call a physiological adaptation.* Display slide T. Ask students to share their ideas for what a definition of physiological adaptation would include. Once the class has come to consensus, ask students to add the definition to their personal glossaries.

ADDITIONAL GUIDANCE

A sample definition for *physiological adaptation* may look like this: *Something happening inside the body system of an organism that makes them well suited to survive and reproduce in a specific environment.*

13 · REVISE RAT POISON EXPLANATIONS USING NEW DATA

15 min

MATERIALS: *Rat Poison Explanation*, science notebook, *Rat Modeling Investigation*, *Rat Genetic Variation*



Use new data to revise explanations for rat poison as a selection pressure. Display slide U and distribute *Rat Poison Explanation* to students. Give students a moment to read over part 1 and ask clarifying questions. Point out how the sentence stems may help students write cause and effect statements that connect small-scale genetic changes to large changes in populations. Allow students to use their science notebooks as a resource as they complete the task. Tell students that you will be collecting this revised explanation as a formative assessment of not only the science ideas about how 80% of rats in Tokyo developed resistance to poison but also as a way to see how they have constructed and revised their explanations. Students will turn in *Rat Modeling Investigation* with *Rat Poison Explanation* so you can see how their explanations change and how they incorporated your feedback in their revisions.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: See *Rat Poison Explanation Key* for guidance.

What to do:

- Collect *Rat Poison Explanation* and *Rat Modeling Investigation* from each student.
- Use *Rat Poison Explanation Key* to evaluate and provide feedback.
- Encourage students to use the feedback they receive on this assessment to support the transfer task they will complete in Lesson 6.
- Provide an opportunity for students to revise their thinking and resubmit their responses either verbally or in writing.

Building toward 3.B.2 Construct and revise an explanation based on evidence from a variety of sources that suggests how individual genetic mutations cause physiological advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to differential reproduction and an increased number of rats in the entire population that carry adaptive genetic variations. (SEP: 6.2; DCI: LS4.B.1, LS4.C.1; CCC: 2.2)

Prompt students to self-reflect on their ability to construct and revise explanations. Display **slide V**. As students finish their explanations in *Rat Poison Explanation* encourage them to move on to Part 2. Provide five minutes to complete the self-reflection.

ADDITIONAL GUIDANCE

Ask students to refer back to their self-reflections when opportunities arise for constructing or revising explanations in the future to remind themselves of personal strengths and areas for improvement. Students will be using this same element of explanation on their transfer task, in Lesson 6.

14 · NAVIGATE

5 min

MATERIALS: None

Celebrate with students that the class figured out how rats in Tokyo developed resistance. Display **slide W** and direct students to turn and talk about the prompts. Bring the class together and summarize what they learned by saying something like, *You all figured out that physiological adaptations in urban rat populations can be the result of poison as a selection pressure. Let's take some time next class to revisit our consensus model.* *

* ATTENDING TO EQUITY

Building classroom culture: It is important to celebrate class progress along the way to explaining our anchoring phenomenon. Figuring ideas out through inquiry and discussion may be new or challenging for some students, and taking a moment to celebrate steps along the way can help them recognize the progress they are making.

Additional Lesson 3 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

WHST.9-12.9 Draw evidence from informational texts to support analysis, reflection, and research.

Students use evidence from slides and *Rat Genetic Variation* to support an explanation about poison resistance in rats.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively.

Students find patterns in various types of data and apply it to their explanations about poison resistance in rats.

LESSON 4: What causes populations of city juncos to be bolder than mountain juncos?

PREVIOUS LESSON We heard that 80% of rats in Tokyo are resistant to poison and decided to investigate. We investigated a model for how rats developed resistance and wrote a preliminary explanation. We gathered additional information from multiple studies about genetic variations in rats that affect their physiology and evaluated the impact of new data on our explanations. We revised and self-assessed our explanations for rat poison as a selection pressure that caused a change in the distribution of resistant traits.

THIS LESSON

INVESTIGATION

3 days



We decide to investigate juncos to see if bold behavior is an advantageous trait for living in the urban UCSD campus. We figure out that boldness is inherited and we develop initial models to explain how the UCSD juncos came to be bolder. We figure out that a hormone called CORT has a negative relationship with boldness and that there are still some unknown components and mechanisms that would explain this phenomenon. We engage in an electronic exit ticket to check our understanding.

NEXT LESSON We will put the pieces together to create a class consensus model for how urbanization causes change in nonhuman populations.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

- 4.A** Use evidence from a field test and common garden experiment to support an explanation about how boldness could cause juncos to have a competitive advantage affecting the number of bold juncos in the population. (SEP: 4.4; DCI: LS4.C.1; CCC: 2.1)
- 4.B** Develop a model based on evidence to explain how bold juncos could have been well suited to survive and reproduce in an urban environment resulting in a population with an increased proportion of bold birds. (SEP: 2.3; DCI: LS4.C.2; CCC: 2.1)
- 4.C** Compare and contrast graphs from a field test and common garden experiment to use as evidence to support a relationship between behavior and environment. (SEP: 4.4; DCI: LS4.C.2; CCC: 2.1)

WHAT STUDENTS WILL FIGURE OUT

- Boldness is a competitive advantage for obtaining food and nesting spaces. This leads to increased survival for birds that are more bold in urban environments.
- Juncos have inherited behavioral traits from their parents.
- Elevated corticosterone (CORT) levels correspond to stress levels in Juncos. This then affects how exploratory (bold) those birds are.
- Over time, juncos that are bolder are more likely to survive and reproduce in the UCSD environment resulting in a greater proportion of bolder juncos living in the city.

Lesson 4 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	7 min		NAVIGATE Ask students to recall what they figured out last lesson and what questions they still have.	A-E	class consensus model from Lesson 1, https://youtu.be/JslBVlo13qc
2	12 min		EXPLORE UCSD CAMPUS AND MOUNT LAGUNA Explore the UCSD campus and Mt. Laguna environments using Google maps.	F-G	computer with internet access, <i>Exploring Juncos' Environment</i>
3	7 min		DISCUSS WHETHER BOLDNESS IS LEARNED OR INHERITED Facilitate a discussion to generate ideas about how to determine whether boldness is inherited or learned.	H	
4	14 min		READ AND DISCUSS METHODS AND RESULTS OF THE COMMON GARDEN EXPERIMENT Share a reading that includes methods and data from a common garden experiment.	I-J	<i>Making Sense: Juncos, Common Garden Experiment</i>
5	5 min		NAVIGATE Give students time to complete an exit ticket.	K	<i>Making Sense: Juncos</i>
End of day 1					
6	5 min		NAVIGATE Review what we figured out in the last class and update personal glossaries with behavioral adaptation.	L-M	
7	10 min		DEVELOP INITIAL MODELS Facilitate individual model development, peer feedback and a brief whole class discussion.	N-P, B-E	class consensus model
8	10 min		INVESTIGATE THE MECHANISM OF BOLDNESS Share data related to stress hormones and facilitate a brief discussion.	Q	<i>Stress and Boldness</i>
9	10 min		MAKE SENSE OF CORT AND BOLDNESS Support students in using their own experiences to make sense of CORT and boldness.	R-T	<i>Stress and Boldness</i>
10	10 min		NAVIGATE Ask students to update their Progress Trackers.	U	<i>Progress Tracker</i>
End of day 2					
11	2 min		NAVIGATE Facilitate a brief discussion about what we figured out and what questions we still have.	V	

Part	Duration		Summary	Slide	Materials
12	13 min		EXPLORE THE CORT AND BOLDNESS RELATIONSHIP Facilitate a discussion between partners and the whole class to make sense of the correlation between CORT and boldness.	W-Y	computers with internet access
13	10 min		BUILDING UNDERSTANDINGS DISCUSSION Facilitate a Building Understandings Discussion about boldness, CORT and fitness in the UCSD junco population.	Z	
14	10 min		REVISE INITIAL MODELS Organize students into small groups to revise their initial models.	AA	
15	10 min		NAVIGATE: ELECTRONIC EXIT TICKET Provide each student with the link to the exit ticket and give them time to complete it.	BB	Internet connected device, copy of https://docs.google.com/forms/d/1TDbNpTnG8gptC8xOv28IDza5CGQxfdSp5cUXzpEnRZI/copy

End of day 3

Lesson 4 • Materials List

	per student	per group	per class
Lesson materials	• computer with internet access • <i>Exploring Juncos' Environment</i> • science notebook • <i>Making Sense: Juncos</i> • <i>Common Garden Experiment</i> • <i>Stress and Boldness</i> • science notebooks • <i>Progress Tracker</i> • Internet connected device • copy of https://docs.google.com/forms/d/1TDbNpTnG8gptC8xOv28IDza5CGQxfdSp5cUXzpEnRZI/copy	• computers with internet access	• class consensus model from Lesson 1 • https://youtu.be/jslBVlo13qc • class consensus model

Materials preparation (30 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Make sure you can open the CODAP file <https://www.openscienced.org/junco-data-excursion/> on student devices. Spend some time familiarizing yourself with the contents of the dataset and possible visualizations for completing the data excursion. In addition, familiarize yourself with relevant features of CODAP by watching <https://youtu.be/1Y18TcxbiAk>. For the exit ticket, make a copy of <https://docs.google.com/forms/d/1TDbNpTnG8gptC8xOv28IDza5CGQxfdSp5cUXzpEnRZI/copy> and make the link to your local copy of the form accessible to students. See *Exit Ticket Guidance* for additional guidance.

Lesson 4 • Where We Are Going and NOT Going

Where We Are Going

In this lesson, students continue building basic explanations for adaptation by natural selection, adding in ideas that behavioral variations exist in populations and different behavioral variations are advantageous for survival.

The evidence from this lesson builds towards the High School DCIs below, which were started in Lessons 2 and 3:

- HS LS4.C.1: 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 these organisms that are better able to survive and reproduce in that environment.
- HS LS4.C.2 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.C.2 will be more fully developed in Lessons 5 and 6.

Students use *analyzing and interpreting data* by first comparing data from a common garden experiment and a field test.

Students use elements of the crosscutting concept *cause and effect* as they first identify correlational evidence for juncos behavioral boldness as heritable.

Students co-construct a definition for fitness and encounter the definition for correlation coefficient. They add these to their personal glossaries.

Where We Are NOT Going

In this lesson, students figure out that boldness is inherited, but scientists have not yet determined which genes are responsible for these traits. Students should recognize that they cannot use tools, such as punnett squares to predict generational change like they did in Lesson 3.

Students co-construct a qualitative definition of fitness. They will add a quantitative component in Lesson 8.

LEARNING PLAN for LESSON 4

1 · NAVIGATE

7 min

MATERIALS: class consensus model from Lesson 1, <https://youtu.be/jslBVlo13qc>

Reflect on what we figured out about rats. Post the class consensus model from Lesson 1 where everyone can see it. Display **slide A**. Ask students what we figured out about how urbanization is a driving force of change from investigating rats. Listen for student responses that some rats in the populations had different alleles for a gene that made a protein that made them resistant to the poison. Say, *So far, we have investigated a case of anatomical adaptation in hawksbeard and a physiological adaptation in rats. Which other case study were we introduced to that we still need to investigate?* Listen for students to recall the juncos.

Reintroduce the different junco populations. Remind students that some of them investigated juncos in Lesson 1. Display **slide B** and call on a few students to share what they remember about the juncos while sharing new information about where they nest and what they eat. Review the data on **slide C** to remind students about the data from the case study in Lesson 1. Then, play <https://youtu.be/jslBVlo13qc> on **slide D**. Facilitate a class discussion about what we know about juncos using prompts similar to the ones below. If students need a reminder about the history of the two populations, display **slide E**.

Suggested prompts	Sample student responses	Follow-up questions
<i>What did scientists notice about the juncos in Mt. Laguna and UCSD?</i>	The UCSD juncos are bolder than the Mt. Laguna juncos.	<i>What relationship did they see between boldness and environment?</i>
<i>Based on what we figured about natural selection in hawksbeard and rats, what ideas do you have to explain why the UCSD population is bolder than the Mt. Laguna population?</i>	Being bolder might be better in the city. They might get more food and resources. Being bolder could make them more likely to survive and reproduce. Over time the bolder juncos survived better than the shy juncos at UCSD.	<i>What resources would the juncos need to survive and reproduce?</i> <i>How could being bold help them get more resources in the UCSD environment?</i> <i>In what ways would bold juncos be better at competing for resources at UCSD?</i>
<i>It seems like boldness and the environment are related. What information would we need to figure out if natural selection has caused differences in these populations?</i>	We need to know about the selection pressures. We need to know about the boldness trait and if/how it could be inherited.	<i>What were the traits that led to greater survival and reproduction in the hawksbeard and rat populations?</i> <i>What selection pressures did we see in those cases?</i> <i>What kinds of traits can be selected for by natural selection?</i>
<i>Are there other mechanisms for explaining behavior in populations that we need to consider? Explain.</i>	They could learn them from their parents. They could learn to be shy if there were a lot of predators around.	<i>How do animals come to have certain behaviors? Is inheritance the only explanation?</i>

Summarize the class discussion. Say, *You all have a lot of great ideas and we now know we need evidence about selection pressures and inheritance of behaviors to be able to explain why the UCSD juncos are bolder than the Mt. Laguna juncos.*

2 · EXPLORE UCSD CAMPUS AND MOUNT LAGUNA

12 min

MATERIALS: computer with internet access, *Exploring Juncos' Environment*

Explore the UCSD campus and Mt. Laguna. Say, *Let's start by exploring the two environments to see if we can get any ideas about selection pressures.* Display slide F. Distribute *Exploring Juncos' Environment* to every student. Introduce students to using Google maps and explain that they will work in pairs with one student exploring the UCSD campus, while the other explores Mt. Laguna. Students should follow the instructions on the slide and the handout as they look for evidence of selection pressures that could cause bold juncos to survive better in the urban environment. After students explore their assigned location, direct them to share and record their findings with their partner. *

ALTERNATE ACTIVITY If the class is limited on time, conduct the virtual explorations as a class, allowing students to complete *Exploring Juncos' Environment* as the teacher navigates to the locations. If students want to see how bold birds behave, replay <https://youtu.be/jsIBVlo13qc>.

Discuss connections between selection pressures and boldness at the UCSD campus. Display slide G. Facilitate a discussion of what students figured out from the exploration using the slide prompts.

Suggested prompt	Sample student response
What do you think the major difference is between Mt. Laguna and UCSD?	Mt. Laguna is a mountain area with lots of trees, open areas, rocks, few people, and not much human development. UCSD has a lot of streets with cars, buildings and people walking around everywhere.
What kinds of selection pressures could exist in the urban UCSD environment?	Humans could scare the juncos and determine where they build nests and get food.
How could boldness make it more likely for juncos to survive and reproduce at UCSD?	Humans alter the environment so there are not as many places to build nests. Juncos that were bold would be better at getting these nesting sites than juncos that were not bold. There might not be as many seeds and bugs so juncos would rely on human food crumbs or bird feeders. Bold juncos would get more food than shy juncos.

*** ATTENDING TO EQUITY**

Universal Design for Learning
Allowing students to choose specifically where they explore within these two different environments provides and supports student ownership of their learning. Students are able to *engage* in the activity using their own interest and ideas by giving them choice, access, and control in this investigation.

3 · DISCUSS WHETHER BOLDNESS IS LEARNED OR INHERITED

7 min

MATERIALS: science notebook

Facilitate a discussion about how to figure out if boldness is learned or inherited. Summarize student ideas by saying, *We have great ideas about selection pressures that could cause boldness to help juncos survive and reproduce in the urban UCSD environment. I heard you say that humans/proximity to humans/human interactions is the likely selection pressure here. You also had some questions about how a behavior like boldness could be inherited. Let's investigate that next.* Display **slide H**. Remind students that some of them investigated this data in Lesson 1. Use the prompts below as a guide:

Suggested prompt	Sample student response
<i>What does this data tell us?</i>	UCSD juncos are bolder, Mt. Laguna juncos are less bold.
<i>What did the scientists do to measure this?</i>	They measured how close the birds let the humans get before they flew away in the wild in both Mt. Laguna and UCSD.
<i>Other than inheritance, what could explain why the juncos were bolder on the UCSD campus?</i>	They could have learned to be bolder from their parents. They could have learned to be scared or not scared by predators (or something else) in their environment.
<i>How can we determine whether natural selection caused the difference we see?</i>	We need more data. We could do some kind of experiment with the juncos in the lab.

4 · READ AND DISCUSS METHODS AND RESULTS OF THE COMMON GARDEN EXPERIMENT

14 min

MATERIALS: *Making Sense: Juncos, Common Garden Experiment*

Read and analyze methods and results from a common garden experiment. Say, *we have some great ideas about how to figure out if boldness is inherited or learned. Since we cannot do this investigation ourselves, I have an example here of a common garden experiment done by researchers who studied the UCSD and Mt. Laguna birds.* Remind students of the common garden experiment we looked at with hawksbeard where scientists grew seeds in the greenhouse and set up plots to study what would happen in a controlled environment. Let them know that scientists conducted similar experiments with juncos. Display **slide I** and distribute a copy of *Common Garden Experiment* to every student. Provide time for them to read, individually.

* ATTENDING TO EQUITY

Students who read below grade level may choose to answer fewer questions by selecting one or two of the variables in question one. The Google version of the reading is accessible to screen-reading technology and online translator services.

* SUPPORTING STUDENTS IN ENGAGING IN PLANNING AND CARRYING OUT INVESTIGATIONS

When investigating the common garden experiment, support students in recognizing that the variables scientists controlled were

Small group sense making. Distribute a copy of *Making Sense: Juncos* to each student. Organize students into small groups to discuss and record answers to the Making Sense questions. *

Discuss the making sense questions as a class. After students finish reading and answering questions, bring the class together and facilitate the following discussion. Use the following prompts, also found on [slide J](#).

confounding variables. Controlling these variables, that could affect junco behavior, helped scientists figure isolate boldness as an inherited behavior.

Suggested prompts	Sample student responses	Follow-up questions
<i>Why did the scientists bring the Mt. Laguna and UCSD juncos to the aviary?</i>	If all the juncos had the same conditions, what they learned would be the same and the differences in boldness would be inherited.	<i>How is studying the juncos in the aviary different from studying them in the wild?</i>
<i>How does this data provide evidence that can help us explain whether boldness is inherited or learned?</i>	They found that in the aviary, the juncos that were from the UCSD population were bolder than those from Mt. Laguna. Since they were not near their parents and had all the same variables, the boldness must be inherited.	<i>What happened when they let the juncos from UCSD and Mt. Laguna explore a new aviary?</i>
<i>How did these findings compare with the findings from the studies of juncos in the wild?</i>	They also found that the juncos from UCSD were bolder. They used a different measure, flight initiation distance vs. exploratory behavior, but they both were measuring boldness.	<i>Did the evidence support our ideas about natural selection?</i>
<i>Explain how boldness could be an adaptation in the urban environment. Why would the bold juncos survive and reproduce better?</i>	The bold juncos would be better at getting food and nests than the shy juncos. If they got more of those things, they could survive better and have more offspring.	<i>What traits would allow juncos to better compete for resources in the urban environment?</i>
<i>What is missing from our explanation?</i>	We need to know how the juncos can inherit boldness.	<i>We think that boldness is inherited, but what do we know/need to know about how that works?</i>

5 • NAVIGATE

5 min

MATERIALS: *Making Sense: Juncos*



Revise responses in handout. Display slide K. Say, *We figured out a lot today! Take a few minutes to revise your responses on Making Sense: Juncos before handing them in.*

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

- The common garden experiment controlled variables to help isolate the inheritance as the cause of boldness in juncos. (SEP: 4.4; CCC: 2.1)
- Data from both sources show that UCSD juncos are bolder than Mt. Laguna juncos. (SEP: 4.4)
- Bolder juncos would be better able to compete for resources at UCSD and therefore, survive and reproduce more. (DCI: LS4.C.1)
- Additional evidence about the mechanism of inheritance is needed to fully explain natural selection. (DCI: LS4.C.1; CCC: 2.1)

What to do: Collect *Making Sense: Juncos* from each student. Provide written feedback to prompt their thinking about cause and effect and what additional information we need to explain how boldness could be inherited and acted on by natural selection.

Building toward 4.A Use evidence from a field test and common garden experiment to support an explanation about how boldness could cause juncos to have a competitive advantage affecting the number of bold juncos in the population. (SEP: 4.4; DCI: LS4.C.1; CCC: 2.1)

End of day 1

6 • NAVIGATE

5 min

MATERIALS: science notebook

Review what the class figured out on day 1 and what questions we still need to answer. Display slide L. Ask a student to summarize what they learned so far. Listen for the following:

- In the field and common garden experiments, UCSD juncos were bolder than Mt. Laguna juncos.
- The common garden experiment provides evidence that juncos' bold behavior is inherited.
- Bold juncos would be better able to compete for food and nesting sites at UCSD compared to shy juncos.

Add behavioral adaptation to personal glossaries. Display slide M. Say, *What I hear you saying is that boldness in an adaptation like the seed type in hawksbeard and resistance to poison in rats. Scientists call this a behavioral adaptation.* Pause and give students time to come to consensus on a definition and add it to their personal glossaries.

ADDITIONAL GUIDANCE

Provide students with time to work together to construct a definition of behavioral adaptation. Student entries may look similar to: a behavior (like boldness) that makes it more likely that organisms will survive and reproduce in their environment.

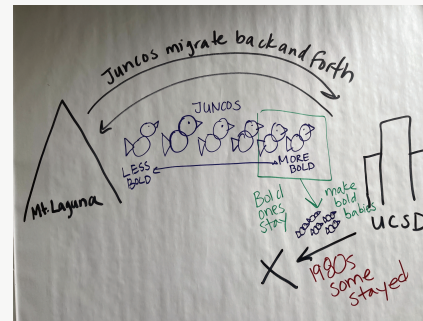
7 · DEVELOP INITIAL MODELS

10 min

MATERIALS: science notebook, class consensus model

Develop initial models individually. Display slide N. Say, *It sounds like we are ready to start to make sense of all these ideas!* Ask students to develop an initial model in their science notebook to explain how the UCSD junco population got to be bolder than the Mt. Laguna population. Before students develop models, refer to the class consensus model and the information on slides B-E.

 **Review initial models in pairs.** Display slide O and share the peer feedback prompts with students. Organize students into pairs to discuss their initial models, provide feedback and revise their models. See the sample student initial model below.



ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: models that propose an initial explanation including: (SEP: 2.3)

- Variation in boldness in the junco population. (DCI: LS4.C.2)
- Inheritance of boldness in juncos. (DCI: LS4.C.2)
- Differences in the traits in the two populations, bolder individuals staying at UCSD year round. (DCI: LS4.C.2)
- Factors that caused them to stay, such as not being afraid, being able to get food, and make nests. (DCI: LS4.C.2; CCC: 2.1)

What to do: Provide feedback to pairs as you circulate around the room using the following prompts:

- Are all the juncos the same? How are they different?
- What caused the juncos to stay?
- What happened when they stayed?
- How do we know if environment and boldness are correlated or whether environment caused the differences in boldness?
- We know boldness is inherited but how does that work?

Building toward 4.B.1 Develop a model based on evidence to explain how bold juncos could have been well suited to survive and reproduce in an urban environment resulting in a population with an increased proportion of bold birds. (SEP: 2.3; DCI: LS4.C.2; CCC: 2.1)

Share with the whole class. Display slide P. Call on several pairs to share what their model can explain and which pieces are still missing. Listen for students to identify that the smaller scale mechanism of what causes boldness has not yet been explained.

8 · INVESTIGATE THE MECHANISM OF BOLDNESS

10 min

MATERIALS: science notebook, *Stress and Boldness*

Investigate the mechanism of boldness. Say, *Your models explain a lot about how the UCSD junco population came to be bolder than the Mt. Laguna junco population. It sounds like you have some questions about what the mechanism of boldness is inside the juncos. Display slide Q.* Explain to students that scientists had this question too. They had an idea based on previous studies about a hormone related to stress in other animals. They thought this hormone called corticosterone (CORT) might be related to boldness.

Small groups discuss CORT data. Distribute *Stress and Boldness* and organize students into small groups of 3-4. * Ask students to review the data in the graphs and answer the questions on the slide. Call on a few groups to share their answers using the prompts below as a guide.

Suggested prompt	Sample student response
What happened to CORT levels after capture?	CORT levels rose for all of the groups of birds.
What differences are there between the Mt. Laguna and UCSD populations?	Mt. Laguna always had higher CORT levels than UCSD.
How does this data compare to the data measuring boldness?	In the boldness data, the UCSD had higher levels of boldness and lower levels of CORT.
How are CORT levels with boldness?	There is a negative relationship. Where CORT is higher, there is less boldness: where CORT is lower, there is more boldness.

* ATTENDING TO EQUITY

Supporting Emergent Multilinguals: Before students engage in whole class discussions, it can be helpful to first provide them with the opportunity to work with others - either in pairs, triads, or small groups - on ideas related to their reasoning. These smaller group structures can be especially helpful for emerging multilingual students because they offer students a chance to engage in sensemaking with their peers and also offer them the space to use their linguistic and nonlinguistic resources to express their ideas and learn from other students' uses of these resources too.

9 · MAKE SENSE OF CORT AND BOLDNESS

10 min

MATERIALS: science notebooks, *Stress and Boldness*

Stop and jot. Say, *We have some new information to make sense of. Let's draw on our own life experiences to see if we can make sense of the relationship between boldness and CORT. Display slide R.* Ask students to stop and jot in their science notebooks about how stress affects them and how it can help us understand junco boldness.

Remind students that boldness was measured by flight initiation distance and exploratory behavior. Ask students to turn and talk to a partner and share their ideas and to discuss the relationship between boldness and CORT. Display slide S and check that students understand the relationship between CORT and boldness.

Co-construct a definition for fitness. Display slide T. If students have not brought up the idea of survival of the fittest. Say, *When people are discussing organisms that survive better and reproduce within a population they sometimes say survival of the fittest. What do they mean by this? What is fitness?*

ADDITIONAL GUIDANCE

During the discussion, the common evolutionary phrase *survival of the fittest* will likely come up. Students' will have explained how boldness leads to better survival and reproduction. When this happens, stop to name this as what scientists call *fitness*. Be sure to help students distinguish between the everyday use of the term and the way we use it in the context of natural selection. Definitions may be similar to: *a measure of how good an organism is at surviving and leaving offspring*.

10 · NAVIGATE

10 min

MATERIALS: science notebook, *Progress Tracker*

Update progress tracker. Display slide U. Say, *We figured out a lot of ideas about how some behaviors can be inherited and can give individuals a competitive advantage to survive better than those without that behavioral trait. Let's record what we figured out in our Progress Trackers. Let students know that in the next class they will use what they recorded here to help them revise their initial models. Give students a few minutes to write and draw what they learned.*

Lesson Number	Lesson Question	What I Figured Out in Words, Pictures and/or Symbols	Questions I Have
4	What causes populations of city juncos to be bolder than mountain juncos?	-Boldness is a competitive advantage for obtaining food and nesting spaces. This leads to increased survival for birds that are more bold in city environments. -Juncos have inherited behavioral traits from their parents. -Elevated corticosterone (CORT) levels correspond to stress levels in Juncos. This negatively affects how bold those birds are. -Overtime, juncos that are more bold survive and reproduce causing a greater proportion of juncos living in the city to be more bold.	-How is CORT inherited? -How did they stay at UCSD in the first place? -What will happen in the future?

End of day 2

11 · NAVIGATE

2 min

MATERIALS: science notebook

Review what we figured out in the last class. Display **slide V**. Say, *What were your main takeaways from the data you investigated in our last class?* Listen for students to indicate the connection between CORT and boldness.

Surface remaining questions about the relationship between CORT and boldness. Say, *What questions do you still have?* At this point, students are likely to have a number of questions about the relationship between the two variables and what it means for the juncos.

12 · EXPLORE THE CORT AND BOLDNESS RELATIONSHIP

13 min

MATERIALS: computers with internet access

Turn and Talk about cause in the CORT and boldness relationship. Say, *At this point, we have an understanding that boldness might give juncos a competitive advantage at UCSD and we know that CORT levels are lower for juncos that are bolder.* Display **slide W**. Ask students to turn and talk about the relationship they see between boldness (measured as exploratory behavior) and CORT. Call on a few pairs to share their thinking. There may be confusion about whether or not there is a negative relationship or no relationship.

Display **slide X**. Ask students to turn and talk about how the best fit line helps them think about the relationship. Call on a few pairs. Listen for students to recognize the negative relationship but also notice that there is a lot of variability in the data.

Display **slide Y**. Explain to students that we can use a statistic called correlation coefficient * to give us a quantitative way to understand the strength relationship between the two variables. Pause to give students time to add correlation coefficient to their personal glossary as a word we encounter. Review the data on the slide and give students time to turn and talk, and discuss the strength of the relationship. Call on a few pairs to share their thinking. Listen for students to recognize that because .53 is right in the middle, it isn't really strong or really weak, it is a medium strength negative relationship. Explain to students that although we know boldness is inherited and that CORT is correlated to boldness, scientists do not know exactly how the boldness is inherited and how genes control CORT. *

ADDITIONAL GUIDANCE

To figure out the correlation coefficient in CODAP, click on the ruler icon on the top right of the graph. Then, click the box for *Least Squares Line*. CODAP will add a line with and r^2 value in a yellow box. To calculate the r value (correlation coefficient) take the square root of r^2 .

* ATTENDING TO EQUITY

Motivated students ready to further develop the practice *analyzing and interpreting data* can complete the data excursion on their own using <https://www.openscienced.org/junco-data-excursion/> and *Junco Data Excursion* where they will use r^2 as evidence for how much of the variability in boldness CORT can explain.

* SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

Students are using statistics, including correlation coefficient, to make sense of their data. This is likely a new use of this practice for students. Support them in understanding that statistics can be a useful way to quantify our evidence.

13 · BUILDING UNDERSTANDINGS DISCUSSION

10 min

MATERIALS: science notebook

Facilitate a Building Understanding Discussion. Say, *We have made a lot of progress in figuring out how the UCSD junco population came to be bolder than the Mt. Laguna juncos. Before we revise our initial models, Let's make sure we are all together in our understanding.* Display **slide Z** and use the prompts below as a guide. *

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

A Building Understandings discussion is a useful kind of discussion to focus students on drawing conclusions based on evidence. Your role during the discussion is to invite students to share conclusions and claims

Suggested prompt	Sample student response
<i>We saw that UCSD and Mt. Laguna had some differences and identified some potential selection pressures, what were they?</i>	Humans and being close to them. Human made structures and cars and noise.
<i>Scientists noted differences in boldness between the two populations, what did they find?</i>	The UCSD population was bolder than Mt. Laguna.
<i>They did studies to figure out if this boldness behavior was inherited, what did they figure out?</i>	When young birds were raised away from their parents, the UCSD juncos were still bolder so it must be inherited.
<i>Scientists investigated the hormone CORT, what did they learn about that?</i>	When juncos are handled by humans they make a stress hormone called CORT. The UCSD juncos always made less CORT than Mt. Laguna juncos.
<i>You investigated the scientists' data related to CORT and boldness, what did you find?</i>	There is a negative relationship between CORT and boldness. More CORT=less bold, less CORT=bolder.
<i>We found that there was a medium strength negative correlation between CORT and boldness. This tells us that CORT is part of the mechanism, but what other pieces are missing that scientists have still not figured out?</i>	They do not know what gene(s) are involved in the inheriting and expressing the boldness trait.

and push them to support them with evidence. Students can disagree with each other and the class does not need to reach consensus on all ideas shared. Areas of disagreement can motivate future investigations. Helpful prompts during these kind of discussions include:

- What can we conclude?
- How did you arrive at that conclusion?
- What is your evidence?

KEY IDEAS

Purpose of this discussion: To build a full understanding of what we know about the mechanism of boldness in juncos and how it could be related to fitness.

Listen for these ideas:

- Boldness is inherited.
- The UCSD juncos are bolder.
- CORT is related to boldness, the more CORT the more scared.
- UCSD juncos have less CORT.
- The relationship between CORT and boldness is medium strength and there are still unknown components in the inheritance mechanism.

14 · REVISE INITIAL MODELS

10 min

MATERIALS: None

Small groups revise initial models. Say, *Wow! We have made a lot of progress here. Let's revisit our initial models and see how we can revise them.* Display slide AA and organize students into small groups. They should discuss together and each revise their initial model individually.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: models that propose an initial explanation including: (SEP: 2.3)

- Variation in boldness in the junco population. (DCI: LS4.C.2)
- Inheritance of boldness in juncos. (DCI: LS4.C.2)
- Differences in the traits in the two populations, bolder individuals staying at UCSD year round. (DCI: LS4.C.2)
- Factors that caused them to stay, such as not being afraid, being able to get food, and make nests. (DCI: LS4.C.2; CCC: 2.1)

What to do: Provide feedback to pairs as you circulate around the room using the following prompts:

- Are all the juncos the same? How are they different?
- What caused the juncos to stay? What happened when they stayed?
- We know boldness is inherited but how does that work?

Building toward 4.B.2 Develop a model based on evidence to explain how bold juncos could have been well suited to survive and reproduce in an urban environment resulting in a population with an increased proportion of bold birds. (SEP: 2.3; DCI: LS4.C.2; CCC: 2.1)

15 · NAVIGATE: ELECTRONIC EXIT TICKET

10 min

MATERIALS: Internet connected device, copy of <https://docs.google.com/forms/d/1TDbNpTnG8gptC8xOv28IDza5CGQxfdSp5cUXzpEnRZl/copy>



Electronic exit ticket. Display slide BB. Say, *Wow, we have figured out a lot about how different inherited traits can give organisms a competitive advantage in urban environments. Let's pause to do a formative assessment to make sure we are all on the same page.* Make sure each student has an internet connected device with access to the copy you made of the Electronic Exit Ticket, <https://docs.google.com/forms/d/1TDbNpTnG8gptC8xOv28IDza5CGQxfdSp5cUXzpEnRZl/copy>.

ASSESSMENT OPPORTUNITY

What to look for/listen for:

- See *Electronic Exit Ticket Key* for guidance on student responses.

What to do: See *Exit Ticket Guidance* for instructions on how to make the electronic exit ticket. See *Electronic Exit Ticket Key* for guidance on student responses.

Building toward 4.C Compare and contrast graphs from a field test and common garden experiment to use as evidence to support a relationship between behavior and environment. (SEP: 4.4; DCI: LS4.C.2; CCC: 2.1)

Additional Lesson 4 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

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

Students read about a common garden experiment and provide a description of the process.

**SUPPORTING
STUDENTS IN
MAKING
CONNECTIONS IN
MATH**

CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively.

Students interpret histograms, line plots, and scatter plots to develop an explanation. They make sense of a scatter plot of CORT levels and exploratory behavior, a line of best fit, and describe the relationship between the variables.

LESSON 5: How can we make sense of the way urbanization could have caused changes in hawksbeard, rat, and junco populations?

PREVIOUS LESSON *We decided to investigate juncos to see if bold behavior is an advantageous trait for living in the urban UCSD campus. We figured out that boldness is inherited and we developed initial models to explain how the UCSD juncos came to be bolder. We figured out that a hormone called CORT has a negative relationship with boldness and that there are still some unknown components and mechanisms that would explain this phenomenon. We engaged in an electronic exit ticket to check our understanding.*

THIS LESSON

PUTTING PIECES TOGETHER

2 days



Clémence Delmas, CC BY 3.0

We synthesize our knowledge of how urbanization causes change in nonhuman populations to create a class consensus model. We compare our explanatory model to Lamarck's and Darwin's theories of evolution and recognize that our model supports evolution by natural selection. We decide to apply our model to an unknown scenario.

NEXT LESSON *We will apply what we figure out to a new context and will complete a transfer task about bacteria that develops resistance to antibiotics.*

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

5.A Develop and revise a model to explain how urban environmental factors could cause the evolution of populations by natural selection. (SEP: 2.3; DCI: LS4.C.1, LS4.C.2; CCC: 2.2)

WHAT STUDENTS WILL FIGURE OUT

- All populations have heritable variations between individuals.
- There are selection pressures in urban areas.
- Not all individuals in populations survive to reproduce. Those with variations that are better adapted to the environment survive to reproduce more than those that are not well adapted.
- Offspring inherit favorable traits.
- Over many generations, the proportion of favorable traits in a population increases, and the proportion of less favorable traits decreases.
- Our consensus model is similar to Darwin's theory of evolution by natural selection.

Lesson 5 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		REVISIT WHAT WE LEARNED Guide students to review what they learned during Lesson Set 1 and to develop a consensus model.	A-B	<i>Progress Tracker</i> , junco model from Lesson 4
2	10 min		CREATE A GOTTA-HAVE-IT CHECKLIST Facilitate building a Gotta-Have-It Checklist in preparation for building models.	C	chart paper, chart paper markers
3	13 min		DEVELOP GROUP MODELS Support student groups as they develop explanatory models that generalize all three case studies.	D-E	3x3 sticky notes, chart paper, chart paper markers
4	7 min		TWO STAY, OTHERS STRAY GALLERY WALK Facilitate a gallery walk to compare group models.	F	group models
5	5 min		REVISE GROUP MODELS Support model revision based on what students learned from sharing their ideas with other groups.	G	group models
6	5 min		NAVIGATE Facilitate sharing components and ideas students appreciated and borrowed from other models.	H	group models
<i>End of day 1</i>					
7	5 min		NAVIGATE Facilitate a review of what students learned in the previous class.	I	group models
8	15 min		CONSENSUS DISCUSSION Facilitate the creation of a class consensus model.	J-K	chart paper, chart paper markers, group models, 6x8 sticky notes
9	13 min		COMPARE CLASS MODEL TO OTHER EXPLANATIONS Students read about Darwin's and Lamarck's theories of evolution and compare them to the class consensus model. They name their model <i>Evolution by Natural Selection</i> .	L-R	<i>Population Change Theories</i> , class consensus model
10	9 min		REVISIT DRIVING QUESTION BOARD Facilitate acknowledgement of the questions students have answered from the DQB.	S	Driving Question Board
11	3 min		NAVIGATE Motivate applying the consensus model to a novel phenomenon.	T	
<i>End of day 2</i>					

Lesson 5 • Materials List

	per student	per group	per class
Lesson materials	• science notebook • <i>Progress Tracker</i> • junco model from Lesson 4 • <i>Population Change Theories</i>	• 3x3 sticky notes • chart paper • chart paper markers • group models	• chart paper • chart paper markers • group models • 6x8 sticky notes • class consensus model • Driving Question Board

Materials preparation (5 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Make sure chart paper and chart markers, or an alternative way to capture the group and consensus models, are available.

Lesson 5 • Where We Are Going and NOT Going

Where We Are Going

The lesson supports students in synthesizing concepts learned in Lessons 2–4 to develop a generalized model that encompasses selection pressures that act on anatomical, physiological, and behavioral traits in nonhuman populations, including high school disciplinary core ideas:

HS LS4.C.1: 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.

HS LS4.C.2 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.

Students use elements of the science practices of *Developing and Using Models* to create and revise their model of evolution by natural selection using the case studies from Lessons 2–4.

Students use elements of the crosscutting concept *Cause and Effect* to describe how various selection pressures in urban areas act on heritable traits in nonhuman populations to cause evolution.

Students co-construct the definition for evolution and revise their definition of natural selection from Lesson 2.

Where We Are NOT Going

Students will briefly read about Darwin's theory of evolution by natural selection but will not learn about the evidence Darwin used to develop his theory.

LEARNING PLAN for LESSON 5

1 · REVISIT WHAT WE LEARNED

5 min

MATERIALS: science notebook, *Progress Tracker*, junco model from Lesson 4

Review progress on our Unit Question. Display **slide A**. Say, *Wow! We have figured out a lot of big science ideas over the past few lessons. Let's try to remember everything we did and learned.* Provide time for students to turn and talk to review their science notebooks, junco models, and Progress Trackers.

Motivate the creation of an updated class consensus model. Display **slide B**. Say, *We gathered a great deal of information about how urbanization is a driving force for change in nonhuman populations. What are some of the ways that we make sense of a lot of ideas and bring them together to answer our driving questions? How do we make connections between ideas that we have?* Pause to give students an opportunity to share their ideas about what practices they might engage in.

Listen for ideas such as:

- We use pictures and/or words to explain concepts.
- We create models to show relationships between components and ideas.
- We communicate our ideas with others.

Display the class consensus model from Lesson 1. Say, *Great ideas! Let's take what we have learned and make a revised class consensus model to explain how urbanization is a driving force for change in nonhuman populations.*

2 · CREATE A GOTTA-HAVE-IT CHECKLIST

10 min

MATERIALS: science notebook, chart paper, chart paper markers

Develop a Gotta-Have-It Checklist. Ask students how we should go about creating a class consensus model. Listen for students to suggest creating a Gotta-Have-It Checklist. If they do not mention this, ask how we know what needs to go into our model and how we have tracked that in our past units. Display **slide C**. Give students a minute to stop and jot ideas in their science notebooks. Then facilitate the creation of a list of components and interactions to include in the model. Ask one student to give one response and then use a “popcorn” strategy, asking that student to call on another student to provide another idea. Include as many voices as possible in creating the list.

Introduce ways to generalize the Gotta-Have-It Checklist. Once the list is complete, ask the students to consider which ideas might be grouped into larger categories. Discuss one example all together, such as juncos, rats, and hawksbeard can all be grouped together as nonhuman populations; or fragmentation, poison, and fear of humans can be grouped as selection pressures. Encourage them to start thinking about additional groupings that generalize their ideas to bring to their small-group discussion. They should also start thinking about the mechanisms that cause the interactions to occur.*

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

This lesson asks students to bring together a number of science practices, science ideas, and crosscutting concepts they have been working on in smaller pieces in previous lessons. The model they develop in groups and revise as a class (SEP) on day 1 builds a more complete explanation of evolution by natural selection (DCI) even before those precise terms are applied on day 2. In order to build that model (SEP), they must describe how the selection pressures (DCI) in the larger urban system interact (CCC) with phenotypic expression of genetic variation in individuals (DCI). These interactions cause change (CCC) in populations over multiple generations (DCI).

Suggested prompt	Sample student response
<i>What components do we want in our model?</i>	Selection pressures Fragmentation Poison Limited food and nesting space Variation Genetic variations Mutations Difference in genetic expression Nonhuman populations Juncos Rats Hawksbeard People

Suggested prompt	Sample student response
<i>What interactions do we want in our model?</i>	Sexual reproduction (fitness) Mixing genes Interactions between nonhuman populations and environment Hawksbeard seeds and soil Juncos and nesting sites Rats and food Interactions between nonhuman populations and selection pressures Rats and poison Hawksbeard and soil plots Juncos and people Death Time

3 · DEVELOP GROUP MODELS

13 min

MATERIALS: 3x3 sticky notes, chart paper, chart paper markers

Take stock of our Community Agreements. Say, *In a minute or so, I am going to send you into groups to put these ideas from our Gotta-Have-It Checklist together to make a model. This is a good place to stop and remind ourselves of all of our Community Agreements.* Display **slide D** and discuss the question on the slide. Focus on ideas to work equitably in teams to move our science thinking forward. *



Develop group models. Display **slide E**. Divide students into groups of 4-5. Provide each group with sticky notes, chart paper, and markers. Suggest that they begin by writing the components from the Gotta-Have-It Checklist on the sticky notes. They can then arrange the components on chart paper and connect them by adding interactions. *

* ATTENDING TO EQUITY

Building classroom culture: This is an important opportunity to emphasize that each individual has contributions to make to their community of learners. It is through differences in thinking that the class will move their science knowledge forward together. Remind students that when building complex models such as this, they should be open to learning from classmates, as everyone will bring unique, valuable components to the development of a clear model. Considering diverse ways of describing mechanisms will lead to a deeper understanding of the phenomenon being explained.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: As students work in teams to create a model look/listen for **creation of a model that explains (SEP 2.3):**

- All **populations have genetic variations between individuals.** (DCI: LS4.C.1)
- **Variation comes from mutations and sexual reproduction.** (DCI: LS4.C.1)
- **Heritable variations can be anatomical, physiological, or behavioral.**(DCI: LS4.C.2)
- There are **selection pressures** in urban areas that **cause some individuals to survive better than others.** (DCI: LS4.C.1, CCC: 2.2)
- **Not all individuals in populations survive to reproduce. Those with variations that are better adapted to the environment survive to reproduce more than those that are not well adapted.** (DCI: LS4.C.1, LS4.C.2; CCC: 2.2)
- **Offspring inherit favorable traits.** (DCI: LS4.C.1)
- **Over many generations, the proportion of favorable traits in a population increases, and the proportion of less favorable traits decreases.** (DCI: LS4.C.1, LS4.C.2)

What to do:

- Say, *That is really good at explaining [specific example]. How could we make that apply to any scenario or all populations? Did we see something similar to that in [juncos/rats/hawksbeard]?*
- Ask if there is an order in which the items should occur if time/generations are involved.
- Ask what mechanism causes the interaction to occur.
- Prompt students to think about the scale of the evidence they investigated in each example (anatomy in hawksbeard, genetics/physiology in rats and behavior in juncos).
- Ask if their model would work for the hawksbeard, rat, and junco.
- After the gallery walk, ask, *What is something you saw in someone else's model that you really liked, that you wish you would've added to your own model if you had time to revise?*

Building toward 5.A.1 Develop and revise a model to explain how urban **environmental factors cause the evolution of populations by natural selection.** (SEP: 2.3; DCI: LS4.C.1, LS4.C.2; CCC: 2.2)

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Students are bringing together observations and data collected at multiple scales (genetic, physiological, ecological) to piece together a complete explanation of the causes of evolution by natural selection. Although the evidence they collected is across three case studies they can extrapolate patterns that occur in all populations at each scale. Student understanding of genetic mechanisms from *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)* will help them recreate these patterns connecting genetic differences to changes in physiology, anatomy or behavior across populations.

4 • TWO STAY, OTHERS STRAY GALLERY WALK

7 min

MATERIALS: science notebook, group models

Facilitate a gallery walk. Say, *I like all of the different ideas I see about how to model the impact of urbanization on nonhuman populations. All of the groups approached the task a little differently. Let's take some time to compare the group models.* Display **slide F**. To help students find the items they may be missing or struggling to add to their models, they will now have a chance to see how other groups have been working through this process. Each group should choose two individuals to talk visitors through their model. The other members of each group will split up to listen to explanations from other groups. Encourage students who stray to ask clarifying questions after they observe the explanation from another group. Students who stray should take notes about similarities and differences and bring back ideas to their group for revision. Provide time for each student who strays to observe one or two other models.

5 · REVISE GROUP MODELS

5 min

MATERIALS: science notebook, group models

Revise group models. Display **slide G**. Students who strayed should return to their model groups to share what they learned and help their groups revise their models.

6 · NAVIGATE

5 min

MATERIALS: group models

Facilitate a shout-out to other model groups. Display **slide H**. Say, *It looks like you got some good ideas for revising your models from the gallery walk.* Ask a few students to share what they learned from other models that was useful in revising their own. This may include components, interactions, or mechanisms they may have missed or ways to describe their understanding. Encourage comments that point out strengths from a variety of group models. After students share, say, *Thank you for sharing the strengths you saw in other models. It would be great to try to put all of these ideas together into one class consensus model. Let's do that in the next class.*

End of day 1

7 · NAVIGATE

5 min

MATERIALS: group models

Review what students learned in the last class. Post the group models on the wall where all students can view them. Display **slide I**. Call on one or two students to answer the prompts. Provide a minute or two for students to quietly look at the group models to remember what they made.

8 · CONSENSUS DISCUSSION

15 min

MATERIALS: science notebook, chart paper, chart paper markers, group models, 6x8 sticky notes

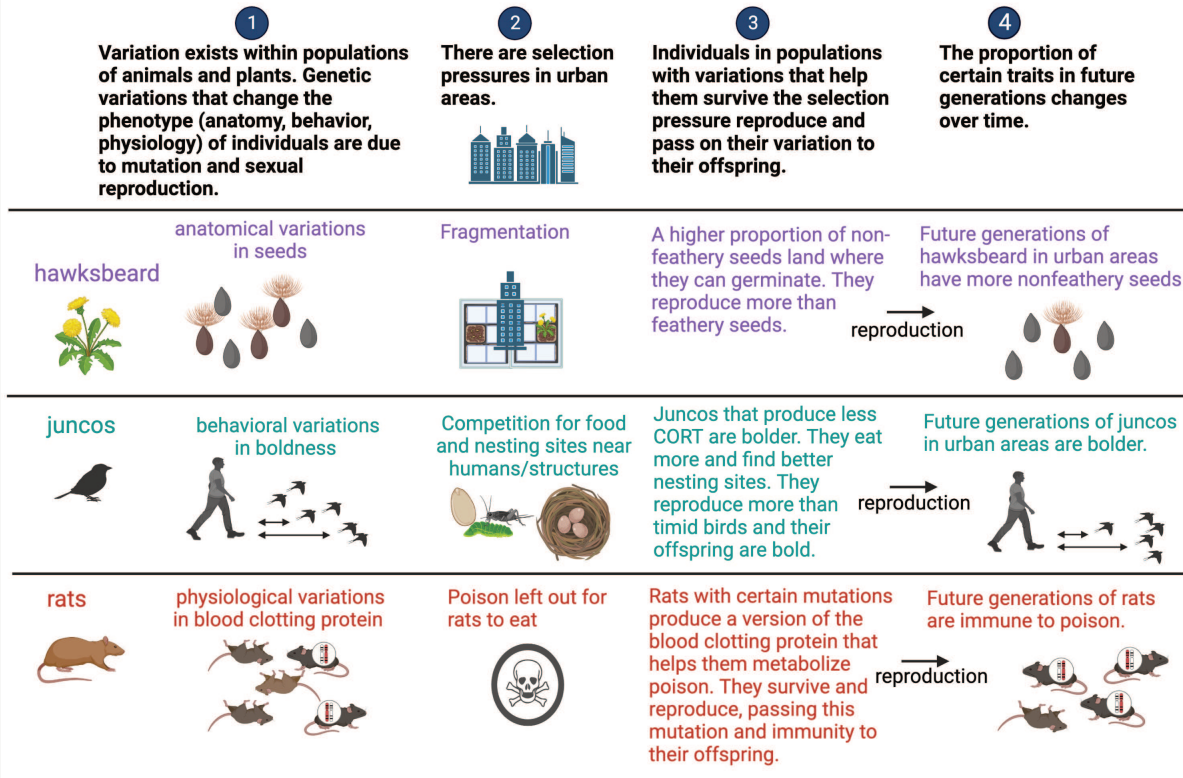


Develop a class consensus model. Display **slide J**. Ask students to gather in a Scientists Circle. Have students bring their science notebooks and make sure the group models are visible nearby. Begin by talking through the similarities and differences they saw in the models. Write ideas where there is agreement on large sticky notes and put them on the chart paper. Use the differences they raise to challenge students to combine ideas about one case study into larger themes and mechanisms. As useful, review the strengths they mentioned in shout-outs in the last class to create a clear way to organize the model. Build a generalized model similar to the 4 steps shown in the top row of the example below. The rows in the example highlighting hawksbeard, rat, and junco provide ways to leverage the case studies to support the more generalized ideas. *

* STRATEGIES FOR THIS CONSENSUS DISCUSSION

A consensus discussion is different from other kinds of discussions because the purpose of the discussion is to converge on one or more ideas that the whole class agrees upon. In this discussion, your classroom community is pressing toward a common (class-level) explanation of how urbanization is a force of change for nonhuman populations.

How is urbanization a driving force for change?



Illustrations created by OpenSciEd in BioRender

During this work, encourage students to respond and build directly on one another's ideas and to resolve disagreements where possible. Your role is to help students see where they agree and where they still disagree. Helpful prompts include:

- What ideas are we in agreement about?
- Would anyone have represented this idea in a different way?
- Who feels like their idea is not quite represented here?
- Are there still places where we disagree? Can we clarify these?

To encourage students to speak directly to one another, provide them with sentence stems they used in previous discussions such as:

- We also added _____ because. . .
- I think we could write that in a more general way if we. . .

KEY IDEAS

Purpose of this discussion: To build a consensus model to explain how urbanization is a driving force for change in nonhuman populations.

Listen for these ideas:

- All populations have variation between individuals.
- Heritable variations can be anatomical, physiological, or behavioral.
- Selection pressures exist in urban areas.
- Not all individuals in populations survive to reproduce. Those with variations that are better adapted to the environment survive to reproduce more than those that are not well adapted.
- Offspring inherit favorable traits.
- Over many generations, the proportion of favorable traits in a population changes increases, and the proportion of less favorable traits decreases.

ADDITIONAL GUIDANCE

To save time, begin the discussion by focusing on one group model that contains a number of the desired elements but still needs refining. Remind students that creating a model of this type is complex and they were given limited time to create their first draft, so we do not expect any model to be complete. The goal is to combine elements from all of the models to build the best explanatory model. Explain that you are choosing this model as a base for the class model and then refining it. Note which parts of that model everyone agrees on and which parts others represented differently and which parts are different.

Say, *Do we all agree with what we have here? Thumbs up if you agree, thumbs down if you do not.* If students disagree, be sure to address their concerns before moving on.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: As students work together as a class to create a class consensus model, look/listen for [creation of a model that explains \(SEP 2.3\)](#):

- All [populations have genetic variations between individuals.](#) (DCI: LS4.C.1)
- [Variation comes from mutations and sexual reproduction.](#) (DCI: LS4.C.1)
- [Heritable variations can be anatomical, physiological, or behavioral.](#) (DCI: LS4.C.2)
- There are [selection pressures](#) in urban areas that [cause some individuals to survive better than others.](#) (DCI: LS4.C.1, CCC: 2.2)
- [Not all individuals in populations survive to reproduce. Those with variations that are better adapted to the environment survive to reproduce more than those that are not well adapted.](#) (DCI: LS4.C.1, LS4.C.2; CCC: 2.2)
- [Offspring inherit favorable traits.](#) (DCI: LS4.C.1)
- [Over many generations, the proportion of favorable traits in a population increases, and the proportion of less favorable traits decreases.](#) (DCI: LS4.C.1, LS4.C.2)

What to do:

- Say, *That is really good at explaining [specific example]. How could we make that apply to any scenario or all populations? Did we see something similar to that in [juncos/rats/hawksbeard]?*
- Ask if there is an order in which the items should occur if time/generations are involved.
- Ask if their model would work for the hawksbeard, rat, and junco.
- Ask them to compare what they have in the model to a particular group model that was called out in the previous class for its strength in organizing or symbolizing missing ideas.

Building toward 5.A.2 [Develop and revise a model to explain](#) how urban [environmental factors cause the evolution of populations by natural selection.](#) (SEP: 2.3; DCI: LS4.C.1, LS4.C.2; CCC: 2.2)

Co-construct the term *evolution*. As the consensus discussion ends, display [slide K](#). Explain that scientists use the term *evolution* to describe the process of change over time they are explaining in their model. Co-construct the term *evolution* and provide time for students to add it to personal glossaries.

ADDITIONAL GUIDANCE

Student definitions may be similar to *evolution is the process of a population changing the proportion of particular traits over many generations.*

9 · COMPARE CLASS MODEL TO OTHER EXPLANATIONS

13 min

MATERIALS: *Population Change Theories*, class consensus model

Celebrate and motivate testing the model. Display **slide L**. Say, *Nice work! That was a challenging question to explain!* Discuss the prompt. If necessary, ask students if they know of any scientists who made models or ideas that explained phenomena similar to ours. Listen for students to mention Charles Darwin or other scientists who study natural selection. If they do not mention it, let them know that you know of a few, including Charles Darwin.

Introduce other explanatory theories for change in populations. Display **slide M**. Say, *We spent some time developing a model for how urbanization drives change in nonhuman populations. How could it be useful to compare our model to other theories about why or how populations change over time?* Listen for ideas such as:

- It would help confirm our ideas if they agree.
- We can learn other possible explanations or ways to think about the same evidence we have not considered.
- It might give new ideas for how to make connections and explain why things happen. *

Display **slide N**. Explain that they will be learning about explanations from two scientists. One theory was developed by Jean Baptiste de Lamarck, and the other was developed by Charles Darwin. Ask students to share what they know about these two scientists if the class did not discuss them previously. They should make a three-column chart in their notebooks similar to the one shown on the slide. Display **slide O** and ask support students to transfer the big ideas from the class consensus model to the leftmost column of the chart. Distribute *Population Change Theories* and read the first paragraph together.

ADDITIONAL GUIDANCE

As needed, explain that theories are similar to explanatory models and are based on evidence. Students may wish to add the word *theory* to their personal glossaries as a definition they encounter. For the purposes of this lesson, we are treating the terms *model* and *theory* synonymously. Both are explanatory and based on scientific evidence.

Compare theories. Provide five minutes for students to read Lamarck's and Darwin's theories on their own and fill in the table. After five minutes, display **slide P** and ask students to turn and talk about the question. After a minute or two, bring the class together and display **slide Q**. Ask one group to recap their discussion, using *Models of Population Change Key* as a guide. When critiquing Lamarck's theory, students should recognize that changes to physical features that occur during an individual's lifetime, like stretching, are not heritable. Ask if other pairs agree or disagree with the ideas that were shared. Once the class agrees that the consensus model is most like Darwin's theory, ask, *Does our model support Darwin's theory of evolution by natural selection?* Listen for agreement. *Should we add this theory to our model?* If students agree, add the phrase *evolution by natural selection* to the model.

ADDITIONAL GUIDANCE

Note that people did not use the term *genetics* until after Lamarck and Darwin developed their theories. Gregor Mendel was a contemporary of Darwin but did not publish his work until 1866. The term *gene* was not used until the early 20th century by Danish botanist Johannsen (Portin, P., & Wilkins, A., 2017).

This is a moment to recognize the additional evidence now present supporting Darwin's theory. Scientific developments in the 20th century related to genetics and the connection between genetic mutation, protein function, and physiology added more empirical support to his earlier explanations.

Portin, P., & Wilkins, A. (2017). The evolving definition of the term "gene". *Genetics*, 205(4), 1353-1364.

Co-construct a revised definition of natural selection. Display **slide R**. Ask students to compare how the explanation of natural selection we are discussing in this lesson is different from what they wrote in their personal glossaries in Lesson 2. Ask students to take a moment to revise their definitions.

* SUPPORTING STUDENTS IN ENGAGING IN CONSTRUCTING EXPLANATIONS AND DESIGNING SOLUTIONS

The class model is one type of explanation. The readings here will help students recognize that scientific explanations related to evolution have been in use by the scientific community for well over a century, and we keep adding to and revising these explanations as we gain more evidence.

ADDITIONAL GUIDANCE

In Lesson 2, students may have defined natural selection in relation to adaptation, writing something similar to *adaptation by natural selection leads to the dominance of certain traits in a population and the suppression of others. Traits that support successful survival and reproduction in the new environment become more common; those that do not become less common.* They should now modify this to include the steps from the consensus model, which explains evolution by natural selection. Add in genetic variation, selection pressures, differential reproduction for those who express favorable genetic traits, and other concepts from the model that were not included in the original definition.

10 • REVISIT DRIVING QUESTION BOARD

9 min

MATERIALS: Driving Question Board

Revisit the Driving Question Board. Display slide S. Say, *Hurray! We built a model that supports a well known scientific theory! That is quite an accomplishment. Let's look back at the Driving Question Board and see what else we have accomplished.* Ask students to scan the questions silently for 1 minute. Call on volunteers to read the questions that the class has answered. When students identify questions that have been answered, mark the sticky note with a star or move the answered questions to one side of the board.

11 • NAVIGATE

3 min

MATERIALS: None

Motivate looking at other populations. Display slide T. Say, *So it appears we have developed a model that supports Darwin's theory of evolution by natural selection. But we only used our model with populations experiencing urbanization. How can we figure out if our model works for situations we have not seen yet?* Listen for suggestions to try applying it to novel scenarios. Explain that they will complete a transfer task tomorrow to test that out.

Additional Lesson 5 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

RST-11.12.8 Evaluate the hypotheses, data, analysis, and conclusions in a science or technical text, verifying the data when possible and corroborating or challenging conclusions with other sources of information.

Students evaluate Lamarck's and Darwin's theories of evolution and compare them to the class consensus model, deciding which theory best matches the evidence they collected in the last three lessons.

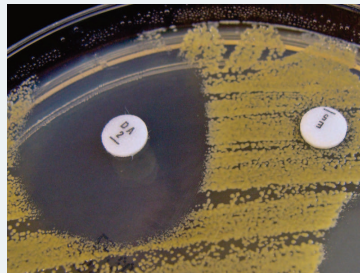
LESSON 6: Can we apply what we know about evolution by natural selection to another phenomenon?

PREVIOUS LESSON We synthesized our knowledge of how urbanization causes change in nonhuman populations to create a class consensus model. We compared our explanatory model to Lamarck's and Darwin's theories of evolution and recognized that our model supports evolution by natural selection. We decided to apply our model to an unknown scenario.

THIS LESSON

PUTTING PIECES TOGETHER

1 day



We apply what we figured out to a new context and complete a transfer task about bacteria that developed resistance to antibiotics.

NEXT LESSON We will explore a new case of a nonhuman population affected by urbanization, the Florida panther, and a fast-growing urban area in Buckeye, AZ where mountain lions live. We will generate questions to help figure out how the city's growth plan can support resilient populations.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

6.A. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. (SEP: 6.2; DCI: LS4.C.2; CCC: 2.1)

WHAT STUDENTS WILL FIGURE OUT

- Some bacteria have traits that keep antibiotics from killing them.
- There is a positive relationship between antibiotic use and antibiotic resistance.
- Natural selection causes an increase in the proportion of bacteria in the population that are resistant to antibiotics.
- If we reduce our use of antibiotics, we will slow the rate at which bacteria develop resistance to antibiotics.

Lesson 6 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		NAVIGATE Students review Progress Trackers and notes in preparation for the transfer task.	A	<i>Progress Tracker</i>
2	35 min		COMPLETE A TRANSFER TASK Orient students to the transfer task and administer.	B	<i>Antibiotic Resistance Transfer Task</i>
3	2 min		NAVIGATE Celebrate student accomplishments.	C	

End of day 1

Lesson 6 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Progress Tracker</i> <i>Antibiotic Resistance Transfer Task</i>		

Materials preparation (minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Lesson 6 • Where We Are Going and NOT Going

In this lesson, students have the opportunity to use what they have figured out related to DCI HS: LS4.C.2:

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.

Students use the science practice *constructing explanations and designing solutions* to develop an explanation for how bacteria develop antibiotic resistance.

Construct and revise 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.

Students also use elements of the crosscutting concept, *cause and effect*, when they use empirical evidence to support a claim of the cause and effect of using antibiotics on bacteria.

LEARNING PLAN for LESSON 6

1 · NAVIGATE

8 min

MATERIALS: science notebook, *Progress Tracker*

Review science notebook and Progress Tracker. Display **slide A**. Say, *We have figured out a lot of great science ideas in this unit about how to use our understanding of natural selection to design cities that have resilient populations and ecosystems. Today, you will have a chance to apply what you have learned to a new scenario.* Ask students to review *Progress Tracker* and any additional materials they wish in their science notebooks.

2 · COMPLETE A TRANSFER TASK

35 min

MATERIALS: *Antibiotic Resistance Transfer Task*

Orient students to the Antibiotic Resistance Transfer Task. Display **slide B**. Distribute *Antibiotic Resistance Transfer Task* and give students a few minutes to read over the scenario and ask clarifying questions. Consider allowing your students to use their completed *Progress Trackers* to support them as they complete the transfer task.



Administer the task. Give students the rest of the period to complete the task, then collect assessments before students leave.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: After students complete *Antibiotic Resistance Transfer Task*, use *Antibiotic Resistance Task Key* to evaluate their responses.

What to do: Provide feedback using *Antibiotic Resistance Task Key* as guidance.

Building toward 6.A. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. (SEP: 6.2; DCI: LS4.C.2; CCC: 2.1)

3 · NAVIGATE

2 min

MATERIALS: None

Close the lesson set. Display **slide C**. Congratulate students on all that they have figured out so far about how evolution by natural selection works. After experiencing the transfer task, ask students to consider and share ideas about other populations that they think are interesting that could be affected by urbanization and natural selection.

LESSON 7: What happens when nonhuman populations are harmed by urbanization and what can we do about it?

PREVIOUS LESSON We applied what we figured out to a new context and completed a transfer task about bacteria that developed resistance to antibiotics.

THIS LESSON

PROBLEMATIZING

2 days



National Park Service, Rodney Cammauf

We explore a new case of a nonhuman population affected by urbanization, the Florida panther. We use our class consensus model and figure out that it cannot explain what we observe. We generate new questions that we need to answer to explain this case. We hear that this is happening in other places too and that some people want to work to prevent it. We hear about a fast-growing urban area in Buckeye, AZ where mountain lions live. We generate questions to help figure out how the city's growth plan can support resilient populations.

NEXT LESSON We will use a mathematical model to generate data to help explain why nonhuman populations that experience fragmentation have lower genetic diversity.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

7.A Ask questions to clarify and refine the model for natural selection based on new information about how urbanization could cause reduced fitness in populations and threaten their survival. (SEP: 1.4; DCI: LS4.C.4; CCC: 2.2)

7.B Ask questions based on observation to seek answers about solutions that support urbanization in a growing city and resilience of nonhuman populations. (SEP: 1.1; DCI: ETS1.B.1; CCC: 2.3)

WHAT STUDENTS WILL FIGURE OUT

- Some populations have reduced fitness in urban environments.
- Our natural selection model cannot fully explain why this happens.
- As cities grow, they can plan for systems that prevent harm to nonhuman populations.

Lesson 7 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	2 min		NAVIGATE Review what we figured out and motivate considering organisms that do not or cannot adapt to urbanization.	A	
2	5 min		INTRODUCE A NEW PUZZLING CASE Introduce students to the puzzling case of the Florida panther.	B-E	
3	15 min		READ ABOUT THE FLORIDA PANTHER Ask students to complete a reading and facilitate a small-group discussion.	F-H	<i>Florida Panther</i>
4	8 min		APPLY CLASS CONSENSUS MODEL TO FLORIDA PANTHER CASE Support students in applying their models of evolution by natural selection to the Florida panther case.	I	class consensus model
5	15 min		NAVIGATE: ADD NEW QUESTIONS TO THE DQB Review what we figured out and brainstorm new questions.	J	3x3 sticky notes, chart paper, colored markers
<i>End of day 1</i>					
6	3 min		NAVIGATE Revisit the new questions that students highlighted on day 1.	L	Driving Question Board
7	3 min		INTRODUCE ADDITIONAL CASES Introduce other species that have been negatively affected by urbanization.	M	
8	3 min		DISCUSS PREVENTING HARM Facilitate a whole-class discussion about how harmful effects can be prevented.	N	
9	13 min		INTRODUCE THE CITY OF BUCKEYE Introduce students to the case of the city of Buckeye, AZ.	O-X	internet-connected device, https://docs.google.com/presentation/d/1uXVSro4c-PTe8xPQ6lZ3PR0OqQJeMcCKd6bsyOoFj6g/edit?usp=sharing , Laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i>
10	8 min		WATCH A VIDEO ABOUT GROWTH IN BUCKEYE	Y-Z	Laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i>

Part	Duration		Summary	Slide	Materials
11	15 min		NAVIGATE: ADD QUESTIONS TO DQB	AA	3x3 sticky notes, chart paper, colored markers

End of day 2

Lesson 7 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Florida Panther</i>	- internet-connected device https://docs.google.com/presentation/d/1uXVSro4c-PTe8xPQ6IZ3PRO0qQJeMcCKd6bsyOoFj6g/edit?usp=sharing	- class consensus model 3x3 sticky notes - chart paper - colored markers - Driving Question Board - Laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i>

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Make sure internet-connected devices are available for small groups on day 2 to display <https://docs.google.com/presentation/d/1uXVSro4c-PTe8xPQ6IZ3PRO0qQJeMcCKd6bsyOoFj6g/edit?usp=sharing>

Lesson 7 • Where We Are Going and NOT Going

Where We Are Going

This lesson serves to re-anchor the unit around new information that does not fit the model students have developed. Thus far, the model explains how evolution by natural selection causes the proportion of advantageous traits in a population to increase in frequency. In the case of the Florida panther introduced here, students see that the fitness of the population is lower, which cannot be explained by their models. After considering this case, they hear that it is a problem worldwide and are introduced to a city in Arizona where plans for urbanization can include designs that support resilient nonhuman populations. Students generate new questions for the DQB about both the life science ideas related to the case and the engineering ideas related to urbanization.

Students build on their previous development of DCIs related to natural selection in Lesson Set 1.

They also build on their use of HS ETS1.B.1 from *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and *OpenSciEd Unit B.3: Who gets cancer and why? What can we do about it? (Cancer Unit)* where students evaluated solutions considering a number of constraints.

Students use the practice *asking questions* in a new way as they consider how the model they developed in the first lesson set can or cannot explain a new scenario. The questions they ask will arise in part from this exploration.

Students continue to develop their use of the crosscutting concept *cause and effect*. They use this concept in a new way on day 2 as they generate questions to seek information related to the design of an urban system and how it can have reduced harmful effects on nonhuman populations,

Where We Are NOT Going

While this lesson introduces students to interesting cases, such as the Florida panther, this case is used to support student questioning and understanding of how small isolated or fragmented populations may have reduced fitness. The case of the Florida panther and its genetic rescue is fascinating but will not be explored in the unit. If students want to know more about what has happened to the Florida panther, you can point them to resources found in *Teacher Background Knowledge*.

LEARNING PLAN for LESSON 7

1 · NAVIGATE

2 min

MATERIALS: science notebook

Review what we figured out in Lesson Set 1. Display slide A. Say, *We have figured out a lot about how urbanization has the potential to cause changes in the proportion of traits in populations. All of the populations we investigated seem to be doing well in urban environments. Do you think that is true for all organisms?* Ask students to turn and talk with a partner. Then call on a few pairs to share their thinking. Listen for students to suggest that there might be cases where populations do not or cannot adapt via natural selection. If students do not recall some of their ideas from Lesson 1, remind them that they noted that organisms could move, adapt, or die.

ADDITIONAL GUIDANCE

Prompt students to recall what they figured out in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* with prompts like, *What happens to the system when we lose organisms or a whole population?* Remind them of the terms *biodiversity* and *resilience*, which they defined in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*.

2 · INTRODUCE A NEW PUZZLING CASE

5 min

MATERIALS: science notebook

Introduce students to the Florida panther. Display slide B. Say, *I found an interesting example that I think we should explore, the Florida panther.* Remind students who investigated the Everglades in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* that they might recall hearing about this species.

Make a Notice and Wonder chart to record ideas. Ask students to make a T-chart in their science notebooks to record what they notice and wonder about the Florida panther. Review the information on slides B-D.

Turn and talk with a partner about noticings and wonderings. Display slide E. Give students several minutes to talk about what they noticed and wondered about the Florida panther. Call on a few pairs to share using the prompts below as a guide.

Suggested prompts	Sample student responses	Follow-up questions
What did you notice about the Florida panther?	The population got small because humans hunted the panthers. The panthers have traits that help them survive in Florida. They are protected now, but urbanization might be harming them.	What selection pressures might affect the population? What traits might be advantageous?
What did you wonder?	What is going on with the low fitness?	How could the population be well adapted AND have low fitness?

3 · READ ABOUT THE FLORIDA PANTHER

15 min

MATERIALS: science notebook, *Florida Panther*

Read about the Florida panther. Say, *It sounds like you all have a lot of great ideas and questions about the Florida panther. I have a reading that I think might help you answer some of your questions.* Display **slide F** and distribute *Florida Panther* to each student.*

Small-group discussion. Display **slide G**. Let students know that they will work together in small groups to make sense of the reading. Organize students into groups of 3-4 and ask them to answer the questions on **slide G** in their science notebooks.

Whole-group discussion. Ask small groups to share their responses with the whole class. Use the prompts below as a guide.

Suggested prompts	Sample student responses	Follow-up questions
<i>What unique adaptations do the Florida panthers have?</i>	Darker color, lower weight, longer legs, smaller feet.	<i>How could these adaptations help them survive and reproduce in South Florida?</i>
<i>What selection pressures could have caused a high proportion of the individuals in the population to have those adaptations?</i>	It was hot and swampy, so having longer legs and smaller feet could help them get around.	<i>How are the Everglades different from other places mountain lions live?</i>
<i>What selection pressures are affecting the population now?</i>	Urbanization means they only have a small habitat area. Cars run them over on highways and fragment their habitat. Maybe not having enough food.	<i>Where do they live and why?</i>

Revisit personal glossaries. Display **slide H** and ask students to revisit the definition they co-constructed for biodiversity and resilience in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. Say, *What did you learn from the reading that can help us revise our definitions for biodiversity.* Listen for students to suggest adding genetic diversity to the definition of biodiversity. Ask students to revisit their definition for resilience.

* ATTENDING TO EQUITY

The Florida Panther reading is written at a level that should be accessible for many students. However, since it is long and pivotal to the overall lesson, you may consider providing students with a strategy that builds community and teaches students to work together to understand a challenging reading. The Coherent Reading Protocol is well suited to *Florida Panther*. A description of the Coherent Reading Protocol can be found in the OpenSciEd Teacher Handbook: High School Science. Encourage students to read the text with a partner. They can stop after each section to paraphrase what they understood.

4 · APPLY CLASS CONSENSUS MODEL TO FLORIDA PANTHER CASE

8 min

MATERIALS: science notebook, class consensus model

Revisit the class consensus model. Orient students to the class consensus model developed in Lesson Set 1. Display **slide I** and ask small groups to discuss what the class consensus model does and does not explain about the Florida panther case. Ask them to record their ideas in their science notebooks. Encourage them to use pictures and/or words to explain their thinking.

Share thinking with the whole group. Call on a few groups to share their thinking. Listen for groups to indicate that while the model can explain how the Florida panthers came to be well adapted to their environment, it does not explain how they have low levels of fitness and genetic diversity. If students need an additional prompt, ask students to consider how the model can explain the reduced fitness seen in the case of the Florida panthers. Use the prompts below as a guide:

Suggested prompt	Sample student response
What parts of the Florida panther case does our model explain?	It explains how the panthers came to be well adapted to the hot, damp southeast.
What parts of the case does our model NOT explain?	How they got to have low fitness. All the examples we looked at had higher fitness.
What questions do we need to answer to explain what is happening with the Florida panthers?	How did they get to have that low genetic diversity? Why do they have low fitness?

5 · NAVIGATE: ADD NEW QUESTIONS TO THE DQB

15 min

MATERIALS: science notebook, 3x3 sticky notes, chart paper, colored markers

 **Develop new questions to add to the DQB.** Display slide J. Distribute sticky notes to each group. Ask students to consider what new questions they have based on what they have investigated today. Ask them to write their questions on a sticky note, one question per note. Ask them to put their initials on the back of the sticky note to help monitor their progress.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Questions (SEP: 1.4) such as:

- How did the panthers get to be adapted to their environment? (DCI: LS4.C.4; CCC: 2.2)
- What happened to the panthers to make their population so small? (DCI: LS4.C.4; CCC: 2.2)
- Was the selection pressure human?(DCI: LS4.C.4)
- Is the selection pressure the same as it was in the past? (DCI: LS4.C.4)
- What will happen to the panthers in the future?
- Why is their fitness so low? (DCI: LS4.C.4)
- What is making it so they cannot have offspring? (DCI: LS4.C.4; CCC: 2.2)
- What about their genes is causing the lower fitness?(DCI: LS4.C.4; CCC: 2.2)
- Can we help them get higher fitness?(DCI: LS4.C.4; CCC: 2.2)

What to do: Encourage students to look back at the class consensus model and *Florida Panther* to support question development. At this point in the course sequence, most students will not need additional support in developing testable questions. However, if they do, additional support can be found in *Supporting Questioning*.

Prompt students to ask questions at multiple scales including the genetic, physiological and ecological scales.

Building toward 7.A Ask questions to clarify and refine the model for natural selection based on new information about how urbanization could cause reduced fitness in populations and threaten their survival. (SEP: 1.4; DCI: LS4.C.4; CCC: 2.2)

Gather in a Scientists Circle to add new questions to the DQB. Organize students into a Scientists Circle oriented toward the DQB. Call on one student to share their question with the class. Then ask students with similar questions to add their questions. Continue until all the questions have been added.

Motivate next steps. Before the end of class, display **slide K** and share the lesson question, *What happens when nonhuman populations are harmed by urbanization and what can we do about it?* Ask students to consider which group of questions would be most helpful as a starting point to help us make progress on the lesson question. Ask them to consider if there are any missing questions that we should have on our DQB to help us answer that question.

ADDITIONAL GUIDANCE

In Lesson 5, students identified questions they could and could not answer. While there may still be some unanswered questions, students will have answered the majority of their questions and will be adding new questions during this lesson to motivate Lesson Set 2.

End of day 1

6 · NAVIGATE

3 min

MATERIALS: Driving Question Board

Revisit new questions added to the DQB. Display **slide L**. Say, *Yesterday, we added new questions to the Driving Question Board related to our investigation of the Florida panther.* Review the categories of questions students added to the DQB. Let students know that they added some great questions and they also identified the fact that we do not have many questions on the DQB that will help us make progress on what to do about populations that are harmed by urbanization.

7 · INTRODUCE ADDITIONAL CASES

3 min

MATERIALS: None

Share additional cases. Display **slide M**. Let students know that you discovered that the problem the class investigated with the Florida panther is not the only case where this has happened. It is happening in other places too. These include the hairy-nosed wombat in Australia, the plant *Luehea divericata* in Brazil and the mountain lion in California. *

ADDITIONAL GUIDANCE

The purpose of the cases presented here is to make clear to students that the case of the Florida panther is not unique. In many places around the world, urbanization is causing low genetic diversity in populations that are often fragmented or isolated. This low genetic diversity often leads to reduced fitness. For more information about these cases see *Teacher Background Knowledge*

* SUPPORTING STUDENTS IN DEVELOPING AND USING PATTERNS

Support students in recognizing that the phenomenon of reduced fitness in urban populations is a pattern at the level of populations across the world. Patterns can serve as evidence to explain phenomena. Encourage students to think about what it means that this pattern repeats at the scale of the species.

8 · DISCUSS PREVENTING HARM

3 min

MATERIALS: science notebook

Turn and Talk. Display **slide N**. Say, *After discovering how urbanization can harm species, scientists and policy makers have taken steps to reduce harm.* Call on a few students to share their ideas about the prompts on the slide.

9 · INTRODUCE THE CITY OF BUCKEYE

13 min

MATERIALS: science notebook, internet-connected device, <https://docs.google.com/presentation/d/1uXVSRo4c-PTe8xPQ6IZ3PRO0qQJeMcCKd6bsyOoFj6g/edit?usp=sharing>, Laminated Buckeye Area Map or color print out of *Buckeye Area Map*

Introduce Buckeye, Arizona. Display **slide O**. Say, *There are a lot of urban areas where groups of people are coming together to think about urbanization and nonhuman populations. I found a great example near Phoenix, AZ. This area is one of the fastest-growing urban areas in the United States and also an ecosystem with high biodiversity. Let's take a look to see where urbanization might harm nonhuman populations.*

Notice and wonder in small groups. Ask students to set up a Notice and Wonder chart in their science notebooks. Organize students into small groups and provide each small group with an internet-connected device with access to <https://docs.google.com/presentation/d/1uXVSRo4c-PTe8xPQ6IZ3PRO0qQJeMcCKd6bsyOoFj6g/edit?usp=sharing>. The slides students will be investigating can also be found on **slides P-W**.

Whole-class discussion about noticings and wonderings. Display **slide X**. Facilitate a whole-class discussion to give groups a chance to share what they found in the visual inquiry. Use the prompts below as a guide.

Suggested prompt	Sample student response
<i>What did you notice?</i>	Buckeye has grown a lot and will continue to grow. There are a lot of species that live there. Mountain lions live there, and they need a lot of space. They move across large distances. Where Buckeye is growing is right in the path they take between mountains.
<i>What did you wonder?</i>	Can the city grow and protect the species? Will the mountain lions have the same thing happen to them as the Florida panthers? What can be done to make sure the mountain lions are ok? How do people feel about the mountain lions?

10 · WATCH A VIDEO ABOUT GROWTH IN BUCKEYE

8 min

MATERIALS: science notebook, Laminated Buckeye Area Map or color print out of *Buckeye Area Map*

Organize the class to view a video. Say, *I found a video from the White Tank Mountain Conservancy that can help us better understand what people are doing in Buckeye. The White Tank Mountain Conservancy is a group that cares about protecting biodiversity as urbanization happens. Display slide Y. Play https://youtu.be/_6S8PfiW_E. After students have viewed it once, display slide Z and ask students to jot down their ideas about the questions in their science notebooks. It is not critical that they answer these completely, but the ideas will help them generate questions for the DQB in the next activity. It may be helpful to play the video one more time after they have looked at the questions.*

11 · NAVIGATE: ADD QUESTIONS TO DQB

15 min

MATERIALS: science notebook, 3x3 sticky notes, chart paper, colored markers



Add questions to DQB. Say, *We have a lot of new questions about how we can design cities to support resilient populations. Display slide AA. Let's spend a few minutes writing down our questions and adding them to our DQB.* Encourage students to use the questions they generated from both the visual inquiry and the video to support their question development. Organize students into a Scientists Circle and encourage students to take leadership roles as they add questions to the DQB. Here it may make sense to draw a line down the middle of the DQB to distinguish questions oriented around science ideas from those related to engineering design ideas.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment:

Questions (SEP: 1.1) such as:

- How many people is the **right number** to move to Buckeye?(CCC: 2.3)
- How many mountain lions are there and how much space do they need?
- How can the **city grow** and keep **connections to the mountains for the animals**?(DCI: ETS1.B.1; CCC: 2.3)
- What about the **deer that the mountain lions eat? Where do they go?** (DCI: ETS1.B.1)
- What kinds of **solutions** have people built in other places that we could learn from to help the mountain lions? (CCC: 2.3)
- What do the **people** who live in Buckeye or want to move there **care about?** (DCI: ETS1.B.1)
- What would **happen** if the **mountain lion population got really small?** (DCI: ETS1.B.1; CCC: 2.3)

What to do: Encourage students to look back at the visual inquiry and *Florida Panther* to support question development. Support students in thinking about the whole ecosystem and what they might need to know about the mountain lion habitat. At this point in the course sequence, most students will not need additional support in developing testable questions. However, if they do, additional support can be found in *Supporting Questioning*.

Building toward 7.B Ask questions based on observation to seek answers about **solutions that support urbanization in a growing city and resilience of nonhuman populations.** (SEP: 1.1; DCI: ETS1.B.1; CCC: 2.3)

Additional Lesson 7 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

CCSS.ELA-LITERACY.RST.11-12.2

Determine the central ideas or conclusions of a text; summarize complex concepts, processes, or information presented in a text by paraphrasing them in simpler but still accurate terms.

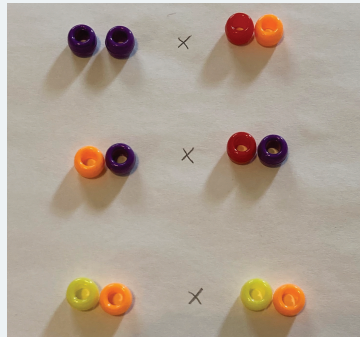
LESSON 8: How can fragmentation lead to lower genetic diversity?

PREVIOUS LESSON We explored a new case of a nonhuman population affected by urbanization, the Florida panther. We used our class consensus model and figured out that it cannot explain what we observed. We generated new questions that we need to answer to explain this case. We heard that this is happening in other places too and that some people want to work to prevent it. We heard about a fast-growing urban area in Buckeye, AZ where mountain lions live. We generated questions to help figure out how the city's growth plan can support resilient populations.

THIS LESSON

INVESTIGATION

2 days



We use a mathematical model to explain why nonhuman populations that experience fragmentation have lower genetic diversity. We learn that alleles randomly disappear from very small populations and the loss of certain alleles may impact fitness when a selection pressure is present. We learn that large populations are more fit because the diversity of alleles provides options for adapting to more environmental changes. We wonder about ways to apply this information to areas experiencing urbanization.

NEXT LESSON We will reflect on the Lesson 8 model and wonder if we could help protect populations from fragmentation. We will investigate if connecting habitats to make them bigger helps nonhuman populations be more stable and resilient. We will discover there are different structures that humans use to connect habitat for nonhuman populations. We will apply mathematical and statistical thinking to help us evaluate how effective these human structures are at removing barriers and connecting habitat. We will revisit the city of Buckeye, AZ and think about what criteria the community of Buckeye would need to consider if they were to add these structures.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

8.A Use a mathematical model to generate data to explain why nonhuman populations lose genetic diversity and become unstable in a fragmented environment. (SEP: 2.6; DCI: LS4.C.4; CCC: 7.1)

8.B Use mathematical representations of allele frequencies to describe and support an explanation for how traits in an urban nonhuman population change or remain stable as their physical environment changes. (SEP: 5.2; DCI: LS4C.3, LS4.C.4; CCC: 7.1)

WHAT STUDENTS WILL FIGURE OUT

- Fragmentation can create smaller, isolated populations.
- Fragmented populations become less fit if they lose individuals with alleles that provide a selective advantage.
- Selection pressures and random chance can cause loss of allelic diversity in populations.
- If populations lose genetic diversity, they cannot always adapt to a changing environment.

Lesson 8 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	5 min		NAVIGATE Facilitate a review of the main question raised in the last lesson and brainstorm a way to develop a model to test that question.	A-B	Driving Question Board
2	15 min		INVESTIGATE THE MODEL: FRAGMENTATION Collect data from the first generation of the model. Discuss the random effect of fragmentation on the gene pool of each isolated population.	C-D	calculator, <i>Fragmentation Investigation</i> , pony beads (variety pack), two-cup plastic storage containers with lids, <i>Model Instructions/Key</i>
3	10 min		COMPARE STARTING FREQUENCIES Facilitate data sharing for generation one. Discuss differences between groups and ask questions about the data.	E-F	calculator
4	10 min		DISCUSS DATA REPRESENTATION Facilitate a discussion of the best way to visually represent changes in allele frequency over time.	G	
5	5 min		COLLECT SELECTION PRESSURE IDEAS Students complete exit tickets that suggest selection pressures to add to the model.	H	
<i>End of day 1</i>					
6	3 min		NAVIGATE Facilitate a review of what students learned from the basic model on day 1.	I	<i>Fragmentation Investigation</i>
7	5 min		INTRODUCE SELECTION PRESSURES Introduce the selection pressure options and describe how to use the model to simulate reproduction.	J-N	<i>Fragmentation Investigation, Model Instructions/Key</i>
8	12 min		INVESTIGATE SELECTION PRESSURES Facilitate small group investigations into one selection pressure, data analysis and group sharing.	P	calculator, <i>Fragmentation Investigation</i> , pony beads (variety pack), two-cup plastic storage containers with lids, 4-sided die, blank piece of paper, colored pencils (variety pack), <i>Model Instructions/Key</i>
9	7 min		COMPARE RESULTS Pair up groups of students to share and compare results. Provide time for individual reflection on the answer to the lesson question.	Q-R	<i>Fragmentation Investigation, Model Instructions/Key</i>
10	13 min		FACILITATE A CONSENSUS DISCUSSION Facilitate a consensus discussion to explain how natural selection changes populations with lower genetic diversity. Motivate questions about possible solutions for urban design to prevent a reduction in genetic diversity.	S-T	<i>Fragmentation Investigation, Model Instructions/Key</i>

Part	Duration		Summary	Slide	Materials
11	5 min		UPDATE PROGRESS TRACKER Students record what they learned about the lesson question in the Progress Tracker. They also record questions for further investigation.	U	<i>Progress Tracker</i>

End of day 2

Lesson 8 • Materials List

	per student	per group	per class
Lesson materials	- calculator <i>Fragmentation Investigation</i> - science notebook <i>Progress Tracker</i>	- pony beads (variety pack) - two-cup plastic storage containers with lids 4-sided die - blank piece of paper - colored pencils (variety pack)	- Driving Question Board <i>Model Instructions/Key</i> - pony beads (variety pack)

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Day 1: Fragmentation Investigation

- Group size:** 4-5 students.
- Setup:** Get a variety pack of pony beads with 6 colors with roughly equal numbers of each color. Scoop out approximately 120 beads for each group into a plastic 2-cup container with a lid. Provide each group with 2 additional containers. Keep a large supply of extra beads available for students to exchange colors as needed.
- Safety:** To prevent falls make sure all dropped beads are picked up promptly.
- Cleanup:** If you teach more than one section, make sure students return all beads at the end of class and mix them before scooping beads for the next section.

Day 2:

- Revise **slide J** to represent the selection pressures submitted by students in their exit tickets. Update **slide K** as needed to match your bead colors. Print out a copy of the rules on **slide K** for each group.
- Update **slide T** to reflect the Lesson Set 2 driving question and lesson question for your class.
- Gather pony beads, 2 small containers, a 4 sided-die, colored pencils, and a blank piece of paper for each group. Follow instructions on *Model Instructions/Key*.

Lesson 8 • Where We Are Going and NOT Going

Where We Are Going

Students manipulate a model to investigate the impact of fragmentation on genetic diversity and overall fitness in a population. They learn that the diversity of alleles in a population can quickly change in a small population due to random chance. When populations face new selection pressures in the environment, students will figure out that maintaining a large population provides a population with more stability and greater fitness because there are more genetic variations available for natural selection to act upon to adapt to changes in the environment.

The evidence from this lesson works towards High School DCIs below:

1. LS4C.3. Adaptation Adaptation also means that the distribution of traits in a population can change when conditions change.
2. LS4C.4 Adaptation 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.~~

Students use elements of the science practices of *developing and using models* and *using mathematics and computational thinking* to gather evidence to support an explanation of why fragmentation leads to reduced genetic diversity.

Students use elements of the crosscutting concept of *stability and change* to explain the long term consequences of fragmentation on a population's ability to adapt to changes in the physical environment.

Students encounter the terms gene pool and allele frequency and add to their definition of fitness from Lesson 4.

Where We Are NOT Going

Although the model may demonstrate the concepts of genetic bottleneck and genetic drift, the formal terms are not introduced here as they are unnecessary to understand how populations can or cannot adapt to changes in the environment based on their genetic diversity. Individual teachers may choose to introduce the terms. For students interested in an extension about genetic drift and how population size influences allele fixation, direct them to experiment with changing allele frequency parameters and population sizes in the computer Population Genetics simulation at https://www.radford.edu/~rsheehy/Gen_flash/popgen/. Instructions for using the simulation can be found by pushing the blue “info” button.

DCI LS4C.4 will be addressed again in *OpenSciEd Unit B.5: What will happen to Arctic bear populations as their environment changes?*(*Speciation Unit*) which focuses on mechanisms of speciation.

LEARNING PLAN for LESSON 8

1 · NAVIGATE

5 min

MATERIALS: Driving Question Board

Review what we figured out about fragmentation, genetic diversity, and fitness. Display slide A. Use the prompts below as a guide. *

Suggested prompt	Sample student response
<i>What did we figure out about small fragmented populations, genetic diversity and fitness that our model could not explain?</i>	The populations of panthers were fragmented and had low genetic diversity and fitness. Our model showed how advantageous traits could be selected for and that could improve fitness. It does not explain a decrease in fitness.
<i>What new questions did we add to the Driving Question Board about these ideas.</i>	How did genetic diversity decrease? Why did natural selection not select for traits that increase fitness in panthers? How can cities plan to grow and support genetically diverse populations at the same time?

Motivate working with a new model. Say, *Before we figure out how to solve problems associated with urbanization, let's figure out what is going on with low genetic variation in populations. Since the consensus model we drew in Lesson Set 1 could not explain our new scenario, we need to figure out a way to explain what is happening to the panthers and other nonhuman populations. The rat investigation we did in Lesson 3 with the beads really helped us think about the connection between genetics, selection pressures, and changes in the population.* Display **slide B** and discuss the prompts on the slide. Listen for students to suggest starting with a large population with more than 2 alleles and then fragmenting it; adding selection pressures; measuring fitness and tracking the number of alleles in the population over time. Prompt students to review *Rat Modeling Investigation* if they need more ideas. Remind them that the problem is related to genetic diversity and fragmentation.

* SUPPORTING STUDENTS IN THREE-DIMENSIONAL LEARNING

In Lesson Set 1, students developed a model of evolution by natural selection as a mechanism of change that explains how populations adapt to the environment. In this lesson, students use a related model to show how random chance interacts with small populations (SEP), reducing fitness if the environment changes (DCI). Students will use the model to generate data that they will compare with other groups (SEP). They will use the model to build an explanation for how small populations can become less resilient (CCC) as they lose allelic diversity.

2 · INVESTIGATE THE MODEL: FRAGMENTATION

15 min

MATERIALS: calculator, *Fragmentation Investigation*, pony beads (variety pack), two-cup plastic storage containers with lids, *Model Instructions/Key*

Demonstrate the basic model. Say, *I have a model that includes many of your ideas that we can use to investigate how fragmentation leads to lower genetic diversity in populations. Let me show you what I have and after we try it out, we can add in more of your ideas.* Display **slide C**. Distribute *Fragmentation Investigation* and demonstrate steps 1–3 using suggestions from *Model Instructions/Key*. Explain that although the table has space for 4 generations, they will only complete generation one right now.*

* ATTENDING TO EQUITY

Students whose math abilities are below grade level may need to review how to calculate allele frequencies. Encourage them to review *Seed Dispersal Investigation* to remember how they made this calculation before. Consider pairing students who are

ADDITIONAL GUIDANCE

The data table in *Fragmentation Investigation* provides space for six alleles. If the bead pack you purchase contains more than 6 colors, consider grouping all similar colors into the same allele (for example light and dark blue beads as one group of blue beads), or presorting the beads so that only six colors are available. The class can work with larger or smaller numbers of alleles, but larger numbers will take more time and smaller numbers may reduce the amount of genetic diversity in the population too quickly in the model.

Evodots, <http://faculty.washington.edu/herronjc/SoftwareFolder/EvoDots.html/>, is a virtual alternative for investigation. It can also be used as an extension if students benefit from more time and another modality for processing ideas.

not confident with these calculations with a student who can support them with the math throughout this lesson.

ADDITIONAL GUIDANCE

Gene pool is a word we encounter in the course of running the investigation. Students may wish to add this word to their personal glossary. A possible definition is *all of the alleles available in a population available for reproduction*.

Explain that when working with alleles, scientists often call the proportion of each allele an *allele frequency*. Calculating allele frequency is similar to calculating the proportion or percentage of traits in a population as students did in Lesson Set 1.

Generate data from fragmented populations. Display **slide D**. Divide the students into groups of 4-5. Explain that each group will be responsible for monitoring the genetic health of one population of Florida panthers. The population used to be much larger, but due to hunting and urbanization, the population was fragmented into smaller populations at locations around the urban development. Large highways and construction projects isolated the panthers into small pockets of protected space.

Each group should pick up a container of beads and complete steps 1-4 on *Fragmentation Investigation*. Monitor the groups to make sure they understand the process for selecting panthers, counting alleles and calculating frequencies. Create a shared data table at the front of the room with rows for each group. Ask one student from each group to enter their generation 1 allele frequencies on the shared data table.

3 · COMPARE STARTING FREQUENCIES

10 min

MATERIALS: calculator



Share and compare starting frequencies. After all groups have shared their data on the class table, display **slide E** and direct students to Turn and Talk about what they notice and wonder about the class data. Facilitate a discussion of what they see. Direct students to answer the Day 1 analysis questions during this discussion.

Suggested prompt

What did you notice?

What causes the differences between groups?

Sample student response

Not everyone had the same alleles.

Group 1 had a much higher allele frequency of red than group 5.

They picked different alleles at random.

Fragmentation.

Small population size.

Calculate the full class allele frequencies. If students do not ask, display **slide F** and discuss the prompt: What would the allele frequencies be if the populations were not fragmented? Calculate the frequency of each allele for the entire class. Divide the work by assigning small groups of students to calculate the frequency for one color to share with the class.

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: As students answer and discuss the differences between the **data collected** by each group in the **model (SEP 2.6)**, look and listen for the following ideas:

- Identification of **changes to allele frequencies between groups that represent changes in fragmented populations.** (DCI: LS4.C.4; CCC: 7.1)
- Identification of **random chance causing changes in allele frequencies in each small, fragmented population.** (DCI: LS4.C.4; CCC: 7.1)
- Questions about the **impact of increasing or reducing population size on the unequal distribution of alleles.** (DCI: LS4.C.3, LS4.C.4; CCC: 7.1)
- Questions about **further testing the model over more generations with selection pressures.** (DCI: LS4.C.4; CCC: 7.1)

What to do:

- Ask, *What would the allele frequencies be if the populations were not fragmented?* Calculate the frequency of each allele for the entire class and compare to the results of the smaller groups.
- Ask why the alleles were chosen at random and how this affects the results.
- Ask what to add next to the model to make it more realistic.

Building toward 8.A Use a mathematical model to generate data to explain why nonhuman populations lose genetic diversity and become unstable in a fragmented environment. (SEP: 2.6; DCI: LS4.C.4; CCC: 7.1)

4 · DISCUSS DATA REPRESENTATION

10 min

MATERIALS: science notebook

Discuss data visualization to find how populations change or stay the same. Say, *Our model helps us see how fragmentation immediately affects the genetic diversity of panther populations, but how does this lead to lower fitness? Earlier, you mentioned that we need a selection pressure in this model. Let's think about how a selection pressure can cause allele frequency or fitness to change over time. We know from Lesson Set 1 that evolution by natural selection causes the proportion of alleles to change over many generations. So to investigate this, the panthers in our model need to reproduce so we can track what happens to allele frequencies in each panther population over time. Let's plan ahead a bit. Once we collect that data, we need to figure out how to represent it so we can see if the allele frequencies stay the same or change in each fragmented population.* Display **slide G**. Facilitate a Turn and Talk for students to decide how to set up a graph that can track changes in the allele frequency data for all 6 alleles over multiple generations. Ask them to draw a sample graph on a piece of paper they can hold up and show the class. After a few minutes, ask all groups to hold up their ideas and look around the room to compare. Facilitate a discussion of which type of graph portrays the data most clearly. A sample graph is found in *Model Instructions/Key*. **

ALTERNATE ACTIVITY

As an extension, instruct students how to create their preferred graph using a computer spreadsheet program or CODAP to produce graphs similar to those shown in *Model Instructions/Key*. Explain how to organize data in the spreadsheet, make simple calculations, and cut and paste repeated formulas.

* ATTENDING TO EQUITY

Universal Design for Learning: Providing a computer spreadsheet to students with impaired motor skills or dysgraphia supports multiple means of *action and expression*. This may allow them to spend more time thinking about analysis rather than grappling with the mechanics of making a graph. Depending upon the students' ability, repopulate all headings, formulae, and links to a graph that auto-draws as data is entered.

Thapliyal, M., & Ahuja, N. J. (2021). Underpinning implications of instructional strategies on assistive technology for learning disability: a meta-synthesis review. *Disability and Rehabilitation: Assistive Technology*, 1-9.

* SUPPORTING STUDENTS IN ENGAGING IN USING MATHEMATICS AND COMPUTATIONAL THINKING

On day 2, students will be assessed on their use of mathematical representations to explain how fragmentation reduces the genetic diversity and fitness of a population. The graphs they are designing here will be the mathematical representations they will use to make comparisons of different fragmented populations to develop their explanation.

5 · COLLECT SELECTION PRESSURE IDEAS

5 min

MATERIALS: science notebook

Complete an exit ticket to gather selection pressure ideas. Say, *Let's think about what selection pressures we want to add to our model.* Display **slide H** and gather ideas as students leave. *

ADDITIONAL GUIDANCE

Read through the exit ticket responses and choose 4 commonly mentioned selection pressures from the suggestions. Revise **slides J and K** to match the class choices and bead colors.

* ATTENDING TO EQUITY

Print out the rules from **slide K** in advance to provide a written copy to each group. This allows emergent multilingual language learners and those who process oral information more slowly additional time to read and interpret the rule associated with their selection pressure.

End of day 1

6 · NAVIGATE

3 min

MATERIALS: *Fragmentation Investigation*

Review what we learned last time. Display **slide I** and provide time for students to Turn and Talk about what they accomplished in the last class. Encourage them to use *Fragmentation Investigation* to review where their group left off.

7 · INTRODUCE SELECTION PRESSURES

5 min

MATERIALS: *Fragmentation Investigation*, *Model Instructions/Key*

Introduce selection pressures and rules. Display **slide J**. Explain that you compiled the ideas from the exit tickets to create the list on the slide. Each group will begin today by setting up the 6 panthers from generation 1 using the 12 allele beads they left off with in the last class. As a class, choose two selection pressures from the list to investigate. Assign half the groups to investigate each one. Display **slide K** and assign one selection pressure the class chose to rule A and the other to rule B. See *Model Instructions/Key* for examples of how to assign rules.

Explain that these rules govern fitness for that selection pressure. Point out the location on *Fragmentation Investigation* to write down the selection pressure and rule. Use **slides L-O** to explain instruction steps 1-4 for day 2 from *Fragmentation Investigation*. Emphasize that students should not change the pairs they begin with to match the rule they were assigned. *

8 · INVESTIGATE SELECTION PRESSURES

12 min

MATERIALS: calculator, *Fragmentation Investigation*, pony beads (variety pack), two-cup plastic storage containers with lids, 4-sided die, blank piece of paper, colored pencils (variety pack), *Model Instructions/Key*

Run the model with a selection pressure. Display **slide P**. Provide time for groups to run the model and complete their analysis. They should be prepared to share what they learned with other students in the class.

ALTERNATE ACTIVITY

If time allows, ask groups to carry out reproduction steps for a fourth generation. Assume all individuals from generations 1-3 are still alive and reproducing. This will provide additional data before answering question 3 on *Fragmentation Investigation*.

9 · COMPARE RESULTS

7 min

MATERIALS: *Fragmentation Investigation*, *Model Instructions/Key*

Compare results. Display **slide Q**. Pair up groups to present the selection pressures they investigated and the results. Groups should compare similarities and differences between outcomes.

Reflect on the results. Display **slide R** and provide time for students to think or write about the prompts.

10 · FACILITATE A CONSENSUS DISCUSSION

13 min

MATERIALS: science notebook, *Fragmentation Investigation*, *Model Instructions/Key*



Facilitate a consensus discussion. Display **slide S**. Ask students to gather in a Scientists Circle. Have students bring their science notebooks and make sure their group graphs are available. Make comparisons for allele frequency and total population size between groups with the same selection pressure and groups with different selection pressures. Use *Model Instructions/Key* as a guide for responses. Facilitate a discussion that includes sharing what they learned from the model and the limitations of the model to explain what happens in real urban populations. For example, ask students what would happen in the model if one individual out of six in the first generation had been hit by a car while crossing the road, a common cause of death for panthers. *

KEY IDEAS

Purpose of this discussion: There are two goals for this discussion: 1. To explain how fragmentation and small population size can lead to lower genetic diversity and reduced fitness. 2. To stimulate ideas and questions about how to maintain larger populations as urbanization occurs.

Listen for these ideas: See the assessment box below.

* STRATEGIES FOR THIS CONSENSUS DISCUSSION

A Consensus Discussion is different from other kinds of discussions because the purpose of the discussion is to converge on one or more ideas that the whole class agrees upon. Do not require students to take notes at this time. Have them work on listening and linking to the ideas that other people share. In this discussion, the classroom community presses toward a common (class-level) explanation. During this work, the class resolves disagreements where possible. Your role is to help students see where they agree and where they still disagree. Helpful prompts include:

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: Mathematical representations that provide evidence for (SEP 5.2):

- Fragmentation can create smaller, isolated populations. (DCI: LS4C.3, LS4.C.4)
- Populations can lose alleles because of a selection pressure, or due to random chance. (DCI: LS4C.3, LS4.C.4; CCC: 7.1)
- Fragmented populations become less fit if they do not include individuals with adaptations that may exist in different populations. (DCI: LS4C.3, LS4.C.4; CCC: 7.1)
- Selection pressures on populations change over time and populations continually adapt to those changes. (DCI: LS4C.3, LS4.C.4; CCC: 7.1)
- If populations lose genetic diversity they are less resilient and cannot always adapt to a changing environment. (DCI: LS4C.3, LS4.C.4; CCC: 7.1)
- Questions about ways to increase fitness and stabilize the population by reconnecting isolated populations in urban areas to reintroduce lost alleles or create a larger population size. (SEP: 5.2; DCI: LS4C.3, LS4.C.4; CCC: 7.1)

What to do:

- Ask students to connect scenarios from their model to what is happening in Buckeye, AZ.
- Take a population from one group and apply a new selection pressure with a new rule to the population to see what happens.
- Compare the outcome of a selection pressure on the unfragmented, original large population.
- Ask students to critique the model by asking if panther population size rises indefinitely as our model shows, or if natural selection acts this quickly in real populations.
- Ask students to consider what happens to a fragmented population if just one individual dies from being hit by a car, which is a common cause of death.
- Remind students of statements they made while they ran and analyzed the model, such as “What if we just trade panthers with their group?”
- Ask what instincts they had to increase the fitness of their panther population and how that could happen in a real scenario.

Building toward 8.B Use mathematical representations of allele frequencies to describe and support an explanation for how traits in an urban nonhuman population change or remain stable as their physical environment changes. (SEP: 5.2; DCI: LS4C.3, LS4.C.4; CCC: 7.1)

Refine definition of fitness. Display slide T. During the discussion, as students bring up fitness or differential survival rates, revisit the definition of fitness that was introduced in Lesson 4. Ask, *What are we measuring when we talk about fitness?* Listen for students to mention allele frequency and number of individuals that survive. Explain that when scientists talk about fitness, they measure survival rates with allele frequencies or, most commonly, genotype frequencies. Refine the definition of fitness students wrote in their personal glossary. Discuss the limitation of this model for tracking changes in genotype frequency.

ADDITIONAL GUIDANCE

Revised definitions of fitness add in the quantitative measurement of survival rates by tracking changes in allele frequency or genotype frequency in a population.

- What ideas are we in agreement about?
- Would anyone have put this point a different way?
- Who feels like their idea is not quite represented here?
- Are there still places where we disagree? Can we clarify these?

MATERIALS: *Progress Tracker*

Update Progress Tracker. Display **slide U**. Say, *We made some important discoveries today. Let's be sure to make a record of what we figured out.* Encourage students to write down questions or wonderings they have at this time that we could investigate to prevent the loss of genetic diversity in nonhuman populations. Provide time for students to update their Progress Tracker.

Additional Lesson 8 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively.

CCSS.MATH.PRACTICE.MP4 Model with mathematics.

CCSS.MATH.CONTENT.S.IC. Make inferences and justify conclusions from ~~sample surveys, experiments, and~~ observational studies.

Students use the results of a quantitative model to develop a supported explanation for why nonhuman populations lose genetic diversity when they are fragmented by urbanization.

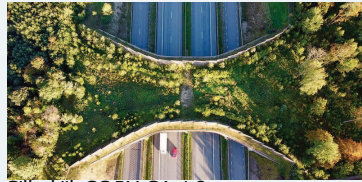
LESSON 9: How can we plan urban areas to protect genetic diversity in nonhuman populations?

PREVIOUS LESSON We used a mathematical model to explain why nonhuman populations that experience fragmentation have lower genetic diversity. We learned that alleles randomly disappear from very small populations and the loss of certain alleles may impact fitness when a selection pressure is present. We learned that large populations are more fit because the diversity of alleles provides options for adapting to more environmental changes. We wondered about ways to apply this information to areas experiencing urbanization.

THIS LESSON

INVESTIGATION

2 days



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We reflect on the Lesson 8 model and wonder if we could help protect populations from fragmentation. We decide to investigate if connecting habitats to make them bigger helps nonhuman populations be more stable and resilient. We discover there are different structures that humans use to connect habitat for nonhuman populations. We apply mathematical and statistical thinking to help us evaluate how effective these human structures are at removing barriers and connecting habitat. We revisit the city of Buckeye, AZ and think about what criteria the community of Buckeye would need to consider if they were to add these structures. We wonder what the Buckeye community is currently planning.

NEXT LESSON

We will investigate the conflicting requirements for protecting biodiversity while urbanizing and providing for the needs of human populations in Buckeye, AZ. We will evaluate two proposed designs, focusing on how to balance the needs of human and nonhuman populations.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

9.A. Apply statistics to determine how designed systems with connected habitats change the distribution of traits in nonhuman populations when conditions change. (SEP: 4.2; DCI: LS4C.3; CCC: 2.3)

9.B. Apply scientific principles to the design of a growing urban system to counteract the adverse impacts of human development with a goal to sustain biodiversity, including stable genetic diversity in nonhuman populations. (SEP: 6.3; DCI: LS4.D.2; CCC: 7.4)

WHAT STUDENTS WILL FIGURE OUT

- Selection pressures lead to shifts in trait distribution.
- Reducing fragmentation maintains genetic diversity so populations can adapt to changing conditions.
- People can maintain resilience and genetic diversity in nonhuman populations by creating corridors to connect fragmented populations.
- We can develop criteria for urbanization that sustains biodiversity that benefits humans and nonhuman populations.

Lesson 9 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		NAVIGATE Reflect on how the populations changed in the model from the previous lesson.	A	<i>Progress Tracker</i>
2	10 min		DATA EXCURSION ABOUT THE EUROPEAN BULLHEAD Analyze data to see if there is a relationship between the size of an area and genetic diversity in European bullhead.	B-E	<i>Fish Study Data Excursion</i> , calculator, computer with internet access
3	9 min		INVESTIGATE CORRIDORS AND GENETIC DIVERSITY Analyze two different studies of humans implementing strategies to connect habitat.	F-K	<i>Fish Ladder Strategy, Making Sense of Fish Ladders</i>
4	8 min		BUILDING UNDERSTANDINGS DISCUSSION Facilitate a Building Understandings Discussion to explain why the genetic diversity decreased in the fish ladder study.	L-M	<i>Fish Ladder Strategy, Making Sense of Fish Ladders</i>
5	5 min		ELECTRONIC EXIT TICKET Give students time to complete an electronic exit ticket, individually.	N	computer with internet access, https://docs.google.com/forms/d/1K9lb61nggKIYgbszUl-emM2FCHn1mOb6W59oPUYS9go/copy , <i>Making Sense of Fish Ladders</i>
6	5 min		NAVIGATE AND HOME LEARNING Prepare for home learning and next steps.	O-Q	<i>Habitat Fragmentation Design Solution Home Learning</i>
End of day 1					
7	8 min		NAVIGATE Revisit community thoughts and concerns about strategies for reducing habitat fragmentation in urban areas.	R-S	<i>Habitat Fragmentation Design Solution Home Learning</i>
8	10 min		CREATE CRITERIA FOR URBAN DESIGNS Review the meaning of criteria and facilitate development of a list of criteria for urban designs that protect nonhuman populations from fragmentation.	T	Chart paper, chart paper markers
9	15 min		BRAINSTORM CRITERIA FOR INTEREST HOLDERS Provide students with additional information about the focal city of Buckeye, AZ. Facilitate a whole-class discussion about criteria from the perspective of local interest holders from that area.	U-Z	Criteria For Urban Planning chart, Laminated Buckeye Area Map or color printout of <i>Buckeye Area Map</i> .
10	7 min		UPDATE PROGRESS TRACKER Ask students to update their Progress Trackers.	AA	Criteria For Urban Designs chart
11	5 min		NAVIGATE Motivate students to think about what additional information from Buckeye, AZ they will need to refine their criteria.	BB	
End of day 2					

Lesson 9 • Materials List

	per student	per group	per class
Lesson materials	• <i>Progress Tracker</i> • <i>Fish Study Data Excursion</i> • calculator • computer with internet access • <i>Fish Ladder Strategy</i> • <i>Making Sense of Fish Ladders</i> • https://docs.google.com/forms/d/1K9lb61nggKIYgbszUL-emM2FCHn1mOb6W59oPUYS9go/copy • <i>Habitat Fragmentation Design Solution Home Learning</i> • science notebook		• Chart paper • chart paper markers • Criteria For Urban Planning chart • Laminated Buckeye Area Map or color printout of <i>Buckeye Area Map</i>. • Criteria For Urban Designs chart

Materials preparation (minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.
Provide an internet-connected device for each student.

For the exit ticket, make a copy of <https://docs.google.com/forms/d/1K9lb61nggKIYgbszUL-emM2FCHn1mOb6W59oPUYS9go/copy> and make the link to your local copy of the form accessible to students. See *Exit Ticket Guidance* for additional guidance.

Lesson 9 • Where We Are Going and NOT Going

Where We Are Going

This lesson has two goals: 1. To analyze the impact of wildlife corridors on expanding the genetic diversity of nonhuman populations, and 2. To apply the science of wildlife corridors to the development of criteria for protecting nonhuman wildlife from changes caused by urbanization. This lesson returns to the situation in Buckeye, AZ introduced in Lesson 7. Criteria students develop in this lesson will be applied in Lesson 10 when students learn more details about plans the city of Buckeye has for its expansion.

The evidence from this lesson works towards High School DCIs below:

LS4.C.3 *Adaptation also means that the distribution of traits in a population can change when conditions change.*

LS4.D.2 *Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.*

Students use elements of the science practices of *analyzing and interpreting data* to determine if wildlife corridors have the desired effect and *constructing explanations and designing solutions* to develop criteria for adding wildlife corridors to areas experiencing urbanization.

Students use elements of the crosscutting concepts of *cause and effect* and *stability and change* to consider the effectiveness of wildlife corridors for maintaining genetic diversity and therefore resilience in nonhuman populations.

Students encounter the term *correlation coefficient*, which was first introduced in Lesson 4, and co-construct the term *standard deviation* and add it to their personal glossaries. R^2 value is a term encountered in the optional *Statistics Extension*.

Where We Are NOT Going

The investigations in this lesson have students using a number of different mathematical and statistical tools to help them analyze the data. The purpose is to help students make sense of what information these tools and measures tell researchers rather than focusing on how to calculate the correlation coefficient or the standard deviation.

In this lesson, students begin thinking about variability and the spread of data. There is an opportunity for high-interest learners to do an extension using the statistical tool of r^2 in *Statistics Extension*. The r^2 value is a useful tool for researchers to help them understand how much of the dependent variable can be explained by the independent variable.

LEARNING PLAN for LESSON 9

1 · NAVIGATE

8 min

MATERIALS: *Progress Tracker*

Reflect on the model from Lesson 8. Display **slide A**. Provide a minute for students to review what they wrote at the end of the last lesson in *Progress Tracker*. Then facilitate a whole-class discussion using prompts on the slide.

Suggested prompts	Sample student responses	Follow-up questions
<i>What happened to the genetic diversity of the population over time during the model?</i>	It was different for each group based on the starting alleles. Fragmentation reduced the genetic diversity in generation 1, which changed the outcome in future generations. (Almost) all groups lost alleles in generation 1. Some lost alleles later too, depending on the selection pressure.	<i>Why did genetic diversity decrease?</i>
<i>If a different rule for a new selection pressure was added at the end of the model, what would happen to the population?</i>	It would depend what alleles were left in the population. They might be ok, or they might be helped, or they might be hurt. Fitness would change. They would have more or fewer offspring in each generation	<i>What if it was a harmful selection pressure, like Rule B?</i> <i>What if it was a helpful selection pressure, like Rule A?</i>
<i>What ideas did you have while you were running the model about protecting the panther population from losing genetic diversity?</i>	We could trade panthers with another group. Panthers could move from one group to another. Could we stop fragmentation somehow and keep the populations bigger? Can we protect them from selection pressures and getting hit by cars?	<i>How would that help the population maintain diversity?</i> <i>How might this happen in real life?</i>

2 · DATA EXCURSION ABOUT THE EUROPEAN BULLHEAD

10 min

MATERIALS: *Fish Study Data Excursion*, calculator, computer with internet access

Introduce a study about a fish, the European bullhead. Summarize student ideas. Say, *We have a lot of ideas from our Lesson 8 model about how we could protect populations from fragmentation. Let's look at some real world examples to see if there is a connection between how big the population is and/or how much space they have and higher genetic diversity.* Display **slides B** to introduce the European bullhead study. Let them know that the European bullhead is a fish that lives in rivers and streams. Ask students to first read the slide silently and then facilitate the following discussion.

Suggested prompt	Sample student response
What were researchers trying to study?	They wanted to see and understand the relationship between patch size and genetic diversity.
What is patch size measuring?	Patch size measures the amount of connected space fish have to swim and live in.
Researchers found a strong positive relationship between patch size and population size. What does this mean?	The larger the patch size, the larger the population.
How does patch size connect to ideas about habitat fragmentation?	Habitat fragmentation reduces the amount of space (patch size) populations can live in.

Small groups work on a Data Excursion. Organize students into small groups of 2-4. Make sure each group has access to an internet-connected device that can run CODAP. Distribute *Fish Study Data Excursion* to every student and make sure they have a calculator. Display **slide C** and point students to <https://www.openscienced.org/european-bullhead-data-excursion/>. Give small groups about 8 minutes to create a graph of the relationship between patch size and genetic diversity and answer questions on *Fish Study Data Excursion*. Tell students to be prepared to share their analysis of the graphs that helped them answer the investigation question to see if there is evidence that reducing fragmentation and connecting habitat help make populations more stable and resilient. *

ADDITIONAL GUIDANCE

Students should be familiar with the concept of independent and dependent variables from middle school and previous OpenSciEd Biology units. Students also encountered these ideas in Lesson 2. If students need support, provide them with the following definitions as they make sense of the data:

Independent variable - A variable whose variation does not depend on another variable.

Dependent variable - A variable whose variation changes as the independent variable changes.

Students should be familiar with the concept of correlation coefficient, r value, from Lesson 4. If students are still struggling with these terms, you can provide them with the following definition as they make sense of the data:

Correlation coefficient (r) is a quantitative measure of the strength of a linear relationship ranging from 0-1.

Additional guidance can be found in Additional guidance can be found in *Fish Data Excursion Key*

* SUPPORTING STUDENTS IN ENGAGING IN ANALYZING AND INTERPRETING DATA

The focus of this work is to ask students to use the correlation coefficient, r value, to determine the relative strength of the relationship between the independent and dependent variables. Students are building on ideas about the relationship between variables from Lesson 4 as well as from *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. When they create the scatterplot they can see that there is a strong positive relationship. The correlation coefficient (.79) can help them see the strength of that relationship quantitatively. The closer it is to 1, the stronger the relationship.

ADDITIONAL GUIDANCE

By this point, students should be familiar with using CODAP and interpreting the relationship between variables by looking at scatter plot graphs. If students are still struggling, first remind them how they figured out the relationship between variables from the work they did in Lesson 4 as well as past units like *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*. If students need additional guidance, then display **slide D** to remind them of what each of these relationships looks like on a scatter plot.

For high-interest learners, display **slide E** and use the extension *Statistics Extension* to investigate r^2 . Use the r^2 value definition to allow students to make sense of the relationship between the independent and dependent variables. Additional guidance can be found in *Statistics Extension Key*

R^2 value: a mathematical and statistical tool to quantify how much of the dependent variable can be explained by the independent variable.

Discuss the findings from the European bullhead data excursion. Bring the class back together to discuss their findings from *Fish Study Data Excursion*. Use prompts similar to the ones that follow to facilitate the discussion.

Suggested prompt	Sample student response
How does the correlation coefficient, r value, help us make sense of the relationships between variables on the graph?	It helps us understand how strong the relationship is between the variables.
What does the mean number of alleles measure?	It measures genetic diversity within the population.
What relationship did we observe between patch size and genetic diversity?	There was a strong positive relationship. This means that as the patch size increased, the genetic diversity also increased.
If we apply what we learn from this study to our urbanization questions, how would reducing fragmentation and connecting habitat help make populations more stable and resilient?	The more connected habitat there is, the larger the population it can support. More connected habitat also allows for greater genetic diversity by supporting more alleles in the population, which means there are more options available for adaptation if the environment changes.

3 · INVESTIGATE CORRIDORS AND GENETIC DIVERSITY

9 min

MATERIALS: *Fish Ladder Strategy, Making Sense of Fish Ladders*

Predict how wildlife corridors and fish ladders would impact wildlife populations. Display **slide F**. Say, *It sounds like connecting habitats to make larger areas might be a good solution for maintaining genetic diversity. I found some pictures of ways people have tried to create structures to connect habitat for different organisms. How do you think these structures would impact the populations and their overall genetic diversity?* Listen for ideas such as:

- These structures look like they would connect habitat where there is currently a barrier.

- We think that these structures would help the populations be more stable and resilient and allow them to have greater genetic diversity.

Introduce the wildlife corridor study. Say, *Let's look closer at these structures to see if they are helping nonhuman populations maintain their genetic diversity.* Display **slides G-H**. Allow students to read the slides, then quickly discuss the following questions:

- What was the physical barrier for bears in this study?
- How did people try to help bears overcome this barrier?
- What did researchers monitor to see if bear populations were resilient and were able to increase genetic diversity?

Turn and talk with a partner about wildlife corridor graphs. Display **slide I**. Allow students to work with a partner as they make sense of the graphs. After a few minutes, bring the class back together to have a short discussion. Use prompts similar to the ones that follow to facilitate the discussion.

Suggested prompts	Sample student responses	Follow-up questions
<i>What is the first graph showing?</i>	This graph is comparing the number of crossings and number of offspring for female bears.	
<i>Is there a relationship between these variables?</i>	No, there seems to be no difference in the number of offspring from females that use the crossings a lot compared to those who use them a little.	<i>How were you able to determine this?</i>
<i>What is the second graph showing?</i>	This graph is comparing the number of crossings and number of offspring for male bears.	
<i>Is there a relationship between these variables?</i>	Yes, there is a positive relationship. The more times a male bear uses a crossing, the more offspring they tend to have.	<i>What does this relationship mean?</i>
<i>How could more crossings and more offspring help maintain genetic diversity?</i>	These graphs are looking at the number of offspring, which is a product of reproduction. These graphs are also comparing it with the number of times each bear uses the crossing, which could allow for bears to reproduce with bears on the other side.	
<i>How does this study connect to the study about patch size?</i>	Both studies looked at the impact on genetic diversity as people looked at ways to connect habitat for species.	

Suggested prompts	Sample student responses	Follow-up questions
Display <i>slide J</i> . Allow students to read the statement. How does this genetic information about the bear population connect to population resilience and/or greater genetic diversity?	Both of the populations are genetically similar. This suggests that the bears from both sides of the highway are reproducing with each other, suggesting that they are not two separate populations. The corridor reduces fragmentation and helps maintain genetic diversity in the bears because males move across and mate.	Does this information suggest they are two separate populations? Explain.

 **Analyze the fish ladder study.** Display *slide K*. Summarize what we figured out from the bear study. Say, *We saw that connecting habitat using corridors allowed male bears to reproduce with bears on the other side of the highway, causing both populations to share alleles and maintain their genetic diversity. This works for bears, but I wonder if corridors can be used to help populations that have been fragmented for a while to recover their genetic diversity?* Explain that you have an article from a study where people connected the habitat of salmon using a fish ladder. Researchers expected the salmon population to become more diverse over time but did not see that in their findings. Suggest to students that they look closer at this study to understand why they got different results. Distribute *Fish Ladder Strategy* and *Making Sense of Fish Ladders* to every student. Allow students to work with a partner to answer the questions to help them make sense of the study and the data.

ASSESSMENT OPPORTUNITY

What to look for/listen for: When students **analyze the data** from *Fish Ladder Strategy*, look for responses on *Making Sense of Fish Ladders* that include: (SEP: 4.2)

- After the introduction of the **fish ladder**, the **mean size of fish decreased over time**. (CCC: 2.3; DCI: LS4C3)
- The **standard deviation of fish size decreased**, indicating that **fish ladders decreased the variation** of fish size. (SEP: 4.2; DCI: LS4C.3; CCC: 2.3)
- The **fish ladder** acted as a **selection pressure on the fish population that changed the distribution of traits**. (CCC: 2.3; DCI: LS4C3)

What to do:

- Collect *Making Sense of Fish Ladders* from each student. Circle places where students missed opportunities to identify patterns or relationships represented in the graphs to support their ideas in questions 5–9.
- Remind students how they analyzed graphs in the previous activities and lessons. Ask students to walk through how they analyzed those graphs and consider how they might use similar strategies to help them analyze these graphs.

Building toward 9.A.1 Apply statistics to determine how **designed systems** with connected habitats **change the distribution of traits in nonhuman populations when conditions change**. (SEP: 4.2; DCI: LS4C.3; CCC: 2.3)

4 · BUILDING UNDERSTANDINGS DISCUSSION

8 min

MATERIALS: *Fish Ladder Strategy, Making Sense of Fish Ladders*

Lead a Building Understandings Discussion to discuss why the fish ladder study decreased genetic diversity. Display slide L. Gather the class in a Scientists Circle with *Making Sense of Fish Ladders* and *Fish Ladder Strategy*. *

KEY IDEAS

Purpose of this discussion: To establish that in the fish ladder study, the genetic diversity decreased over time. This is a very different result than what students observed in the earlier studies where increasing the habitat increased genetic diversity. Students will reflect on other times in the unit where they observed genetic diversity decreasing and conclude that the fish ladder must be acting as a selection pressure on the population. In this study, the fish ladder allowed access for smaller fish, but larger fish were not able to access the ladder system. Following this discussion, students will co-construct a definition for the mathematical and statistical tool standard deviation that helped them make sense of the data.

The discussion is structured to help students use evidence from the data in the graphs to support their arguments.

Listen for these ideas:

- See the responses in the prompt/response table below.

* STRATEGIES FOR THIS BUILDING UNDERSTANDINGS DISCUSSION

Be explicit with students about your role in this discussion, which is to press students for evidence when they bring up ideas for what happened in the fish ladder study. Tell students explicitly, *My role in this discussion is to press for evidence. You might hear me ask, "Where did you see that?" It is my job to push us as a class to articulate the evidence we have to support our ideas.*

Suggested prompts	Sample student responses	Follow-up questions
<i>What happened to the size of the fish over time?</i>	The mean size of the fish decreased over time.	<i>What evidence from the data did you see that supported this?</i>
<i>Does just looking at the mean length of fish over time explain changes in genetic diversity? Explain.</i>	No, because the mean decreasing does not necessarily tell us if most of the fish were similar in size or not.	
<i>What does the standard deviation tell us about the fish using the fish ladder?</i>	The standard deviation tells us how much variation there is in length in the population.	
<i>The previous two studies showed that connecting habitats allows for an increase in genetic diversity. Did we observe similar findings in this study? Explain.</i>	No, we saw that there was less variation in the size of fish over time, which means that the genetic diversity is decreasing too.	<i>What evidence from the data did you see that supported this?</i>

Suggested prompts	Sample student responses	Follow-up questions
<i>This fish ladder system in this study was created to allow fish to have access to more connected habitat and increase genetic diversity. Was this design successful? Explain.</i>	It created a more connected habitat and changed the size of the fish. But it was not successful because the population became less genetically diverse over time. The fish ladder must have selected for smaller fish.	<i>How did the size variation of the fish in the population change?</i> <i>Why did it change?</i>
<i>How can we take what we figured out from the fish ladder study to create better designs in the future?</i>	We need to make sure that the designs that are proposed are not creating a new selection pressure on the population.	<i>Do you think a different design for the fish ladder would have a different outcome?</i> <i>How can we ensure that corridors are successful like they were in the first two studies?</i>

Add standard deviation to personal glossaries. Display slide M. Say, *We just used a new mathematical and statistical tool to help us analyze data. Let's take a minute to add a definition for our personal glossaries.*

ADDITIONAL GUIDANCE

As a class, add the definition of *standard deviation*.

Standard deviation: a mathematical and statistical tool to describe how much variation there is in the data.

The class definitions will vary from these sample definitions but may be similar. Encourage students to include pictures, symbols, and/or words in their definitions.

5 · ELECTRONIC EXIT TICKET

5 min

MATERIALS: computer with internet access, <https://docs.google.com/forms/d/1K9lb61nggKIYgbszUl-emM2FCHn1mOb6W59oPUYS9go/copy>, *Making Sense of Fish Ladders*



Complete an electronic exit ticket. Display slide N. Explain to students that you want to check in with everyone to see how well they are understanding the material. Have students complete the Electronic Exit Ticket <https://docs.google.com/forms/d/1K9lb61nggKIYgbszUl-emM2FCHn1mOb6W59oPUYS9go/copy>. Encourage students to use their notes and *Making Sense of Fish Ladders* to help them answer the questions on the electronic exit ticket.

ASSESSMENT OPPORTUNITY

What to look for/listen for:

- See *Electronic Exit Ticket Key* for guidance on student responses.

What to do: See *Exit Ticket Guidance* for instructions on how to make the electronic exit ticket. See *Electronic Exit Ticket Key* for guidance on student responses.

Building toward 9.A.2 Apply statistics to determine how designed systems with connected habitats change the distribution of traits in nonhuman populations when conditions change. (SEP: 4.2; DCI: LS4C.3; CCC: 2.3)

6 · NAVIGATE AND HOME LEARNING

5 min

MATERIALS: *Habitat Fragmentation Design Solution Home Learning*

Prepare for home learning. Say, *We uncovered some of the challenges and some benefits to humans designing ways to connect habitat in order to limit the effects of fragmentation with the case studies we read and discussed. Here are some additional designs that people have created to attempt to connect habitat.* Display slides O-Q. Introduce students to a range of different designs to address habitat fragmentation. Ask students if they have seen any of those strategies before and if not, if they think they might reduce habitat fragmentation in locations in their communities.

Say, *Let's talk to some community members and see what they think about these strategies for reducing habitat fragmentation and how well they might work for places we care about. Next time we meet, we can use their ideas to start thinking about criteria and/or concerns we would need to consider before implementing strategies.* Distribute *Habitat Fragmentation Design Solution Home Learning* in print or electronically to each student.

End of day 1

MATERIALS: *Habitat Fragmentation Design Solution Home Learning*

Turn and talk to share home learning. Display **slide R**. Ask students to share with a partner what they learned from their community members as they completed their *Habitat Fragmentation Design Solution Home Learning*. Record these ideas on a whiteboard or chart paper to reference later. Listen for students to share ideas such as:

- *My community members feel it is important to consider more than just humans.*
- *My community members are concerned about what types of organisms these strategies will attract or bring into the area.*
- *My community members think public and pet safety is important.*
- *My community members think money will be a concern in our community.*
- *My community members are concerned about the effects of any changes to the places they live.*

Say, *It sounds like there are a lot of requirements and concerns to strategies that prevent fragmentation in the communities you care about. Let us see if we can more clearly define what those requirements and concerns are.* Display **slide S**. Remind students about the nature-culture relationships they learned about in *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)* and *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)* and discuss how the differences between these two philosophies might influence someone's view on urban design. Use the prompts on the slide to lead a short discussion.

Suggested prompt	Sample student response
<i>What do we remember about these two different perspectives about nature and humans' place in it?</i>	The one on the left puts people on top—they are the most important—and see the ones below as resources they can use. People and nature are separate. On the left, humans are most important. On the right, humans and all nonhuman populations are equally important. On the right, people and nature are part of the same system.
<i>How might these perspectives influence people's ideas about designs for urban expansion?</i>	People whose perspective has the man on top of the pyramid prioritize human concerns over those of nonhumans. For the one on the left, people may be thinking about how the city design benefits them and think about how their property and personal life may be impacted. People whose perspective has humans alongside other organisms might look at how all organisms might be impacted by a proposed urban design. People on the right think people and animals are equally important for designing a city.

Say, *We need to keep in mind that communities will have people with both of these perspectives. As we think about urban areas that are expanding, we want to create designs for growth that address habitat fragmentation. These designs need to take into account both human and nonhuman populations. We should also keep in mind who the people with power are that make design decisions.*

ADDITIONAL GUIDANCE

In the Learning in Places framework, the term *nature-culture relations* helps us think about *how our unique cultures impact the decisions we make about human relations and the natural world*.

Learning in Places Collaborative (2022). Nature-Culture Relationships Framework. Bothell, Seattle, WA & Evanston, IL: Learning in Places. P. 1.

Read more about this at: http://learninginplaces.org/wp-content/uploads/2021/10/framework_Nature_Culture_Relations_rev101321.pdf

8 · CREATE CRITERIA FOR URBAN DESIGNS

10 min

MATERIALS: Chart paper, chart paper markers

Introduce criteria for urban designs. Say, *We should keep in mind what we have figured out about how nonhuman populations adapt or die due to small populations or fragmentation. We will want to know if urban planning designs can prevent these problems and support biodiversity.*

Create a class list for criteria for urban designs that minimize habitat fragmentation. *How would we decide if an engineering design is effective or not?* Display **slide T**. Remind students of the term *criteria*. Some students may already be familiar with this term from *OpenSciEd Unit B.2: What causes fires in ecosystems to burn and how should we manage them? (Fires Unit)*. Title a piece of chart paper “Criteria for Urban Designs.” Facilitate the development of a list of criteria on the left side of the page using the prompts on the slide. Call on several students for responses. An example of these ideas can be seen below.

Criteria For Urban Designs	
Class Criteria	
• Nonhuman populations do not get fragmented. • Provides good habitat for plants and animals. • Nonhuman populations maintain high fitness and high genetic diversity. • Nonhuman populations have a large protected habitat. • Minimal to no barriers for movement of nonhuman populations. • Put wildlife corridors over or under all roads. • Green roofs, native landscaping. • Large protected parks for nonhuman populations.	

9 · BRAINSTORM CRITERIA FOR INTEREST HOLDERS

15 min

MATERIALS: science notebook, Criteria For Urban Planning chart, Laminated Buckeye Area Map or color printout of *Buckeye Area Map*.

Revisit the situation in Buckeye. Ask students how the criteria they developed match up with the ideas they heard from the home learning assignment. Ask why the ideas differ. Listen for students to suggest that the class criteria only considered science related to nonhuman populations and did not think much about people's concerns. A city will contain humans and nonhumans. Affirm that it is important for designs to consider the needs of the local community. The things people value and care about in one community may be different than those in another. Say, *Let's go back to Buckeye, Arizona. Recall, this community has a rapidly growing human population, and there were concerns about the impact this would have on mountain lions and other nonhuman populations. Thinking about future urban designs for this area will be very important.* Display **slide U**. Make sure the Buckeye Area Map is on a wall where students can view it as they learn more about the region. Say, *So far we have only developed criteria regarding the general needs of the nonhuman populations. How might our criteria be different when we consider what is happening more broadly in this particular community? How might the people who live there feel about putting in structures to reduce fragmentation?* Facilitate a brief discussion of the slide prompts.

Suggested prompt	Sample student response
<i>What do we need to know about Buckeye to refine our criteria?</i>	We need to know more about the people who will be living in Buckeye and their needs. We need to know more about the plants and animals that live there and their needs. We need to know who various interest holders are.
<i>Why is it important to consider all of the interest holders in the area as we develop criteria?</i>	There might be needs we haven't considered yet. If our criteria are more informed by seeing what multiple interest holders have to say, the final urban designs are more likely to be effective for multiple interest holders, rather than just considering one perspective.

Brainstorm possible criteria from the perspective of people who live in Buckeye. Display **slide V**. Ask students to make a T-chart in their science notebooks, labeling it as it is shown on the slide. Inform students that they will work with a partner to discuss the information you will share with them to learn who the interest holders are in Buckeye and to brainstorm criteria for what the city needs to provide to different community members as the city grows and expands. Display **slides W-Y** for about one minute each, allowing students time to discuss and record their initial ideas in their science notebooks. Encourage students to defer judgment about whether an idea is good or bad and to instead get all ideas on the table.

Build a class list of criteria. Display **slide Z** and facilitate a discussion of the prompts on the slide to complete the right side of the *Criteria For Urban Planning* chart from the perspective of interest holders in Buckeye (see example below). Get input from a number of pairs of students to build this list. If students do not bring up economic issues, ask who is responsible for paying for the items the class suggested on the left side of the list. Also leverage ideas from the home learning to diversify items on the list. Once the list is complete, ask students to reflect on differences between the original class criteria and the interest holder criteria. Listen for students to recognize that the class criteria focused mainly on science ideas and perspectives of nonhuman populations, but adding in diverse interest holders brings in social and economic ideas that may conflict with the science. Mention that balancing these varied criteria may be challenging when creating urban designs. Keep this chart for use in Lesson 10.

Criteria For Urban Designs

Class Criteria	Interest Holder's Criteria
• Nonhuman populations do not get fragmented. • Provides good habitat for plants and animals. • Nonhuman populations maintain high fitness and high genetic diversity. • Nonhuman populations have a large protected habitat. • Minimal to no barriers for movement of nonhuman populations. • Put wildlife corridors over or under all roads. • Green roofs, native landscaping. • Large protected parks for nonhuman populations.	• Housing for all of the people who will live there. • Places to hike and bike. • Roads to commute, deliver materials, etc. • Cannot cost too much to build all the protections for animals. • Be safe for people to live there. • Enough water to live and farm. • People need jobs in Buckeye. • Respect the ancestral home of Indigenous people.

10 · UPDATE PROGRESS TRACKER

7 min

MATERIALS: Criteria For Urban Designs chart



Update Progress Tracker. Say, *We want to make sure we are being thorough and keeping track of everything we have figured out in this unit.* Display slide AA. Have students update their Progress Trackers following the prompts on the slide.

Lesson Number	Lesson Question	What I Figured Out in Words, Pictures, and/or Symbols	Questions I Have
9	How can we plan urban areas to protect genetic diversity in nonhuman populations?	-Keeping large populations in large areas maintains genetic diversity so populations can adapt to changing conditions. -We can maintain population resilience and genetic diversity by creating corridors to connect fragmented populations. -We can develop criteria for urbanization that sustains biodiversity that benefits humans and nonhuman populations. -Sometimes human and nonhuman needs may be in conflict.	-How are they planning to help the mountain lion? -Is the community of Buckeye considering urban designs to address habitat fragmentation? -Is it possible to make a design that is good for people and for animals? -How much do corridors cost to build?

ASSESSMENT OPPORTUNITY

What to look for/listen for: Students apply their scientific knowledge about maintaining genetic diversity (SEP: 6.3) to:

- Suggest maintaining large populations and reducing fragmentation to sustain biodiversity as humans urbanize ecosystems. (DCI: LS4.D.2; CCC: 7.4)
- Suggest creating corridors to connect fragmented populations to maintain biodiversity. (DCI: LS4.D.2; CCC: 7.4)
- Develop criteria for urbanization that benefit both human and nonhuman populations. (SEP: 6.3; DCI: LS4.D.2; CCC: 7.4)

What to do:

- Refer to the Criteria For Urban Designs chart. Ask, *What ideas do you see in both columns? Where are there conflicts?*
- Ask, *What strategies did we consider to reduce habitat fragmentation? Why would those work or not work well for nonhuman populations?*

Building toward: 9.B. Apply scientific principles to the design of a growing urban system to counteract the adverse impacts of human development with a goal to sustain biodiversity, including stable genetic diversity in nonhuman populations. (SEP: 6.3; DCI: LS4.D.2; CCC: 7.4)

11 • NAVIGATE

5 min

MATERIALS: None

Discuss what additional information is needed to help design urban spaces. Display slide BB. Ask students to turn and talk to brainstorm additional information they would need to refine their criteria and help them design a solution for Buckeye, AZ.

Additional Lesson 9 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Students learn about multiple scientific studies through readings, slides, and datasets and analyze and apply this information to determine if wildlife corridors help nonhuman populations maintain or increase genetic diversity.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively.

CCSS.MATH.CONTENT.S.ID Interpret differences in shape, center, and spread in the context of the data sets, accounting for possible effects of extreme data points (outliers). Represent data on two quantitative variables on a scatter plot and describe how the variables are related.

Students interpret scatter plots of data created with CODAP and describe how the variables are related. They interpret additional graphs and data to describe differences in mean and standard deviation for distribution of traits.

LESSON 10: How can we use what we know about natural selection to design cities that support resilient populations and ecosystems?

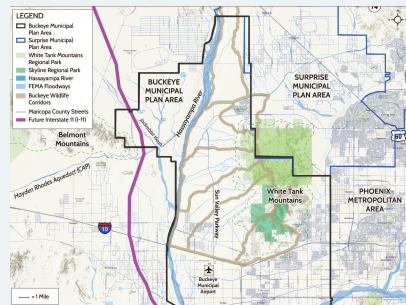
PREVIOUS LESSON

We reflected on the Lesson 8 model and wondered if we could help protect populations from fragmentation. We decided to investigate if connecting habitats to make them bigger helps nonhuman populations be more stable and resilient. We discovered there are different structures that humans use to connect habitat for nonhuman populations. We applied mathematical and statistical thinking to help us evaluate how effective these human structures are at removing barriers and connecting habitat. We returned to the city of Buckeye, AZ, where the population is rapidly growing. We thought about what criteria the community of Buckeye would need to consider if they were to add these structures. We wondered what the Buckeye community is currently planning.

THIS LESSON

PUTTING PIECES TOGETHER

2 days



Adapted from: White Tank Mountains Conservancy, (2021). Data sources: Imagine Buckeye 2040 General Plan. Buckeye, 2018. PDF. www.buckeyeaz.gov/business/development-services/planning-zoning/general-plan, General Plan Land Use. City of Buckeye. GIS data release, 3 Feb. 2020,

We investigate the conflicting requirements for protecting biodiversity while urbanizing and providing for the needs of human populations in Buckeye, AZ. We read about the movement requirements of mountain lions, mule deer and other wildlife. Then we compare our criteria from Lesson 9 to criteria and constraints developed by citizens of Buckeye. We evaluate two proposed designs for urbanizing Buckeye, AZ focusing on how to balance the needs of human and nonhuman populations. We consider how to apply what we learn to areas of concern to us.

NEXT LESSON

We will complete a transfer task to apply what we know about natural selection to consider ways to protect banana crops from fungal infections.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4, HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

10.A Evaluate competing design solutions in a real, complex expanding urban system based on scientific ideas related to creating more stable populations and ecosystems and relevant factors including a range of constraints. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4)

WHAT STUDENTS WILL FIGURE OUT

- Our knowledge of evolution by natural selection helps us evaluate the stability of a proposed urban system for nonhuman populations.
- Urban areas can be designed to prevent fragmentation and allow for gene flow.
- Making decisions involves evaluating the application of science ideas and balancing them with societal impacts.
- Land use decisions are complex, and it may be necessary to prioritize certain criteria over others.

Lesson 10 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	10 min		NAVIGATE: REVISIT THE DQB Facilitate a celebration of questions from the DQB that have been answered and focus students on the questions related to Buckeye that have not yet been answered.	A-B	Laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i> , dry erase markers
2	10 min		INVESTIGATE WILDLIFE REQUIREMENTS Student groups complete a visual inquiry to learn about wildlife needs in Buckeye.	C-D	internet-connected device, https://docs.google.com/presentation/d/135rlhHg2ZRhqsq3-wL9szmuNjKUVdBtSbSm-V28s8vQ/edit?usp=sharing , <i>Investigation Notes</i> , Laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i>
3	10 min		COMPARE CRITERIA AND CONSTRAINTS Students compare criteria and constraints from the city of Buckeye plan to those written by the class.	E-G	<i>Buckeye Criteria and Constraints</i> , <i>Investigation Notes</i> , Laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i> , Criteria for Urban Designs chart
4	13 min		READ PROPOSED DESIGNS FOR BUCKEYE Students read one of two proposals for developing Buckeye, AZ and summarize it to share with their group.	H-J	<i>Buckeye Development Designs</i> , <i>Buckeye Plan Evaluation Tool</i> , <i>Investigation Notes</i> , <i>Buckeye Plan Evaluation Tool Key</i>
5	2 min		NAVIGATE Explain that students will share their design summaries at the beginning of class tomorrow.	K	
End of day 1					
6	7 min		NAVIGATE: SHARE DESIGN SUMMARIES Students share the design summaries they wrote with other members of their group.	L	<i>Buckeye Development Designs</i> , <i>Buckeye Plan Evaluation Tool</i>
7	15 min		EVALUATE DESIGNS Students work together to evaluate two proposed designs for Buckeye.	M-N	<i>Buckeye Development Designs</i> , <i>Buckeye Plan Evaluation Tool</i> , <i>Investigation Notes</i> , <i>Buckeye Plan Evaluation Tool Key</i>
8	10 min		CONSENSUS DISCUSSION Facilitate a consensus discussion to evaluate the two proposed designs for the urbanization of Buckeye.	O-P	<i>Buckeye Plan Evaluation Tool</i> , laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i> , <i>Buckeye Plan Evaluation Tool Key</i>
9	10 min		REVISE EVALUATIONS AND APPLY LEARNING Celebrate the discussion as a class. Students revise their explanations to part 4 of <i>Buckeye Plan Evaluation Tool</i> and complete part 5.	Q-R	<i>Buckeye Plan Evaluation Tool</i> , <i>Buckeye Plan Evaluation Tool Key</i>
10	3 min		INTRODUCE FINAL TRANSFER TASK Prepare students for the final transfer task of the unit.	S	
End of day 2					

Lesson 10 • Materials List

	per student	per group	per class
Lesson materials	- internet-connected device https://docs.google.com/presentation/d/135rlhHg2ZRhsq3-wL9szmuNJKUVdBtSbSm-V28s8vQ/edit?usp=sharing <i>Investigation Notes</i> <i>Buckeye Criteria and Constraints</i> <i>Buckeye Development Designs</i> <i>Buckeye Plan Evaluation Tool</i> - science notebook		- Laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i> - dry erase markers - Criteria for Urban Designs chart <i>Buckeye Plan Evaluation Tool Key</i> - laminated Buckeye Area Map or color print out of <i>Buckeye Area Map</i>

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

- Three-hole-punch all handouts so they can be added to students' notebooks.
- Provide an internet connected device for all students to read <https://docs.google.com/presentation/d/135rlhHg2ZRhsq3-wL9szmuNJKUVdBtSbSm-V28s8vQ/edit?usp=sharing>.
- When possible, print all maps in color.
- Print *Buckeye Development Designs* as one-sided readings so students can read the bullets and see the map at the same time.

Lesson 10 • Where We Are Going and NOT Going

Where We Are Going

This lesson marks the completion of learning around the effect of urbanization on nonhuman populations for this unit (before applying ideas to a new phenomenon in the next lesson's transfer task). Throughout the unit, students have been making sense of science ideas to explain how urbanization interacts with evolution by natural selection. Fragmentation and habitat loss are understood as destabilizing to nonhuman populations. It can be disheartening for students to see nonhuman populations, which they care about, subject to changes at such a great magnitude. This lesson is to help students see themselves as agents of change, thus instilling hope in them that it is not too late to direct urban planning in a direction that can support biodiversity at a genetic, population and ecological level. This lesson focuses on engineering and the application of science learned throughout the unit to a real life situation. They will evaluate two proposed designs for protecting nonhuman populations in Buckeye, AZ as they experience rapid urbanization and a huge growth in human inhabitants. Students will need to balance the needs of the human and nonhuman populations to find the best design option.

The evidence from this lesson works towards High School DCIs below:

LS4.D.1: Biodiversity and Humans

Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.

ETS1.B.1.1: Developing Possible Solutions

When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics, and to consider social, cultural, and environmental impacts. (*secondary*)

Students use elements of the science practices of *engaging in argument from evidence* to evaluate two competing scenarios for the urbanization of Buckeye, AZ using scientific ideas and principles, as well as a variety of other relevant factors.

Students use elements of the crosscutting concept of *stability and change* to consider the generational impact of fragmentation and the proposed wildlife corridors for maintaining genetic diversity, biodiversity and therefore resilience in nonhuman populations, which allows them to adapt to future environmental changes and stabilizes the ecosystem.

Students encounter the terms washes and floodways.

Where We Are NOT Going

Although the proposal in question is in Arizona, where water rights are a significant problem, this lesson does not directly address the debate over water distribution as part of the urbanization dilemma. The city of Buckeye, AZ does have water as part of its general plan, which is available at <https://www.buckeyeaz.gov/business/development-services/planning-zoning/general-plan>.

This lesson also does not investigate in depth best practices for designing wildlife corridors in urban areas. If students are interested in investigating corridor design for this proposal with reference case studies from other parts of the country, refer them to the Buckeye Wildlife Corridors Best Practices Guide linked at <https://www.buckeyeaz.gov/business/development-services/planning-zoning/general-plan/wildlife-corridors>.

The White Tank Mountain Conservancy also provided significant assistance in the development of the focal phenomenon for the second lesson set. Teachers may wish to access additional images and information from the extensive White Tank Mountains Regional Connectivity Initiative Storyline as students evaluate the two development proposals presented in this lesson. <http://storymaps.arcgis.com/collections/6af114926f624c03a5ae89dfc69b9579?item=1>

LEARNING PLAN for LESSON 10

1 · NAVIGATE: REVISIT THE DQB

10 min

MATERIALS: Laminated Buckeye Area Map or color print out of *Buckeye Area Map*, dry erase markers

Revisit the Driving Question Board. Orient the class to the DQB created in Lesson 7. Display **slide A** and facilitate a discussion of the questions that have been answered about how fragmentation can cause reduced genetic diversity in nonhuman populations, but remain unanswered about Buckeye, AZ. Remind students that the goal was to figure out how we can use what we know about natural selection to design cities that have resilient populations and ecosystems. Celebrate the large number of questions that have been answered.

Motivate an investigation of Buckeye, AZ. Motivate students to answer their questions about how to protect nonhuman populations in Buckeye, AZ, which is rapidly growing. Display **slide B** as it supports discussion and circle the area where development is likely to occur on the laminated map of Buckeye. If necessary to increase motivation, mention that what they learn from the situation in Buckeye may also be useful in a situation important to them.

2 · INVESTIGATE WILDLIFE REQUIREMENTS

10 min

MATERIALS: internet-connected device, <https://docs.google.com/presentation/d/135rlhHg2ZRhsq3-wL9szmuNJKUVdBtSbSm-V28s8vQ/edit?usp=sharing>, *Investigation Notes*, Laminated Buckeye Area Map or color print out of *Buckeye Area Map*

Read about wildlife needs. Display **slide C**. Say, *In Lesson 7 we were introduced to the dilemma around mountain lions in the Buckeye region. We had questions on the DQB about their population and how the urbanization of Buckeye might affect them. I found some additional information that might be helpful.* Ask why mule deer are important to mountain lions. Listen for students to mention them as prey that are important to support the mountain lion. They may recall that Florida panthers eat one deer per week to survive and should assume similar needs for the mountain lion. Explain that they will work in groups with each person focusing on part of the visual inquiry using an internet-connected device, as described on the slide. As they read their assigned section, they should annotate places on the map on *Investigation Notes* they think are particularly important for protecting animals and their ecosystems to share with their group. Distribute the <https://docs.google.com/presentation/d/135rlhHg2ZRhsq3-wL9szmuNJKUVdBtSbSm-V28s8vQ/edit?usp=sharing> and *Investigation Notes* to each student and divide them into groups of 3 to work. Allow groups to decide who reads each section.

ALTERNATE ACTIVITY

Print color versions of visual inquiry slides B and D for each group so students can write on them directly as they discuss what the animals need and where the wildlife crossings are located.

Share wildlife needs within groups. After students have 5 minutes to read, display **slide D** and direct them to discuss the prompts. Remind students to take notes on what they learn from their peers on *Investigation Notes*.

3 · COMPARE CRITERIA AND CONSTRAINTS

10 min

MATERIALS: *Buckeye Criteria and Constraints*, *Investigation Notes*, Laminated Buckeye Area Map or color print out of *Buckeye Area Map*, Criteria for Urban Designs chart

Review criteria and constraints from Lesson 9. Say, *So we now know more about the needs of some nonhuman populations in the Buckeye region. As we talked about previously, we know the city of Buckeye is experiencing rapid urbanization.* Refer to the laminated class map and remind students where growth is expected in Buckeye and to think about how that impacts what they just learned about nonhuman populations.

Say, *Our goal is to find a design that meets the needs of both human and nonhuman populations over the long term. During the last lesson we wrote our own criteria to start thinking about this.* Display **slide E**. Direct students to take a minute to quietly review the Criteria for Urban Designs chart they created in Lesson 9.

Compare criteria and constraints to those from Buckeye. Say, *A few years ago the City of Buckeye created a plan for how they want to grow through 2040. They got input from thousands of their citizens and developed criteria and constraints for what was important to the people who live there.* Display **slide F** and point out the map showing one of the major constraints: the construction of I-11, a new interstate that connects Nevada and Arizona. Part of the new interstate runs through the western part of Buckeye. Ask students to turn and talk about the prompt on the slide. Ask a few pairs to share their ideas. Listen for students to mention the I-11 as a barrier to wildlife movement between the Hassayampa River and the Belmont Mountains. It may require a corridor or bridge of some type to prevent fragmentation and reduced gene flow for animals like the mountain lion that move along that route. Encourage students to add the location of the I-11 to the map on *Investigation Notes*.

Ask, *How do the criteria and constraints the citizens of Buckeye came up with compare with ours?* Display **slide G** and distribute *Buckeye Criteria and Constraints*. Provide time for students to read the criteria and constraints on their own. As they read they should also annotate *Investigation Notes*. After 3 minutes, ask students to briefly turn and talk with a partner about making sense questions on the handout and slide. After a few minutes, bring the class back together to answer clarifying questions about Buckeye and to share their noticings and wonderings. In particular, listen for students to mention the following items below that will be relevant to the designs they will see later.

- Focusing development around existing roads.
- Building a network of paths, trails and recreational opportunities in an equitable way throughout the city.
- Protecting natural habitat along the river and wash.
- Preserving the desert ecosystem and using native plantings for landscaping.

ADDITIONAL GUIDANCE

This is a brief introduction to the criteria and constraints developed by the city. Motivate students to raise questions, but do not answer them. Encourage them to bring those questions to the group work that follows where they look at the proposed designs. If students do not mention all of the above bullet points in this discussion, they will have a chance to revisit the criteria later. The bullets will help you support students, but it may take students longer to pull out these ideas as the most relevant criteria for the evaluation.

Criteria and constraints in this lesson were distilled from the Imagine Buckeye: General Plan 2040 Update. As an extension to DCI: ETS1.B.1, students could pursue answers to specific questions about Buckeye in this document. Note that there are many maps in this document that add detail to what is provided in the unit, but it could overwhelm students with information that distracts them from the goals of the lesson.

Matrix Design Group (2022) Imagine Buckeye: General Plan 2040 Update is available at: <https://www.buckeyeaz.gov/business/development-services/planning-zoning/general-plan>.

4 • READ PROPOSED DESIGNS FOR BUCKEYE

13 min

MATERIALS: *Buckeye Development Designs, Buckeye Plan Evaluation Tool, Investigation Notes, Buckeye Plan Evaluation Tool Key*



Facilitate the preliminary evaluation of proposed designs. Explain that you found two proposed designs that came out of discussions in Buckeye and that you would like students to read and evaluate them based on the needs of all the inhabitants of Buckeye, both human and nonhuman. Distribute *Buckeye Development Designs* and *Buckeye Plan Evaluation Tool*. Display **slide H** and answer the first question on *Buckeye Plan Evaluation Tool* together as a class. Briefly preview *Buckeye Development Designs* with students, pointing out the description and map for each design and provide an overview of the questions they will be completing on *Buckeye Plan Evaluation Tool*. Display **slide I** and explain that both designs include wildlife corridors along a “wash” or floodway similar to the image shown.

* ATTENDING TO EQUITY

Allow students to self-select who reads aloud and who finds locations on the map based on their strengths and interests.

They vary in terms of width, human use and vegetation. Display **slide J**. Divide students into groups of 4-5 and explain that half of the group will read one proposal and half read the other. Each sub-group should read the proposal and complete table 1 of the handout for their design. If they have time, they should begin to answer the questions in tables 2 and 3. Suggest that one student read each proposal aloud one bullet at a time, while the partner(s) look at the map noting the locations mentioned in the description. *

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: As students begin work on *Buckeye Development Designs*, *Buckeye Plan Evaluation Tool* look/listen for:

- Explanation of a goal of **designing for stability as maintaining large and/or connected nonhuman populations**. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4)
- Explanation of a **goal that the design maintains biodiversity both in numbers of species and genetic diversity**. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2)
- **Recognition of the constraints on nonhuman populations imposed by needs of a growing human population**. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2)
- **Noticing that wildlife corridors were included in the design, but wondering whether the size of the corridor is sufficient to maintain stable populations of mountain lion and mule deer**. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4)

What to do:

- Refer students to the scientific criteria for maintaining biodiversity they developed in Lesson 9.
- Direct students to the visual inquiry to think about corridor preferences for the mountain lion and mule deer.
- Display **slide B** again to allow students to determine where human and nonhuman populations are expected to intersect.

Building toward 10.A.1 Evaluate competing design solutions in a real, complex **expanding urban system** based on scientific ideas related to creating **more stable populations and ecosystems** and relevant factors including a **range of constraints**. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4)

Optionally, create laminated printouts of each design so students can write on the design with an erasable marker as they think about what is happening on days 1 and 2.

Remove the final page with the future transportation map for students who may be overwhelmed by receiving too much information at once. While the map shows a likely scenario that will impact wildlife movement, students can evaluate the two designs without it.

5 · NAVIGATE

2 min

MATERIALS: None

Prepare students to share what they learned. Display **slide K** and explain that students will share the summaries they wrote with the rest of their team in the next class. They should also be prepared to discuss how they think each design supports the science ideas we discussed and impacts on the people and communities of Buckeye.

End of day 1

6 · NAVIGATE: SHARE DESIGN SUMMARIES

7 min

MATERIALS: *Buckeye Development Designs*, *Buckeye Plan Evaluation Tool*

Share design summaries. Display **slide L**. In their groups, ask students to explain the two proposed designs to one another using the maps, *Buckeye Development Designs*, and summaries they wrote in *Buckeye Plan Evaluation Tool*. Encourage students to ask and answer clarifying questions about what is happening in each proposal.

7 · EVALUATE DESIGNS

15 min

MATERIALS: *Buckeye Development Designs, Buckeye Plan Evaluation Tool, Investigation Notes, Buckeye Plan Evaluation Tool Key*



Evaluate the designs as a group. Display **slide M** and facilitate group work to complete parts 1 and 2 of *Buckeye Plan Evaluation Tool*. As needed, remind individual groups about the Community Agreements for the classroom to ensure equitable participation.

After 10 minutes of group work, **display slide N** and ask students to answer the questions in part 4 on their own. They will have a chance to revise this response after the Consensus Discussion before turning it in. *

ASSESSMENT OPPORTUNITY

What to look/listen for in the moment: As students write and revise part 4 of *Buckeye Plan Evaluation Tool* and when you collect the revised responses at the end of class, look/listen for the ideas on *Buckeye Plan Evaluation Tool Key*.

What to do: See *Buckeye Plan Evaluation Tool Key*

Building toward 10.A.2 Evaluate competing design solutions in a real, complex expanding urban system based on scientific ideas related to creating more stable populations and ecosystems and relevant factors including a range of constraints. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4)

* ATTENDING TO EQUITY

For students who continue to struggle with writing explanations and need additional support to craft a response to the questions in part 4, provide them with some of the following sentence starters:

- It is better than design ____ because ____.
- This would stabilize the genetic diversity of nonhuman populations by ____.
- This would support biodiversity in the ecosystem by ____.
- Evidence I have to support that is ____ and ____.
- This would prevent problems caused by urbanization for the whole ecosystem by ____.
- This design meets the needs of the people of Buckeye because ____.

Provide alternative modalities for presenting their response.

- Allow students to record an answer to question 4 instead of writing it.
- Provide a clean copy of *Buckeye Area Map* for students to draw a compromise design.

8 · CONSENSUS DISCUSSION

10 min

MATERIALS: *Buckeye Plan Evaluation Tool, science notebook, laminated Buckeye Area Map or color print out of Buckeye Area Map, Buckeye Plan Evaluation Tool Key*

Facilitate a consensus discussion about the designs. Display **slide O**. Ask students to gather in a Scientists Circle. Have students bring their science notebooks and *Buckeye Plan Evaluation Tool*. Begin with a show of hands asking who chose proposal 1 and who chose proposal 2. Facilitate a discussion of the scientific merits of each proposal, criteria, and constraints, as well as any compromise designs students are considering. Use **slide P** as needed to talk about the designs. Listen for the key ideas in the callout box below. *

* STRATEGIES FOR THIS CONSENSUS DISCUSSION

It is important to accept all student responses and to encourage students to share their ideas. However, explain that it is your job to press students for evidence to support their responses. Further, it is important to highlight areas of disagreement and help students clearly explicate their

KEY IDEAS

Purpose of this discussion: To build consensus about the benefits and drawbacks of the two designs for the urbanization of Buckeye, AZ within the criteria and constraints developed by students and the city.

Listen for these ideas:

- See *Buckeye Plan Evaluation Tool Key*.
- Discussion balancing the need to protect biodiversity, including connected protected areas for nonhuman populations that maintain genetic diversity, with human needs related to urbanization.
- Wonderings about how people landscape their homes and if native plantings or green roofs could provide additional corridors for animals.
- Wonderings about whose perspectives were included or excluded when developing these designs.

thinking in these areas. Be careful not to favorably respond to any one idea over others so as not to favor one proposal over another.

Prompts for discussion:

- What ideas are we in agreement about?
- What key science ideas or data do we have that could help support or refute this argument or design?
- What seems important to the designer of this proposal that could be guiding their choices?
- Which criteria or constraint leads you to disagree with that statement?
- What changes could be made to the design that might meet the needs of both human and nonhuman populations?

9 • REVISE EVALUATIONS AND APPLY LEARNING

10 min

MATERIALS: *Buckeye Plan Evaluation Tool*, *Buckeye Plan Evaluation Tool Key*

Celebrate the thoughtful debate. Display slide Q. Commend students on their thoughtful evaluation and discussion. Mention that when this lesson was written, these issues were not yet settled. It is likely that in their lifetime they will have an opportunity to participate in similar discussions; question 5 on *Buckeye Plan Evaluation Tool* is an opportunity to think about what they might do for a situation of importance to them.

Provide time to revise answers to part 4 and complete part 5. Display slide R and explain that you would like students to reread and if necessary, revise their answers to part 4 based on what they heard in the class discussion. Encourage them to revise phrasing, add additional evidence or even switch support to a different design based on the discussion. To help them pick a location of interest for part 5, remind students of the investigations and home learning they did in Lessons 1 and 9 where they went outside to look for signs of urbanization, talked to friends and family about examples of the effect of urbanization on nonhuman populations, and discussed experience and opinions about wildlife corridors. Collect *Buckeye Plan Evaluation Tool* and assess responses using *Buckeye Plan Evaluation Tool Key*.

10 · INTRODUCE FINAL TRANSFER TASK

3 min

MATERIALS: science notebook

Prepare for the final transfer task. Display slide S. Say, *We have used our understanding of natural selection to evaluate designs for cities that support resilient populations and ecosystems in specific locations. In the next class, we will see if you can apply the concepts you learned to a new phenomenon.* Suggest that students organize their science notebook so they can use it during the transfer task tomorrow.

Additional Lesson 10 Teacher Guidance

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN ELA

RST.11-12.7 Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g., quantitative data, video, multimedia) in order to address a question or solve a problem.

Students integrate information from scientific sources, municipal documents and conservation plans presented in written and visual formats to evaluate the merits of two proposed designs for the urbanization of Buckeye.

SUPPORTING STUDENTS IN MAKING CONNECTIONS IN MATH

CCSS.MATH.PRACTICE.MP2 Reason abstractly and quantitatively.

Students evaluate the proposed width of wildlife corridors against the measured needs of nonhuman populations. They also interpret multiple maps, which involves spatial reasoning.

LESSON 11: Can we apply what we know about natural selection and genetic diversity to a novel phenomenon?

PREVIOUS LESSON

We investigated the conflicting requirements for protecting biodiversity while urbanizing and providing for the needs of human populations in Buckeye, AZ. We read about the movement requirements of mountain lions, mule deer and other wildlife. Then we compared our criteria from Lesson 9 to criteria and constraints developed by citizens of Buckeye. We evaluated two proposed designs for urbanizing Buckeye, AZ focusing on how to balance the needs of human and nonhuman populations. We considered how to apply what we learn to areas of concern to us.

THIS LESSON

PUTTING PIECES TOGETHER

1 day



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We complete a transfer task to apply what we know about natural selection to consider ways to protect banana crops from fungal infections.

NEXT LESSON

There is no next lesson.

BUILDING TOWARD NGSS

HS-LS4-2, HS-LS4-3, HS-LS4-4,
HS-LS4-5, HS-LS4-6, HS-ETS1-3



WHAT STUDENTS WILL DO

11.A 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. (SEP: 4.2; DCI: LS4.B.1, LS4.B.2, LS4.C.2, LS4.C.3 ; CCC: 1.1)

WHAT STUDENTS WILL FIGURE OUT

- There is a pattern of fungal infections attacking banana populations.
- Most banana crops are grown clonally and have no genetic diversity.
- Scientists can create genetically modified bananas with resistance to one fungus.
- As long as farmers grow only one genetic variety of banana, they will be vulnerable to infections.

Lesson 11 • Learning Plan Snapshot

Part	Duration		Summary	Slide	Materials
1	8 min		NAVIGATE Students review Progress Tracker and notes in preparation for the transfer task.	A	<i>Progress Tracker</i>
2	3 min		INTRODUCE PHENOMENA Watch a video that introduces the problem that bananas may become extinct.	B	<i>Transcript: Introduction to the Banana Task</i> , https://youtu.be/C2V9OnUBR0s
3	32 min		COMPLETE A TRANSFER TASK Orient students to and administer the transfer task.	C	<i>Banana Transfer Task, Progress Tracker Key</i>
4	2 min		NAVIGATE Celebrate student accomplishments.	D	

End of day 1

Lesson 11 • Materials List

	per student	per group	per class
Lesson materials	- science notebook <i>Progress Tracker</i> <i>Transcript: Introduction to the Banana Task</i> <i>Banana Transfer Task</i>		https://youtu.be/C2V9OnUBROs <i>Progress Tracker Key</i>

Materials preparation (20 minutes)

Review teacher guide, slides, and teacher references or keys (if applicable).

Make copies of handouts and ensure sufficient copies of student references, readings, and procedures are available.

Three-hole-punch all handouts so they can be added to students' notebooks.

Lesson 11 • Where We Are Going and NOT Going

Where We Are Going

This lesson is the culminating lesson in the unit. Students complete a transfer task to apply what they have figured out about many of the key ideas of the unit.

Where We Are NOT Going

The introductory phenomenon video mentions a genetically modified (GM) banana variety that could save the fruit from extinction, but Europe has strict regulations on GMs and will not accept those bananas. Students may have questions about why Europe has such strict regulations on GM organisms, but this transfer task will not address this topic. Encourage high interest students to do some additional research on their own and consider allowing them to report what they discover to the rest of the class.

LEARNING PLAN for LESSON 11

1 · NAVIGATE

8 min

MATERIALS: science notebook, *Progress Tracker*

Review science notebook and Progress Tracker. Display **slide A**. Say, *We have figured out a lot of great science ideas in this unit about how to use our understanding of natural selection to design cities that have resilient populations and ecosystems. Today, you will have a chance to apply your understanding of natural selection and the importance of maintaining genetic diversity in populations to another phenomenon.* Ask students to review *Progress Tracker* and any additional materials they wish in their science notebooks.

2 · INTRODUCE PHENOMENA

3 min

MATERIALS: *Transcript: Introduction to the Banana Task*, <https://youtu.be/C2V9OnUBROs>

Introduce the phenomena. Ask students if they or people in their family eat bananas. Display **slide B**. Distribute a copy of *Transcript: Introduction to the Banana Task* to every student. Say, *I recently learned that bananas are in danger! I have a video that introduces a situation where scientists are trying to save and protect bananas from becoming extinct. As we watch this video, highlight or underline what information about bananas and the situation will be important to figuring out if we can protect them. Record any questions you have on Transcript: Introduction to the Banana Task.* Play <https://youtu.be/C2V9OnUBROs>, allowing students to watch and listen to the video while annotating the transcript.

3 · COMPLETE A TRANSFER TASK

32 min

MATERIALS: *Banana Transfer Task*, *Progress Tracker Key*

Orient students to the Banana Transfer Task. Display **slide C**. Distribute *Banana Transfer Task* and give students a few minutes to read over additional information about the scenario. Then allow students to ask clarifying questions from the video or scenario. Consider allowing your students to use their completed *Progress Trackers* to support them as they complete the transfer task.



Administer the task. Give students the rest of the period to complete the task, then collect assessments before students leave.

ASSESSMENT OPPORTUNITY

What to look for/listen for in the moment: After students complete *Banana Transfer Task*, use *Progress Tracker Key* to evaluate their responses.

What to do: Provide feedback using *Progress Tracker Key* as guidance.

Building toward 11.A 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. (SEP: 4.2; DCI: LS4.B.1, LS4.B.2, LS4.C.2, LS4.C.3; CCC: 1.1)

4 · NAVIGATE

2 min

MATERIALS: None

Close the unit. Display **slide D**. Congratulate students on all that they have figured out throughout the unit about how evolution by natural selection works and how we can use what we know to design cities with resilient populations and ecosystems.



Unit B.4 Teacher Reference Materials



ASSESSMENT SYSTEM OVERVIEW

Each OpenSciEd unit includes an assessment system that offers many opportunities for different types of assessments throughout the lessons, including pre-assessment, formative assessment, summative assessment, and student self assessment. Formative assessments are embedded and called out directly in the lesson plans. Please look for the “Assessment Icon” in the teacher support boxes to identify places for assessments. In addition, the table below outlines where each type of assessment can be found in the unit.

Overall Unit Assessment

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 1	List environmental components and interactions of cities Develop initial individual models Driving Question Board	Pre-Assessment The student work in Lesson 1 should be considered a pre-assessment. It is an opportunity to learn more about the ideas your students bring to this unit. Hearing these ideas early on can help you be more strategic in how to build from and leverage student ideas across the unit. The list of environmental components and interactions of cities on day 1 of Lesson 1 is a good opportunity to pre-assess student understanding of how students define and identify the important components and interactions of the urban systems. The initial individual models students draw on day 2 are also a way to assess what students may know about how populations change through adaptation by natural selection and what other ideas they are bringing to bear on the Driving Question. Make note of mechanisms they propose and whether they believe changes happen within individuals or populations. The Driving Question Board is another opportunity for pre-assessment. Reinforce for students to generate open-ended questions, such as how and why questions, and to post to the board. However, any questions students share, even if they are close-ended questions, can be valuable. Make note of any close-ended questions and use navigation time throughout the unit to have your students practice turning these questions into open-ended questions when they relate to the investigations underway
Lesson 2	Exit ticket Discuss initial explanations <i>Seed Dispersal Investigation</i> <i>Hawksbeard Garden Experiment</i> <i>Rat Cross Model Key</i> Driving Question Board	Formative At the end of day 1, students submit an exit ticket summarizing what they learned from the investigation and limitations of the investigation. The ideas discussed here will be used to guide day 2 discussion. On day 2, students discuss their initial formal group explanations of seed dispersal strategies in hawksbeard based on their investigations. This is a first check in students' ability to engage in SEP 6: <i>Constructing explanations and designing solutions</i>. Students read about common garden experiments and learn how they are useful for controlling variables to discover if adaptations are heritable. Formative This Driving Question Board check-in allows students to see if they have answered any of their initial questions and then decide what questions remain unanswered. These serve as motivation for further investigations in the unit.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 3	<i>Historical Rat Study</i> Building Understandings Rat Modeling Investigation Rat Cross Model Key Rat Poison Explanation Rat Cross Model Key Rat Poison Explanation	Formative On day 1, students read about a historical study where rats are poisoned. They discuss how historical information applies to a modern phenomenon in Tokyo. This check-in also allows teachers to discuss students' feelings about the ethics of animal studies. On day 2, the teacher facilitates a discussion of what students understand about data collected from the rat model to connect genetics to the process of natural selection. Formative Students revise their explanation of how 80% of Tokyo rats developed resistance to poison. Self-Assessment On day 2, students do a self-assessment of their ability to construct and revise explanations, focusing on SEP 4.5 and 6.2.
Lesson 4	<i>Exploring Juncos' Environment</i> <i>Exploring Juncos' Environment</i> <i>Junco Data Excursion</i> Lesson 4 Electronic Exit Ticket Electronic Exit Ticket Key	Formative Students read about the design of and interpret outcomes from the common garden experiment to learn if boldness in juncos is learned or inherited. Students read about the design and interpret the outcomes of experiments to measure CORT levels in the blood of birds from different environments under similarly stressful conditions. Students analyze data about CORT levels and exploratory behavior in juncos using CODAP. They interpret the statistical relationship between the variables. Formative + Self-Assessment + Community Building The first electronic exit ticket allows relatively quick individual assessment of students on the 3D elements associated with the lesson-level performance expectations. Teachers can quickly check students' understanding of how to compare and contrast graphs from a field test and common garden experiment to use as evidence to support a relationship between behavior and environment, to see if more practice is necessary, but students also have an opportunity here to reflect on their classroom culture and contributions and engage with metacognitive questions around their own lives, how they used science and engineering practices and crosscutting concepts in sensemaking, and the value of their classmates in supporting their learning.
Lesson 5	<i>Population Change Theories</i> <i>Models of Population Change Key</i>	Formative Students read about different theories of evolution and evaluate which is closest to the class model.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 6	<i>Antibiotic Resistance Transfer Task</i> <i>Antibiotic Resistance Task Key</i>	Formative + Summative Mid-Unit Transfer Task This mid-unit transfer task uses the novel task of antibiotic resistance in bacteria to construct an explanation for how populations adapt via evolution by natural selection. It assesses HS LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations.
Lesson 7	Driving Question Board	Formative This Driving Question Board check-in allows students to add new questions that may have come up after investigating the Florida panther around how urbanization could cause reduced fitness in populations and threaten their survival. Also, they will note that they do not have many questions on the DQB that will help them make progress on what to do about populations that are harmed by urbanization. Formative This second Driving Question Board check-in allows students to add new questions about how they can design cities to support resilient populations.
Lesson 8	<i>Fragmentation Investigation</i> <i>Model Instructions/Key</i>	Formative This assessment opportunity asks students to generate allele frequency and fitness data for a fragmented population undergoing a selection pressure and compare results to what happens to other groups. Students do their data collection and initial data analysis in groups and then compare between groups.
Lesson 9	<i>Fish Study Data Excursion</i> <i>Fish Data Excursion Key</i> Lesson 9 Electronic Exit Ticket <i>Electronic Exit Ticket Key</i>	Formative Students developed the Lesson 8 model about how they could protect populations from fragmentation, so in this lesson they look at real world examples to see if there is a connection between how big the population is and higher genetic diversity on <i>Fish Study Data Excursion</i> . Formative + Self-Assessment + Community Building This second and final electronic exit ticket focuses on how they can apply statistics to determine how designed systems with connected habitats change the distribution of traits in nonhuman populations when conditions change. It also provides an opportunity for students to share their thinking about the importance of considering cause and effect when designing possible solutions and to reflect on the practice of analyzing and interpreting data in their sensemaking. Finally, students again celebrate how they have helped the class make progress.
Lesson 10	Driving Question Board Consensus Discussion <i>Buckeye Plan Evaluation Tool</i> <i>Buckeye Plan Evaluation Tool Key</i>	Formative + Summative The final Driving Question Board check-in allows students to celebrate everything they have figured out in the unit. Students can also identify questions that remain related to the City of Buckeye, which they will address in this lesson. Formative + Summative The teacher facilitates this assessment opportunity where students will discuss the merits and drawbacks of the two proposed designs for Buckeye, AZ, applying the scientific and social criteria and constraints developed earlier. They will use this discussion to revise their final formal assessment on <i>Buckeye Plan Evaluation Tool</i> . Students turn in their final revised evaluation of the proposals for summative assessment.

When	Assessment and Scoring Guidance	Purpose of Assessment
Lesson 11	<i>Banana Transfer Task Progress Tracker Key</i>	Summative End-of-Unit Transfer Task This end-of-unit transfer task engages students with the novel phenomenon of engineering bananas resistant to fungus, which can be explained using ideas from the unit. It assesses students on 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. This task is robust and will take approximately 30-45 minutes. The ideas, crosscutting concepts, and practices students engage with as part of completing this assessment can be found at the top of the Scoring Guidance (key). Please use scoring that works for your class and your requirements. We strongly recommend that you encourage students to use their notebooks as a resource for completing all assessments.
After each lesson	Lesson Performance Expectation Assessment Guidance	Formative Assessment Use this document to see which parts of lessons or student activity sheets can be used as embedded formative assessments.
Occurs in several lessons	<i>Progress Tracker</i>	Formative and Student Self-Assessment The Progress Trackers are thinking tools designed to help students keep track of important discoveries that the class makes while investigating phenomena. They help to figure out how to prioritize and use those discoveries to develop a model to explain phenomena. It is important that what the students write in the Progress Trackers reflects their own thinking at that particular moment in time. In this way, the Progress Trackers can be used to formatively assess individual student progress or for students to assess their own understanding throughout the unit. Because the Progress Tracker is meant to be a thinking tool for kids, we strongly suggest it is not collected for a summative “grade” other than for completion. Students add or revisit their Progress Trackers in Lessons 2, 4, 8, and 9.
Any time after discussion	Teacher Background Information	Self-Assessment This resource is available in the <i>OpenSciEd Teacher Handbook: High School Science</i>. The student self-assessment discussion rubric can be used anytime after a discussion to help students reflect on their participation in the class that day. Choose to use this at least once a week or once every other week. Initially, you might give students ideas for what they can try to improve for the next time, such as sentence starters for discussions. As students gain practice and proficiency with discussions, ask for their ideas about how the classroom and small-group discussions can be more productive. Opportunities for individual self-assessment and reflection outside of this tool may be found in the electronic exit tickets in Lessons 4 and 9 as well as in Lesson 3.

When	Assessment and Scoring Guidance	Purpose of Assessment
Peer Assessment	Teacher Background Information	Peer-Assessment This resource is available in the <i>OpenSciEd Teacher Handbook: High School Science</i> and should be used as needed. Facilitating students to give each other feedback is very valuable for their three-dimensional learning. Additionally, peer feedback can support teachers in managing the time-intensive demands of individualized feedback. We suggest that peer review happen at least two times per unit. Peer feedback is most useful when there are complex and diverse ideas visible in student work. That is, peer feedback works best when not all work is the same. Student models and explanations are good times to use a peer feedback protocol. They do not need to be final pieces of student work. Rather, peer feedback will be more valuable to students if they have time to revise after receiving peer feedback. It should be a formative, not summative, type of assessment. It is also necessary for students to have experience with past investigations, observations, and activities where they can use these experiences as evidence for their feedback. Lesson 4 contains an opportunity for peer-assessment.

For more information about the OpenSciEd approach to assessment and general program rubrics, visit the OpenSciEd Teacher Handbook.

Lesson-by-Lesson Assessment Opportunities

Every OpenSciEd lesson includes one or more lesson-level performance expectations (LLPEs). The structure of every LLPE is designed to be a three-dimensional learning, combining elements of science and engineering practices, disciplinary core ideas and cross cutting concepts. The font used in the LLPE indicates the source/alignment of each piece of the text used in the statement as it relates to the NGSS dimensions: alignment to [Science and Engineering Practice\(s\)](#), alignment to [Cross-Cutting Concept\(s\)](#), and alignment to the [Disciplinary Core Ideas](#).

The table below summarizes opportunities in each lesson for assessing every lesson-level performance expectation (LLPE). Examples of these opportunities include student handouts, home learning assignments, progress trackers, or student discussions. Most LLPEs are recommended as potential formative assessments. Assessing every LLPE listed can be logistically difficult. Strategically picking which LLPEs to assess and how to provide timely and informative feedback to students on their progress toward meeting these is left to the teacher's discretion.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
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Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 1	1.A Ask questions based on observations about potential effects of urbanization on the survival of nonhuman populations. (SEP: 1.1; DCI: LS4.C.4; CCC: 2.4) 1.B Develop and revise models to illustrate the cause and effect relationship between increasing urbanization and survival of nonhuman populations. (SEP 2.3; DCI: LS4.B.2; CCC: 2.2) 1.C Ask and refine questions about the cause and effect of increasing urbanization on the survival of nonhuman populations that can be investigated with available resources. (SEP 1.6; DCI: LS4.C.4; CCC: 2.2)	When to check for understanding: On day 1, when students ask questions about the effects of urbanization on nonhuman populations. What to look for/listen for in the moment: Questions (SEP 1.1) related to: • Unequal changes to the survival rates of some nonhuman populations. (CCC: 2.4; DCI: LS4.C.4) • Examples of changes to nonhuman populations based on changes in cities. (CCC: 2.4; DCI: LS4.C.4) When to check for understanding: When students develop models on day 2. What to look for/listen for in the moment: Models that explain and/or predict (SEP 2.3): • Effects of urbanization over time indicating increased survival and/or reproduction of some individuals. (DCI: LS4.B.2) • Addition of or questions about mechanisms that cause change in survival and/or reproduction of some individuals. (CCC: 2.2; DCI: LS4.B.2) • Description of how urbanization causes change in nonhuman populations. (SEP 2.3; CCC: 2.2) When to check for understanding: On day 3, as students create the Driving Question Board. What to look for/listen for in the moment: • Evaluation and revision of questions that can be answered with available resources through cause and effect investigations. (SEP 1.6; CCC: 2.2) • Questions clustering around the cause and effect of urbanization on the survival of nonhuman populations living in cities. (SEP 1.6; CCC: 2.2; DCI: LS4.C.4) • Questions that focus on the mechanisms that affect nonhuman populations. (SEP 1.6; CCC: 2.2; DCI: LS4.C.4)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 2	2.A Make a directional hypothesis to explain how fragmentation could cause the proportion of traits related to seed dispersal to change in hawksbeard populations. (SEP: 3.5; DCI: LS4.B.2; CCC: 2.1) 2.B Incorporate new data into an explanation of how different traits could become more common in fragmented hawksbeard populations, increasing the chance of survival and opportunity for reproduction. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1) 2.C Compare and contrast how self-generated and published data support the claim that differential survival and opportunity to pass on heritable traits could lead to adaptation in hawksbeard seed dispersal traits. (SEP: 4.4; DCI: LS4.C.2; CCC: 2.1)	When to check for understanding: On day 1, as students answer and discuss questions 1 and 2 on <i>Seed Dispersal Investigation</i>. What to look/listen for in the moment: • Identification of the proportion of surviving nonfeathery and feathery seeds as the dependent variable or effect of fragmentation. (SEP: 3.5; DCI: LS4.B.2; CCC: 2.1) • Identification of fragmented or unfragmented plots as the independent variable as the cause for change. (SEP: 3.5; CCC: 2.1) • A logical prediction that the proportion of each seed type will increase or decrease as a result of fragmentation. (SEP: 3.5; DCI: LS4.B.2; CCC: 2.1) When to check for understanding: On day 1, when groups conduct and analyze their investigation on seed dispersal. What to look for/listen for in the moment: • The collection of data related to the proportion of feathery and nonfeathery seeds with the potential to survive. (SEP: 4.5; DCI: LS4.B.2) • Discussion and writing of explanations about the higher potential for survival and germination of nonfeathery seeds in small fragmented plots compared to large ones. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1) • Discussion and writing about how the new data supports or refutes hypotheses about the effect of urbanization on hawksbeard seed type. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1) • Discussion and writing of explanations of how fragmentation causes fewer feathery seeds to land on soil. (SEP: 4.5; DCI: LS4.B.2; CCC: 2.1) • Questions about the changes in proportion of seed type over generations of plants. (SEP: 4.5; DCI: LS4.B.2) When to check for understanding: On day 2, when students read and discuss <i>Hawksbeard Garden Experiment</i>. What to look for/listen for in the moment: Students comparing the results of their investigation to the investigation described in <i>Hawksbeard Garden Experiment</i> to build their explanation (SEP 4.4) including: • Evidence from both investigations that not all hawksbeard seeds will land in a place where they have a chance to germinate. (SEP: 4.4; DCI: LS4.C.2) • Evidence from both investigations that nonfeathery seeds are anatomically suited to survive and likely to germinate in fragmented places. (SEP: 4.4; DCI: LS4.C.2) • Evidence from both investigations that fragmentation may be a selection pressure that causes a change in the proportion of different seed types that have the potential to survive and germinate. (SEP: 4.4; DCI: LS4.C.2; CCC 2.1) • The proportion of nonfeathery and feathery seeds produced in hawksbeard is likely to be inherited. (DCI: LS4.C.2) • The how common garden experiments generated empirical data that more closely models the natural system to illustrate the effect of fragmentation on hawksbeard. (SEP: 4.4; CCC 2.1) • Discussion of how common garden experiments control variables allowing them to eliminate other variables that might have an effect on the variables. (CCC: 2.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 3	3.A Construct an explanation based on patterns of evidence at the genetic and population scale for rat poison as a selection pressure that causes some rats with particular variations to survive better and therefore reproduce when exposed to poison. (SEP: 6.2; DCI: LS4.B.1; CCC: 1.1) 3.B. Construct and revise an explanation based on evidence from a variety of sources that suggests how individual genetic mutations cause physiological advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to differential reproduction and an increased number of rats in the entire population that carry adaptive genetic variations. (SEP: 6.2; DCI: LS4.B.1, LS4.C.1; CCC: 2.2)	3.A When to check for understanding: On day 1, when students write or draw an explanation (SEP 6.2) for the results from <i>Rat Modeling Investigation</i>. What to look for/listen for: • See <i>Rat Cross Model Key</i>. • Changes in the dominance pattern of red vs. blue alleles before and after the introduction of poison. (DCI: LS4.B.1; CCC: 1.1) • Changes in the percentage of rats carrying the red allele before and after the introduction of poison. (SEP: 6.2; DCI: LS4.B.1; CCC: 1.1) • Explanation of poison as a cause of differential survival and reproduction for some rats. (SEP: 6.2; DCI: LS4.B.1; CCC: 1.1) 3.B.1 When to check for understanding: On day 2, as students stop and jot about how the new evidence supports the revision of their explanations (SEP 6.2). What to look for/listen for: • Rats reproduce often and in large numbers, so if even a small number survive poison, they grow to a big population quickly. (DCI: LS4.B.1, LS4.C.1; CCC: 2.2) • Different mutations exist in different parts of Europe. There are multiple ways (different proteins) rats can be resistant to poison. (DCI: LS4.B.1, LS4.C.1; CCC: 2.2) • Each mutation causes the VKOR gene to be expressed differently and provides resistance to a different amount of poison. (DCI: LS4.B.1, LS4.C.1; CCC: 2.2) • Having two mutated alleles can make more protein that provide resistance compared to just one allele. (DCI: LS4.B.1, LS4.C.1, CCC: 2.2) 3.B.2 When to check for understanding: On day 3, when students complete <i>Rat Poison Explanation</i>. What to look/listen for: See <i>Rat Poison Explanation Key</i> for guidance.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 4	4.A Use evidence from a field test and common garden experiment to support an explanation about how boldness could cause juncos to have a competitive advantage affecting the number of bold juncos in the population. (SEP: 4.4; DCI: LS4.C.1; CCC: 2.1) 4.B Develop a model based on evidence to explain how bold juncos could have been well suited to survive and reproduce in an urban environment resulting in a population with an increased proportion of bold birds. (SEP: 2.3; DCI: LS4.C.2; CCC: 2.1) 4.C Compare and contrast graphs from a field test and common garden experiment to use as evidence to support a relationship between behavior and environment. (SEP: 4.4; DCI: LS4.C.2; CCC: 2.1)	4.A When to check for understanding: On day 1, when students complete <i>Making Sense: Juncos</i>. What to look for/listen for in the moment: - The common garden experiment controlled variables to help isolate the inheritance as the cause of boldness in juncos. (SEP: 4.4; CCC: 2.1) - Data from both sources show that UCSD juncos are bolder than Mt. Laguna juncos. (SEP: 4.4) - Bolder juncos would be better able to compete for resources at UCSD and therefore, survive and reproduce more. (DCI: LS4.C.1) - Additional evidence about the mechanism of inheritance is needed to fully explain natural selection. (DCI: LS4.C.1; CCC: 2.1) 4.B When to check for understanding: When students make their initial models on day 2 and revise those models on day 3. What to look for/listen for in the moment: models that propose an initial explanation including: (SEP: 2.3). - Variation in boldness in the junco population. (DCI: LS4.C.2) - Inheritance of boldness in juncos. (DCI: LS4.C.2) - Differences in the traits in the two populations, bolder individuals staying at UCSD year round. (DCI: LS4.C.2) - Factors that caused them to stay, such as not being afraid, being able to get food, and make nests. (DCI: LS4.C.2; CCC: 2.1) 4.C When to check for understanding: On day 3 when students complete an <i>Electronic Exit Ticket</i>. What to look for/listen for in the moment: See <i>Electronic Exit Ticket Key</i> for guidance on student responses.
Lesson 5	5.A Develop and revise a model to explain how urban environmental factors could cause the evolution of populations by natural selection. (SEP: 2.3; DCI: LS4.C.1, LS4.C.2; CCC: 2.2)	When to check for understanding: On day 1, when the class develops group models and on day 2, when they create the class consensus model. What to look for/listen for: Creation of a model that explains (SEP 2.3): - All populations have genetic variations between individuals. (DCI: LS4.C.1) - Variation comes from mutations and sexual reproduction. (DCI: LS4.C.1) - Heritable variations can be anatomical, physiological, or behavioral. (DCI: LS4.C.2) - There are selection pressures in urban areas that cause some individuals to survive better than others. (DCI: LS4.C.1, CCC: 2.2) - Not all individuals in populations survive to reproduce. Those with variations that are better adapted to the environment survive to reproduce more than those that are not well adapted. (DCI: LS4.C.1, LS4.C.2; CCC: 2.2) - Offspring inherit favorable traits. (DCI: LS4.C.1) - Over many generations, the proportion of favorable traits in a population increases, and the proportion of less favorable traits decreases. (DCI: LS4.C.1, LS4.C.2)
Lesson 6	6.A. Construct an explanation based on evidence for how natural selection leads to adaptation of populations. (SEP: 6.2; DCI: LS4.C.2; CCC: 2.1)	When to check for understanding: After students complete <i>Antibiotic Resistance Transfer Task</i>. What to look/listen for: Use <i>Antibiotic Resistance Task Key</i> to evaluate their responses.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 7	7.A Ask questions to clarify and refine the model for natural selection based on new information about how urbanization could cause reduced fitness in populations and threaten their survival. (SEP: 1.4; DCI: LS4.C.4; CCC: 2.2) 7.B Ask questions based on observation to seek answers about solutions that support urbanization in a growing city and resilience of nonhuman populations. (SEP: 1.1; DCI: ETS1.B.1; CCC: 2.3)	7.A When to check for understanding: On day 1, when the class adds questions to the DQB. What to look for/listen for in the moment: Questions (SEP: 1.4) such as: • How did the panthers get to be adapted to their environment? (DCI: LS4.C.4; CCC: 2.2) • What happened to the panthers to make their population so small? (DCI: LS4.C.4; CCC: 2.2) • Was the selection pressure human?(DCI: LS4.C.4) • Is the selection pressure the same as it was in the past? • What will happen to the panthers in the future? • Why is their fitness so low? (DCI: LS4.C.4) • What is making it so they cannot have offspring? (DCI: LS4.C.4; CCC: 2.2) • What about their genes is causing the lower fitness?(DCI: LS4.C.4; CCC: 2.2) • Can we help them get higher fitness?(DCI: LS4.C.4; CCC: 2.2) 7.B When to check for understanding: On day 2, when the class adds questions to the DQB. What to look for/listen for in the moment: Questions (SEP: 1.1) such as: • How many people is the right number to move to Buckeye?(CCC: 2.3) • How many mountain lions are there and how much space do they need? • How can the city grow and keep connections to the mountains for the animals?(DCI: ETS1.B.1; CCC: 2.3) • What about the deer that the mountain lions eat? Where do they go? (DCI: ETS1.B.1) • What kinds of solutions have people built in other places that we could learn from to help the mountain lions? (CCC: 2.3) • What do the people who live in Buckeye or want to move there care about? (DCI: ETS1.B.1) • What would happen if the mountain lion population got really small? (DCI: ETS1.B.1; CCC: 2.3)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 8	8.A Use a mathematical model to generate data to explain why nonhuman populations lose genetic diversity and become unstable in a fragmented environment. (SEP: 2.6; DCI: LS4.C.4; CCC: 7.1) 8.B Use mathematical representations of allele frequencies to describe and support an explanation for how traits in an urban nonhuman population change or remain stable as their physical environment changes. (SEP: 5.2; DCI: LS4C.3, LS4.C.4; CCC: 7.1)	When to check for understanding: On day 1, as students answer and discuss the differences between the data collected by each group in the model (SEP 2.6). What to look/listen for: • Identification of changes to allele frequencies between groups that represent changes in fragmented populations. (DCI: LS4.C.4; CCC: 7.1) • Identification of random chance causing changes in allele frequencies in each small, fragmented population. (DCI: LS4.C.4; CCC: 7.1) • Questions about the impact of increasing or reducing population size on the unequal distribution of alleles. (DCI: LS4.C.3, LS4.C.4; CCC: 7.1) • Questions about further testing the model over more generations with selection pressures. (DCI: LS4.C.4; CCC: 7.1) When to check for understanding: On day 2, during the consensus discussion as students compare the results of the investigations using the mathematical representations that provide evidence for (SEP 5.2): What to look/listen for: • Fragmentation can create smaller, isolated populations. (DCI: LS4C.3, LS4.C.4) • Populations can lose alleles because of a selection pressure, or due to random chance. (DCI: LS4C.3, LS4.C.4; CCC: 7.1) • Fragmented populations become less fit if they do not include individuals with adaptations that may exist in different populations. (DCI: LS4C.3, LS4.C.4; CCC: 7.1) • Selection pressures on populations change over time and populations continually adapt to those changes. (DCI: LS4C.3, LS4.C.4; CCC: 7.1) • If populations lose genetic diversity, they are less resilient and cannot always adapt to a changing environment. (DCI: LS4C.3, LS4.C.4; CCC: 7.1) • Questions about ways to increase fitness and stabilize the population by reconnecting isolated populations in urban areas to reintroduce lost alleles or create a larger population size. (SEP: 5.2; DCI: LS4C.3, LS4.C.4; CCC: 7.1)

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 9	9.A. Apply statistics to determine how designed systems with connected habitats change the distribution of traits in nonhuman populations when conditions change. (SEP: 4.2; DCI: LS4C.3; CCC: 2.3) 9.B. Apply scientific principles to the design of a growing urban system to counteract the adverse impacts of human development with a goal to sustain biodiversity, including stable genetic diversity in nonhuman populations. (SEP: 6.3; DCI: LS4.D.2; CCC: 7.4)	9.A.1 When to check for understanding: On day 1, when students complete <i>Making Sense of Fish Ladders</i>. What to look for/listen for: - After the introduction of the fish ladder, the mean size of fish decreased over time. (CCC: 2.3; DCI: LS4C3) - The standard deviation of fish size decreased, indicating that fish ladders decreased the variation of fish size. (SEP: 4.2; DCI: LS4C.3; CCC: 2.3) - The fish ladder acted as a selection pressure on the fish population that changed the distribution of traits. (CCC: 2.3; DCI: LS4C3) 9.A.2 When to check for understanding: On day 1, when students complete the <i>Electronic Exit Ticket</i>. What to look for/listen for: - See <i>Electronic Exit Ticket Key</i> for guidance on student responses. 9.B When to check for understanding: On day 2, when students update their Progress Trackers. What to look for/listen for: Students applying their scientific knowledge about maintaining genetic diversity (SEP: 6.3) to: - Suggest maintaining large populations and reducing fragmentation to sustain biodiversity as humans urbanize ecosystems. (DCI: LS4.D.2; CCC: 7.4) - Suggest creating corridors to connect fragmented populations to maintain biodiversity. (DCI: LS4.D.2; CCC: 7.4) - Develop criteria for urbanization that benefit both human and nonhuman populations. (SEP: 6.3; DCI: LS4.D.2; CCC: 7.4)
Lesson 10	10.A Evaluate competing design solutions in a real, complex expanding urban system based on scientific ideas related to creating more stable populations and ecosystems and relevant factors including a range of constraints. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4)	When to check for understanding: On day 1 as students work on <i>Buckeye Development Designs</i> and <i>Buckeye Plan Evaluation Tool</i>. What to look/listen for: - Explanation of a goal of designing for stability as maintaining large and/or connected nonhuman populations. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4) - Explanation of a goal that the design maintains biodiversity both in numbers of species and genetic diversity. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2) - Recognition of the constraints on nonhuman populations imposed by needs of a growing human population. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2) - Noticing that wildlife corridors were included in the design, but wondering whether the size of the corridor is sufficient to maintain stable populations of mountain lion and mule deer. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4) When to check for understanding: On day 2 as students write and revise part 4 of <i>Buckeye Plan Evaluation Tool</i> and when you collect the revised responses at the end of class. What to look/listen for: - See <i>Buckeye Plan Evaluation Tool Key</i>.

Lesson	Lesson-Level Performance Expectation(s)	Assessment Guidance
Lesson 11	11.A 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. (SEP: 4.2; DCI: LS4.B.1, LS4.B.2, LS4.C.2, LS4.C.3 ; CCC: 1.1)	11.A When to check for understanding: On day 1, when students complete <i>Banana Transfer Task</i> . What to look for/listen for in the moment: See <i>Progress Tracker Key</i> .



Lesson-Specific Teacher Materials



Example Community Agreements

Respectful Our classroom is a safe space to share.	• We provide one another with support and encouragement. • We share our time to talk. We do this by giving others time to think and share. • We critique the <i>ideas</i> we are working with but not the <i>people</i> we are working with.
Equitable Everyone's participation and ideas are valuable.	• We monitor our own time spent talking. • We encourage others' voices who we have not heard from yet. • We recognize and value that people think, share, and represent their ideas in different ways.
Committed to Our Community We learn together.	• We come prepared to work toward a common goal. • We share our own thinking to help us all learn. • We listen carefully and ask questions to help us understand everyone's ideas. • We speak clearly and loud enough so that everyone can hear.
Moving Our Science Thinking Forward We work together to figure things out.	• We use and build on others' ideas. • We use evidence to support our ideas, ask for evidence from others, and suggest ways to get additional evidence. • We are open to changing our minds. • We challenge ourselves to think in new ways.

UDL for Jigsaw Readings

Engagement	Representation	Action & Expression
Purposeful & Motivated	Resourceful & Knowledgeable	Strategic & Goal-Directed
Recruit interest: Allow students to choose readings. Sustaining effort: Jigsaws are social, and all participants are treated as experts.	Perception: Electronic format supports screen reading; images support background knowledge. Language & Symbols: We pay attention to structure and text features. Comprehension: Students access key information relevant to the big question.	Physical action: Using computers optimizes access to translation/screen readers. Expression & Communication: The lesson encourages use of text features. Executive Function: Students have a distinct goal/purpose for reading and use handouts to organize ideas.

Here are some text structures and design features that benefit **all readers** in this lesson and can be applied to other texts your students may encounter:

1. **Focus questions before reading:** These questions provide students with a purpose for reading and encourage students to access prior knowledge, make predictions, draw comparisons, and monitor meaning.
2. **Images & graphics:** There is a reason “a picture is worth a thousand words.” Images help readers engage with the text on a sensory level before the reading activity begins. An image or diagram that is closely related to the text’s main content can activate sensemaking that includes students’ previous experiences, cultural funds of knowledge, and their curiosity.
3. **Short sentences and paragraphs:** If a reader has to decode a lot of words in a sentence, it is hard to remember the concepts from previous parts of a sentence to string together. One way to alleviate this is with shorter sentences that maintain the meaning of an idea or paragraph.
4. **Titles, subtitles, and other section names:** Titles highlight the purpose of the text and “set the stage” for students to make conceptual connections to the text. Students can use their background knowledge and cultural funds of knowledge to connect with the reading right away.
5. **Language register:** Science articles can take on different registers of language depending on the audience and purpose. Articles written for youth may have more colloquial language, while articles written for professionals will have more highly specialized language. While specificity is important, it should not come at the expense of general comprehension for any audience. One general guideline is the 90% rule: If 1 in 10 words is unfamiliar to students, the reading or text is not easily comprehensible.

The Google versions of these articles are accessible to screen-reading technology and online translator services. The articles have the following embedded features:

Reading	Universal Design Features	Differentiation Guidance
Juncos	• Pre-reading questions • Images • Diagrams • Optional video for further explanation • Relatively concise sentences • Short paragraphs • Short overall length	This reading is the shortest and most accessible to students. A diagram provides a visual representation of the study described in the text. https://youtu.be/jsIBV1o13qc describes boldness in the birds and may be useful for students who read below grade level.
Hawksbeard	• Pre-reading questions • Images • Graphs • Optional video for further explanation • Short overall length	The data presented in the reading involves <i>Crespi's sancta</i> , but observation of a similar species, like the common dandelion, is useful to demonstrate seed dispersal as many students have personal experience with it. For students who read about hawksbeard but may be less familiar with seed dispersal, provide https://youtu.be/DwovtvnYqum . This reading is accompanied by a graph and an equation, making it ideal for students who like to think mathematically. The text is relatively short and includes images.
Rats	• Pre-reading questions • Images • Diagrams	This reading is comparatively long and requires students to read a genetic code. Some new terms are presented, but the overall language is accessible and not highly specialized.

References

(2018). Universal Design for Learning Guidelines version 2.2. CAST. Retrieved December 14, 2022, from <https://udlguidelines.cast.org/>

Lesson 1 Teacher Reference

Supporting Questioning

1. What is the question you are working on?
2. What is the purpose of your question?
Here are some reasons why people ask questions in science:
We do not fully understand how the phenomenon (or a part of the phenomenon) works.
We have a disagreement (in our model or with someone's explanation or argument).
We need to test an idea we have.
Other reason: _____
3. Is your question close-ended or open-ended? Circle one. close-ended (Complete step 4.) open-ended (Skip to step 5.)
- Close-ended and open-ended questions:** Questions that can be answered with "yes" or "no" or with a single word are close-ended questions. Asking open-ended questions gives you space to figure out more things. Scientific questions are open-ended questions.
4. Revise your question to make it an open-ended question. Think about what you want to explain about the phenomenon.
Try using one of these question stems:
How does ... ?
Why does ... ?
What happens when ... ?
What happens if ... ?
What is the difference between _____ and _____ ?
Write your revised question:
5. What information or data do you need to answer your question?
6. How would this information or data help you achieve the purpose you circled in step 2?

Provide feedback to another student using the table below.

Criteria	Yes or no?	Feedback and/or suggested revision
Is the question open-ended?		
Does the information or data in step 5 help answer the question?		
Does the question help the student achieve their purpose for asking the question?		

Seed Investigation Protocol

Follow this procedure to introduce the seed dispersal investigation.

Gather your materials: large adjustable fan, large beach towel or picnic blanket, 2 terry cloth washcloths, feathers (variety pack), 2 #2 paper clips (1 1/8 inch), ruler

1. Show and explain the materials to students: a large beach towel will represent a large field in a nonurban area; washcloths represent small, urban fragmented plots of soil; paper clips and feathers represent nonfeathery and feathery seeds. The fan will produce wind needed to disperse feathery seeds.
2. Turn on the fan in the location and at the setting you predetermined. The best location is in a setting for all student groups to experience enough wind to move feathers off of the washcloth plots without moving feathers closest to the fan too far away. The wind should be light enough that most feathers land on the large beach towel, representing the field.
3. Lay out the large towel or “field” on the ground where all students can access it. Demonstrate how to disperse seeds from a “seed head” by gathering the 2 paper clips and 8 feathers of one color in your hand. Use a ruler to hold your hand approximately one foot above the towel and then slowly release the seeds so they do not stick together. Explain that the proportion of feathery to nonfeathery seeds is similar to what was in the graph they saw on **slide A** (range of 0.10 to 0.15 nonfeathery seeds). Each group should use different color feathers so they can track where they land.

When students run the investigation, one student from each group should position themselves near the end of the towel closest to the fan to release the seeds, so if the feathers are blown, they have a chance to land on the towel.

4. Count the number of each type of seed that has the potential to survive, meaning they will be able to germinate and grow into the next generation of hawksbeard. Emphasize that we are assuming that seed survival leads to germination. Negotiate with students what it means for a seed to survive (completely on the towel/plot or partially on the towel/plot).
5. Use the example you just demonstrated to explain how to record data in the non-urban trial table on *Seed Dispersal Investigation*. After they record the result from one plant, they should pick up all 10 of the seeds and repeat the process again until they have simulated the release of seeds from 5 plants. All groups will share the nonurban field.
6. Explain how to set up and test the fragmented urban plots. Each group will lay out 2 washcloths 1-2 feet apart depending on your available space, one downwind of the other. They will release the seeds the same way as in the non-urban trial, with their hand one foot above the center of the washcloth that is upwind. Students will repeat this process for the seedheads of 5 plants, gathering up and dropping the same 10 seeds each time.
7. Assign half of the groups to begin with the nonurban plot and half to begin on their own urban plots to reduce crowding at the nonurban plot.
8. When they finish collecting data, students should total their results from each column and work from the larger data set rather than comparing individual plant rows. To complete the analysis, they should calculate and compare proportions of surviving nonfeathery seeds similar to the researchers.
9. Finally, students should answer questions 4 and 5 on *Seed Dispersal Investigation*. The answer to question 4 will be different for everyone based on their origins prediction. The answer to question 5 can be discussed as a group.

Sample data

Table 1. Non-urban trial.



Plant	Starting feathery	Starting nonfeathery	Surviving feathery	Surviving nonfeathery	observations
1	8	2	7	2	Most feathers land on towel
2	8	2	6	2	
3	8	2	8	2	
4	8	2	7	2	
5	8	2	6	1	One clip bounced out
Total	40	10	34	9	
Proportion	40/50=.8	10/50=.2	34/43=.79	9/43=.21	

Most seeds survived and landed in a place they can germinate. The proportion of nonfeathery and feathery seeds did not change from starting to surviving.

Table 2. Urban trial.

Plant	Starting feathery	Starting nonfeathery	Surviving feathery	Surviving nonfeathery	observations
-------	-------------------	----------------------	--------------------	-----------------------	--------------

1	8	2	3	2	Most feathers blew downwind
2	8	2	2	2	
3	8	2	1	1	
4	8	2	4	2	
5	8	2	3	2	
Total	40	10	13	9	
Proportion	$40/50=.8$	$10/50=.2$	$13/22=.59$	$9/22=.41$	

Fewer than half of the seeds landed in a place they can germinate. The proportion of nonfeathery seeds almost doubled and the proportion of feathery seeds decreased. The same number of nonfeathery seeds survived urban and nonurban trials, but their proportion of the total survivors doubled in the urban trial.

We do not have enough empirical evidence. We need more information about the mechanism that supports the cause. We want to see what it is like in the real world with real plants.

Garden Experiment Key

Investigation set-up

Scientists conducted what is called a **common garden experiment** using hawksbeard. This means that they grew them under controlled, experimental conditions rather than observing them growing naturally.

Scientists collected feathery seeds from 11 locations, 3 were nonurban and 8 were urban. They raised all of the seeds in the same greenhouse in individual pots containing the same type of soil. All plants received the same amount of water, light and nutrients. They kept 30 plants from each location.

When it was time for the hawksbeard to flower, scientists knew that the plants would not make new seeds unless they were pollinated so they released bumblebees into the greenhouse. The bees randomly pollinated the flowers in the greenhouse.

They used the plants in two experiments:

For one experiment scientists recreated the conditions for urban seed dispersal. They built three artificial, outdoor urban soil plots made of wood, identical in size to the soil plots in the city. They coated the wood with a sticky substance to catch seeds when they fell. On a calm day, they placed 7 potted plants on each plot. They compared the proportion of each seed type in the parent plant before seeds fell to the proportion that landed on the artificial soil plot. The proportion of nonfeathery seeds on the parent plant was 0.15. The proportion landing in the soil was 0.28.

In their second experiment, they wanted to find out if feathery seeds from urban areas produce a different proportion of nonfeathery seeds than those grown in nonurban areas. Once the seeds were mature, they collected two seed heads from each plant and counted how many feathery and non-feathery seeds were produced (about 100 seeds per seed head). The results are shown in Figure 2 below.

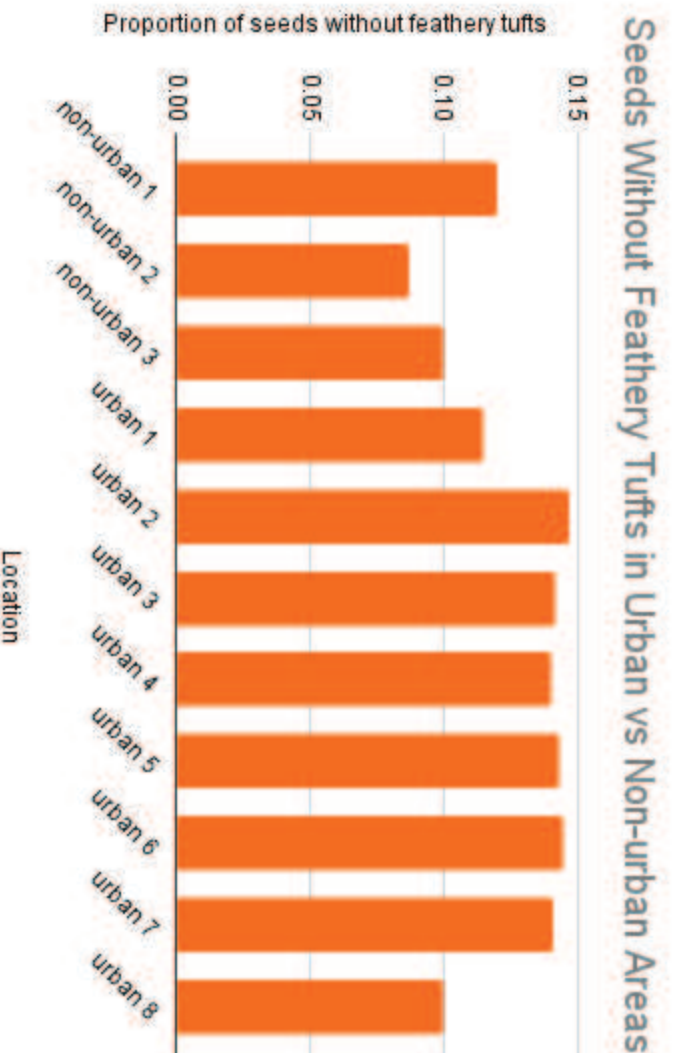


Figure 2. Mean proportion estimates of nonfeathery seeds from 11 locations measured in a common environment in a greenhouse. Data Source: Cheptou et al. (2008)

1. How do the results of this experiment compare with our classroom observations? Explain similarities and differences.

The results were similar. It confirmed that more nonfeathery than feathery seeds land on the soil in urban areas. Nonfeathery seeds are almost twice as likely to land in a place they can germinate. Many feathery seeds did not land on the artificial soil plots and would not be able to germinate, the same as our experiment. Some students may note that there was no wind in the common garden experiment and seeds could only land on one plot vs two in the class-generated urban data. This may or may not impact the results you are comparing.

2. The original seeds that the researchers collected were **feathery**. When these seeds grew into plants, they produced **15% nonfeathery** seeds. What questions does this raise about seed dispersal in hawksbeard?

Do plants from feathery seeds always make 15% nonfeathery seeds?

What kinds of seeds do plants from nonfeathery seeds make?

Table 1. Descriptions of sample sites near Montpellier, France.

Location description	
non-urban 1	abandoned field (30 km from Montpellier)
non-urban 2	grape field (30 km from Montpellier)
non-urban 3	grape field (30 km from Montpellier)
urban 1	urban grape field (Montpellier)
urban 2	near CNRS buildings (edge of Montpellier)
urban 3	sidewalk along Voie Domitienne Street (Montpellier)
urban 4	sidewalk along Jacques Cartier Street (Montpellier)
urban 5	sidewalk along Auguste Broussonnet Street (Montpellier)
urban 6	sidewalk along Henri Marès Street (Montpellier)
urban 7	sidewalk along Chemin des Barque Street (Montpellier)
urban 8	sidewalk along La Roqueturière Street (edge of Montpellier)

3. Read the location descriptions in Table 1 of where the seed samples were collected. Which collection sites do you think are fragmented? Star the bars you think are fragmented on the graph in Figure 2. **Urban 2-7**

4. How can data from the common garden experiment help us support fragmentation as a cause of the differences in proportion of nonfeathery seedling in urban and non-urban locations?

Data from the common garden experiment helps us know that the results we got in our classroom investigation are reasonable and like what the scientists found so we can use it as evidence.

They also helped control variables so we can be more certain the fragmentation was the cause and not something else going on in the environment.

5. Predict what you think would happen to the proportion of nonfeathery seeds in the urban hawksbeard population over many generations. Explain your thinking.

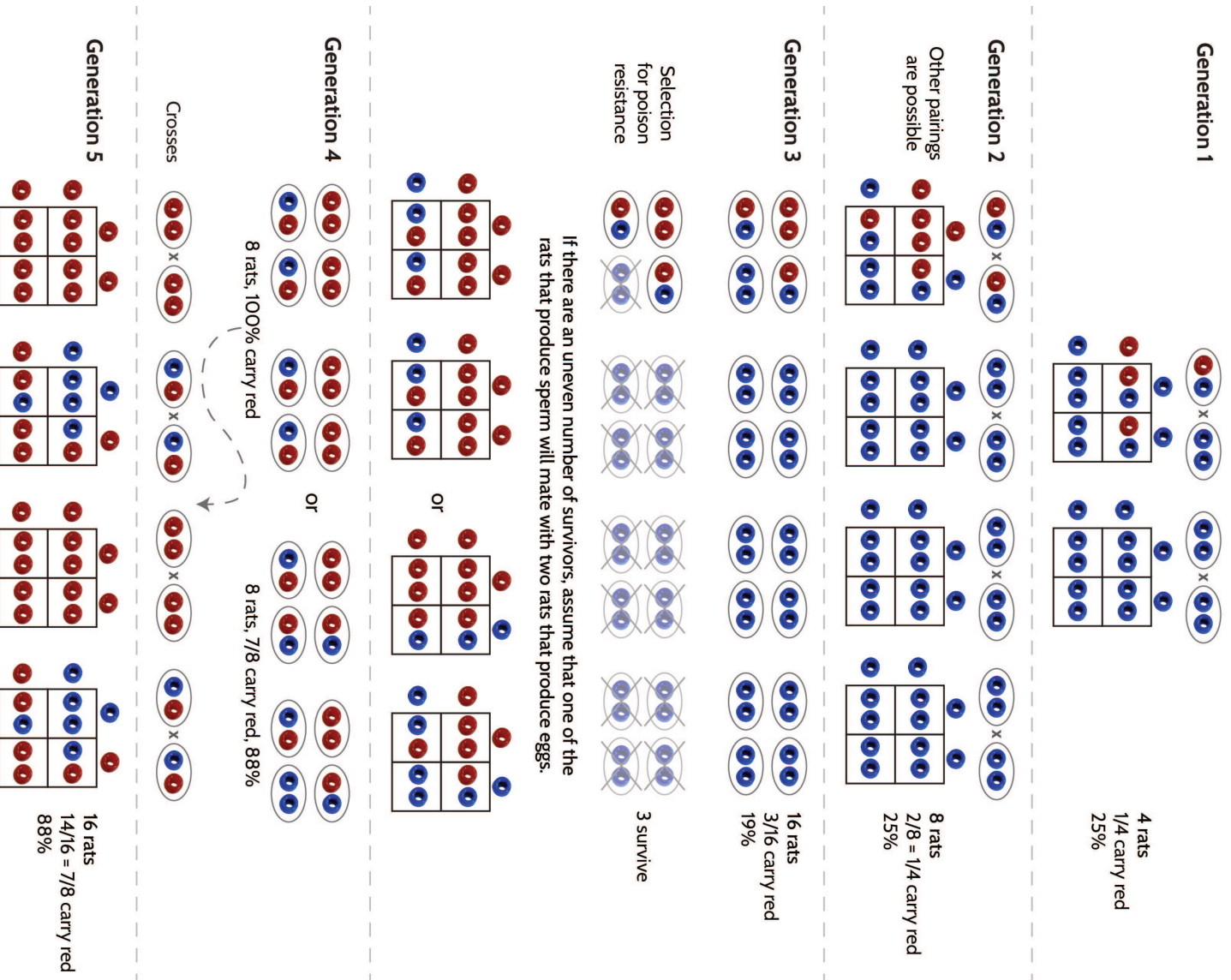
If the seed type is inherited, over time more nonfeathery seeds will survive and reproduce in the urban plots. Those nonfeathery seeds are likely to make more nonfeathery seeds and the proportion of nonfeathery seeds will continue to increase and feathery will decrease in the urban plots.

References

Cheptou, P. O., Carrue, O., Rouifed, S., & Cantarel, A. (2008). Rapid evolution of seed dispersal in an urban environment in the weed *Crepis sancta*. *Proceedings of the National Academy of Sciences*, 105(10), 3796-3799.

Rat Cross Model Key

The image below shows one possible outcome for the rat cross model. There are many possible outcomes, but results will be similar.



- A. The blue allele dominates in the first 3 generations. Yes, I would expect that pattern to hold in these environmental conditions.
- B. The red allele dominates in generations 4-5. Yes, I would expect that pattern to repeat as long as poison is a selection pressure and red provides resistance.
- C. First draft sample answer. We know from the reading that not all rats in the population die from poison. The red allele was hidden in the population at first and did not help the rats in any way. The red allele stayed in the population as rats reproduced and was neutral, and about 20-25% percent of the rat population carried the allele. When the selection pressure came around, the red allele gave rats who had it an advantage over the blue allele. Those with the red allele survived and got to reproduce and pass on their genes. The percentage of rats in the population with red alleles went up to 100%. This is not exactly the same as in Tokyo. Maybe there are some rats who did not eat poison ever so more blue alleles stayed around in the population. Or maybe they caught some of the blue-blue genotype babies before they were exposed to poison.

Rat Poison Explanation Key

3.B. Construct and revise an explanation based on evidence from a variety of sources that suggests how **individual genetic mutations cause physiological advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to differential reproduction and an increased number of rats in the entire population that carry adaptive genetic variations.** (SEP: 6.2; DCI: LS4.B.1, LS4.C.1; CCC: 2.2)

3D Elements Addressed in This Assessment		
SEP	Construct and revise 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.	
DCI	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.	
	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.	
CCC	Cause and effect relationships can be suggested and predicted for complex natural and human-designed systems by examining what is known about smaller-scale mechanisms within the system.	

Part 1: Revising Explanation with New Data

Instructions: Use works and/or pictures to construct an explanation supported by evidence from the lesson describing how it would be possible for 80% of rats in Tokyo to have resistance to poison today. Make sure your explanation includes why 20% of the rats are not resistant.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	In this explanation, look for: Student explains how individual genetic mutations cause advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to an increased number of rats in the entire population that carry adaptive genetic variations.	In this explanation, look for: Student explanation is based on evidence from at least two data sources that suggests how individual genetic mutations cause advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to differential reproduction and an increased number of rats in the entire population that carry adaptive genetic variations.	In this explanation, look for: Student explanation is based on evidence from the class model, reproductive data and published data on genetic variations that suggests how individual genetic mutations cause physiological advantages that increase the ability of certain individuals in a population to survive when exposed to rat poison, leading to differential reproduction and an increased number of rats in the entire population that carry adaptive genetic variations.

Example	Rat poison is a selection pressure in rats. Some rats have a mutation that helps them to resist the poison. Rats with adaptive mutations that survive would pass resistance on to their offspring and grow in number quickly. Not all rats are the same. It is likely that rats in Tokyo carry mutations that provide resistance to poison. Twenty percent of rats in Tokyo do not have a resistance gene.	Rat poison is a selection pressure in Tokyo because some rats have a genetic mutation that gives them an adaptation allowing them to resist the poison. Only 80% of rats have resistance to poison because there is genetic variability in the rat population. Twenty percent of the rats may not have been exposed to poison or may be offspring of resistant rats that inherited two alleles that do not provide resistance. In our model, we found that rats with the allele for resistance survived when poison was introduced and quickly spread to the rest of the population. Rats with adaptive mutations that survive would pass resistance on to their offspring and grow in number quickly. We also learned that there are at least 6 genetic mutations in the VKOR gene in Europe. It is likely that rats in Tokyo carry these genes or other mutations like them that provide resistance to poison. The 20% of rats in Tokyo that do not have resistance either have a wild-type genotype or a mutation that does not give very much resistance to poison.	Rat poison is a selection pressure in Tokyo because some rats have a genetic mutation that gives them a physiological adaptation allowing them to resist the poison. Only 80% of rats have resistance to poison because there is genetic variability in the rat population. Twenty percent of the rats may not have been exposed to poison or may be offspring of resistant rats that inherited two alleles that do not provide resistance. In our model, we found that rats with the allele for resistance survived when poison was introduced and quickly spread to the rest of the population. This would happen even more quickly in city rats because they reproduce up to 5 times per year and have 4-8 babies at a time. Rats with adaptive mutations that survive would pass resistance on to their offspring and grow in number quickly. We also learned that there are at least 6 genetic mutations in the VKOR gene in Europe that provide different levels of resistance to rats. It is likely that rats in Tokyo carry these genes or other mutations like them that provide resistance to poison. Because different mutations provide different levels of resistance to poison, the 20% of rats in Tokyo that do not have resistance either have a wild-type genotype or a mutation that does not give very much resistance to poison.
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Feedback /What to Do	Linking:	Organizing:	Extending:
	Ask students to include data from the class model, information on how quickly rats reproduce, or <i>Rat Genetic Variation</i> . Ask if all rat mutations work in the same way. Ask students to revise their models after review.	Ask students to include data from the class model, information on how quickly rats reproduce, or <i>Rat Genetic Variation</i> . Ask how the mutations change the physiology of the rat. Ask students to revise their models after review.	Ask students to describe what evidence they still need to support their claim that poison is a selection pressure in Tokyo.

References

- Feng, A. Y., & Himsworth, C. G. (2014). The secret life of the city rat: a review of the ecology of urban Norway and black rats (*Rattus norvegicus* and *Rattus rattus*). *Urban Ecosystems*, 17(1).
- Grandemange, A., Lasseur, R., Longin-Sauvageon, C., Benoit, E., & Berry, P. (2010). Distribution of VKORC1 single nucleotide polymorphism in wild *Rattus norvegicus* in France. *Pest Management Science: formerly Pesticide Science*, 66(3), 270-276.
- Pelz, H. J., Rost, S., Hünnerberg, M., Fregin, A., Heiberg, A. C., Baert, K., MacNicoll, A. D., Prescott, C. V., Walker, A. S., Oldenburg, J., & Müller, C. R. (2005). The genetic basis of resistance to anticoagulants in rodents. *Genetics*, 170(4), 1839–1847.

Lesson 4 Teacher Reference

Exit Ticket Guidance

What are Electronic Exit Tickets?

These are short **formative** assessments that occur 2-3 times per unit, in between other assessments. They include items to check for understanding of lesson-level PEs, to make connections between content and students' lives, and to elicit information about their experiences and to help students reflect on their own progress in focal SEPs and CCCs. **They are built in Google Forms, but can be ported to any survey software.**

How to create Electronic Exit Tickets

In *OpenSciEd Unit B.1: How do ecosystems work, and how can understanding them help us protect them? (Serengeti Unit)*, the two Electronic Exit Tickets in this unit are found:

- at the end of Lesson 4 (slide BB);
- and at the end of Lesson 9 (slide O).

Select the link for the Electronic Exit Ticket that corresponds with the lesson you are teaching.

<https://docs.google.com/forms/d/1TDbNpTnG8gptC8xOv28IDza5CGQxfdSp5cUXzpEnRZl/copy>

<https://docs.google.com/forms/d/1K9lb61nggKIYgbszUl-emM2FCHn1mOb6W59oPUYS9go/copy>

Spanish versions are available here:

<https://docs.google.com/forms/d/1CxU-DQ6zOHMhQUcVrykQaP10e5tpHanRCkqZSuzDUpw/copy>

<https://docs.google.com/forms/d/1CxU-DQ6zOHMhQUcVrykQaP10e5tpHanRCkqZSuzDUpw/copy>

Attending to Equity

Some students may benefit from completing the Electronic Exit Tickets on a printed version. Complete the steps below to create a copy of the Electronic Exit Ticket. Once you have created a copy in your own Google Drive, click on the 3 dots in the upper right side of the form next to the SEND button. This should give you an option to print a paper copy of the Electronic Exit Ticket.

When you select the link, it will ask you to make a copy in your own Google Drive.

Copy document

Would you like to make a copy of **Family and Friends MRE Survey**?

Make a copy



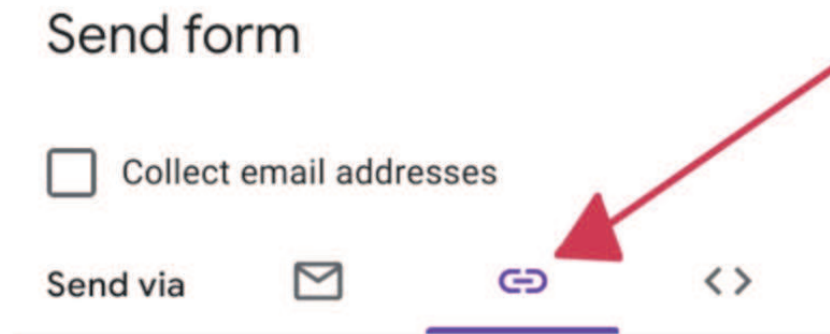
The student survey will open in your own Google Drive.



Select the “Send” button in the upper right corner to get a link to give to students.



In the “Send via” panel select the middle icon in order to choose to send the survey via a link.



Copy the link it provides you or select the “Shorten URL” box then copy the link. This second option creates a link that will be easier for students to type.

Link

<https://forms.gle/9YFjGS5FQhY3P7VR6>



Shorten URL

Press Ctrl+C to copy

Cancel

Copy

Once people submit responses they will show up in your Google Form under "Responses". Google will automatically provide you with some visualizations of these responses.

The image shows the 'Responses' tab of a Google Form. At the top, there are two tabs: 'Questions' and 'Responses', with 'Responses' being the active tab. Below the tabs, the text '0 responses' is displayed. To the right of this text is a green square icon with a white plus sign and a vertical ellipsis menu icon. Below these icons is a toggle switch labeled 'Accepting responses', which is currently turned on. At the bottom of the panel, the text 'Waiting for responses' is displayed.

If you want to see the data in a spreadsheet format, click the sheet icon to create a Google Sheet of your data. It will automatically populate when people respond to the survey.

For each survey, you will need to repeat the process above. You can choose to make a copy of the survey for each of your classes or choose to have one survey for all your classes.

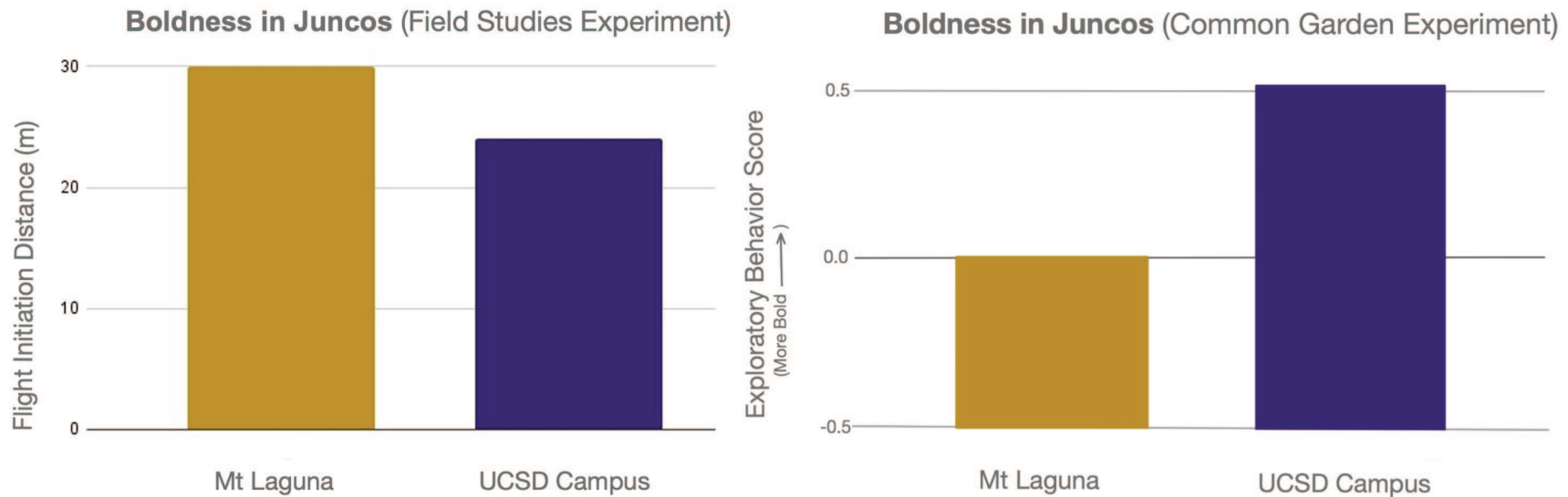
Lesson 4: Answer Key

Electronic Exit Ticket Key

4.C. Compare and contrast graphs from a field test and common garden experiment to use as evidence to support a relationship between behavior and environment. (SEP 4.4; DCI: LS4.C.2; CCC 2.1)

Where these elements are addressed in this assessment.	4.4 Analyzing and Interpreting Data Compare and contrast various types of data sets (e.g. self-generated, archival) to examine consistency of measurements and observations.	LS4.C.2: Adaptation Natural selection leads to adaptation, that is, to a population dominated by organisms that are anatomically, behaviorally and physically 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.	2.1 Cause and Effect Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.
Q1	X	X	
Q2		X	X
Q3			
Q4	X		X
Q5	X		
Q6			X

Question 1



Data Source: Atwell et al. (2012)

Which of the experiments provides evidence that juncos in UCSD are bolder than birds in Mt. Laguna?

- The field studies experiment
- The common garden study experiment
- **Both experiments**
- Neither experiment

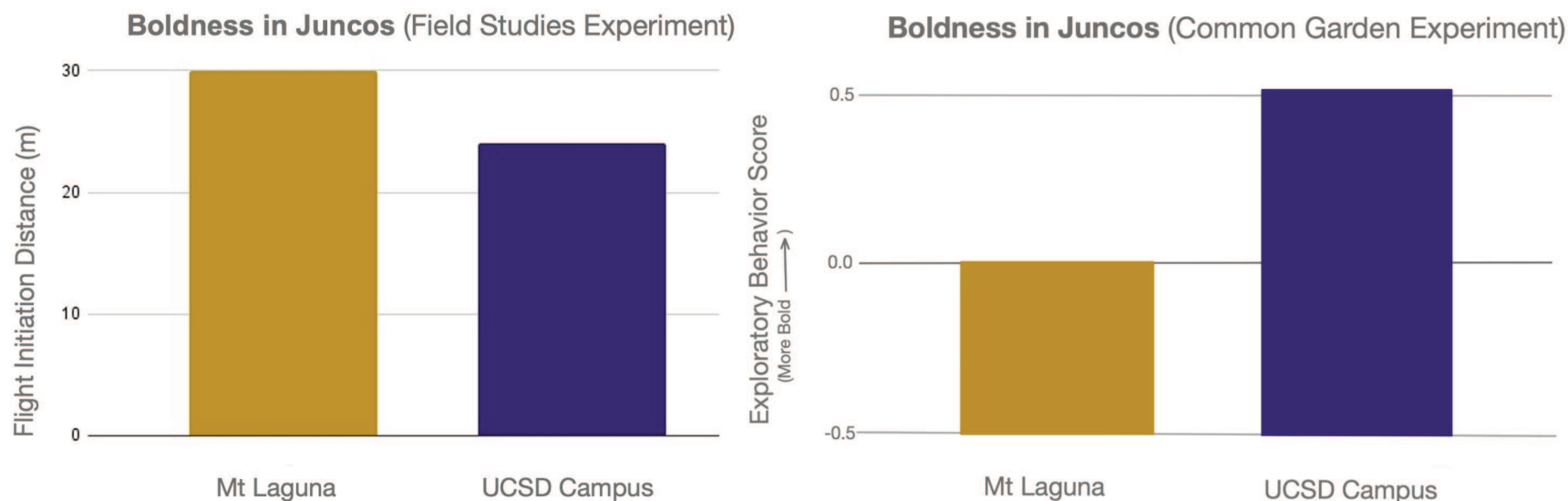
Correct response:

Both graphs show that juncos in UCSD are more bold than birds in Mt. Laguna.

Rationale for correct response: Flight initiation distance (FID) in UCSD is shorter than FID in Mt. Laguna. Juncos in UCSD demonstrate more exploratory behavior than Mt. Laguna birds.

What to do: If students interpret the two graphs as showing opposing information, review what flight initiation distance and exploratory score measure. Ask students to explain or act out flight initiation distance and exploratory behavior. Ask if increasing numbers means more or less boldness.

Question 2



Data Source: Atwell et al. (2012)

Which of the following is best supported by the data?

- **There is a correlation (relationship) between inheriting boldness and location.**
- Living in UCSD caused the juncos to inherit boldness.
- There is no correlation (relationship) between inheriting boldness and location.
- Living in UCSD caused the juncos to learn boldness.

Correct response:

- There is a **correlation** (relationship) between **inheriting boldness** and location.

Rationale: Both graphs show more boldness in UCSD birds compared to Mt. Laguna birds. The common garden study demonstrates that boldness is inherited, the birds are born with boldness, they do not learn it from anyone. However, these studies did not provide a mechanism or cause that provides evidence about why or how a certain location causes a particular behavior.

What to do: If they answered that living in UCSD causes the juncos to inherit boldness, ask students if they have any evidence from the graph for why birds in one location are bolder than another. If they answered that juncos learned boldness, ask what information from the graph explains how they learned boldness. Ask them to consider what information COULD support the incorrect statements that could be collected in a different investigation.

Question 3

What other animals have you interacted with that were surprisingly bold?

What to look for in response:

Accept all responses. Validating these responses engages students in activating the **relevance** and **interest** in these issues, which can motivate future questions.

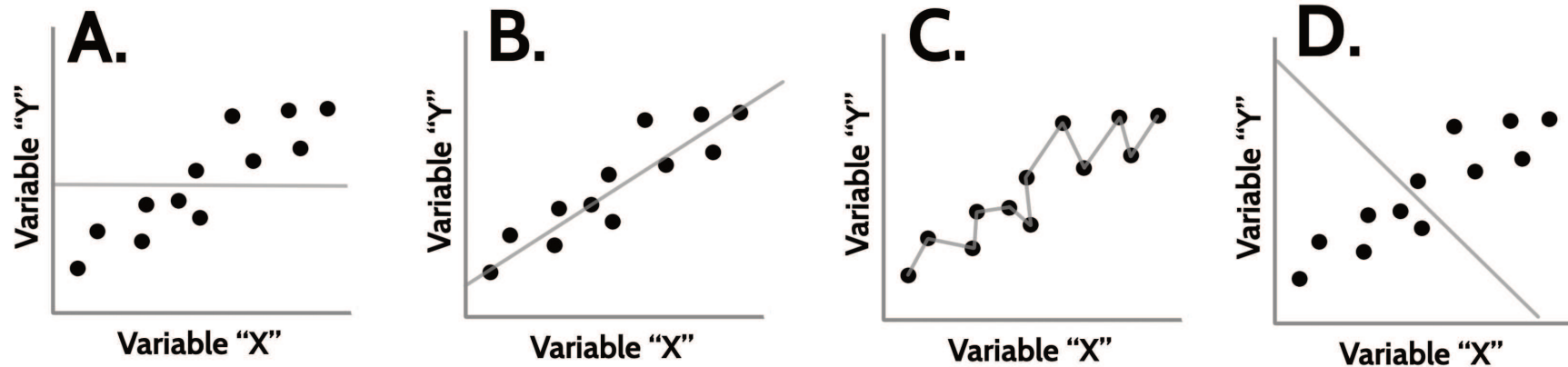
What to do:

Encourage students to look at the three-column chart and individual models they made in Lesson 1 for ideas.

Question 4

A line of best fit is a **mathematical tool** that uses all the data points to create a straight line. This line **describes how the “Y” variable changes in response to the “X” variable changing**. Scientists and researchers use this line to summarize the data, predict unobserved values, and **understand the relationship between variables**.

Scientists are trying to understand the relationship between variable “X” and variable “Y.” They wonder if there is any correlation between these two variables. Which of the following **graphs most accurately uses a line of best fit** that can help scientists and researchers understand the **relationship between these two variables**?



Correct response:

Graph B

Rationale: This **mathematical representation (graph)** shows a **straight line** that shows a **positive correlational relationship** between variable “X” and variable “Y.” Scientists and researchers could use this line to describe the data and make generalized predictions about expected Y values for X values not represented in the current data set.

What to do:

Revisit the Junco CODAP data. Ask students to think of the data like a cloud. Have students describe how this cloud looks and ask students if there is a straight line that follows the shape of the cloud of data.

Question 5

How did **comparing and contrasting multiple graphs** help you make sense of the relationship between the inheritance of boldness and the environment in junco populations?

What to look for in response: *Note: These could be different for each student.*

- Confirm the same relationship in both graphs, therefore more certain of the relationship.

What to do:

Encourage students to think about how well they could make sense of the relationship with only one graph and not the other.

Question 6

How did **the evidence** from the graphs help you decide if we can claim a **causal or correlational** relationship between boldness and inheritance?

What to look for in response:

- We can claim correlation, but not causation because our evidence does not include a mechanism. Inside and outside the common garden experiment there is a behavioral difference between UCSD and Mt. Laguna juncos, implying they are inherited, but we do not know how. There is no evidence of what is happening inside the bird.

What to do:

Ask students to consider what information the graphs do and do not provide. Consider how the data was collected and whether scientists know why birds are bold in urban areas.

Question 7

Name one way you helped the class make progress on the lesson question today.

What to look for in response:

- Students identify how they helped another student or groups of students during the investigations.
- Students articulate how they contributed to helping the class achieve their goals for the lesson.

What to do: Depending on student responses, it may be beneficial to revisit the community agreements.

- If many students do not identify how they helped, spend time revisiting the community agreements to ensure that students are using the agreements as they work together to make progress on figuring out science and engineering ideas.
- If many students do articulate how they contributed, revisiting the community agreements may encourage students to think about what specific agreement they could adhere to be more helpful.

Models of Population Change Key

Our Model	Lamarck's Theory	Darwin's Theory
1. Variations exist within populations of animals and plants. Genetic variations that change the phenotype of individuals are due to mutation and sexual reproduction. 2. There are selection pressures in urban areas 3. Individuals in populations with variations that help them survive the selection pressure reproduce and pass on their genetic variation to their offspring. 4. The proportion of certain traits in future generations changes over time.	Individuals change during their lifetimes. Sometimes animals need something, so they change. (Giraffes needed food, so they stretched their necks.) (What they need could be a selection pressure.) Animals pass on changes to their bodies that they need. The ones they don't need go away. The next generation is better adapted to the environment (related result).	There are variations between individuals in a population. There may not be enough of everything a population needs in the environment. There is competition for survival in a particular environment between individuals. (Giraffes with long necks could eat; giraffes with short necks could not.) Survivors reproduce and pass on their traits to their offspring. Over many generations, favorable traits make up a higher proportion of the population.

Making Sense:

Which model is more similar to ours (Lamarck's or Darwin's)? Explain your thinking.

Sample student answers in purple. Similarities between the class consensus model and other theories are highlighted.

Students should recognize the similarities between the class model and Darwin's theory. However, the class model importantly adds in genetic (and perhaps physiological and behavioral) mechanisms not present in Darwin's model.

References

Kováč, L. (2019). Lamarck and Darwin revisited. *EMBO reports*, 20(4), e47922. <https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6446194/>

Antibiotic Resistance Task Key

HS LS4-4: Construct an explanation based on evidence for how natural selection leads to adaptation of populations. [Clarification Statement: Emphasis is on using data to provide evidence for how specific biotic and abiotic differences in ecosystems (such as ranges of seasonal temperature, long-term climate change, acidity, light, geographic barriers, or evolution of other organisms) contribute to a change in gene frequency over time, leading to adaptation of populations.]

3D Elements Addressed in this Assessment								
	1	2	3	4	5	6	7	
SEPs	6.2 Constructing Explanations and Designing Solutions Construct and revise 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.							
DCIs	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.							
CCCs	2.1 Cause and Effect Empirical evidence is required to differentiate between cause and correlation and make claims about specific causes and effects.							

When we get sick, we rely on antibiotics to help us fight bacterial infections. Antibiotics are used to kill bacteria. For example, if you have ever had strep throat, you had an infection caused by streptococcus bacteria. You may have been given antibiotics like amoxicillin to treat it. In recent years, doctors and scientists have found that many of the common bacteria that make us sick are resistant to many widely used antibiotics. This means the antibiotics we have used for many years no longer kill the bacteria. This phenomenon is called **antibiotic resistance**. The World Health Organization thinks this is a major threat to human health because it could lead to a situation where no antibiotics are available to treat common infections. People could get very sick or die from what was once an easily treatable illness.

In this task, you will investigate the following question: Why is this phenomenon happening and what can we do to stop it?

1. When bacteria have enough resources, they can grow and divide. **Figure 2** shows bacteria grown in dishes containing nutrients (food). Image (a) was taken just after the lid was closed. The other two images were taken after 1 day (b) and 2 days (c). Make a claim about bacteria's ability to increase in number, given the images above. What can you infer from this about what is happening in our bodies when bacteria feed on nutrients inside our bodies?

If bacteria have enough nutrients, they can grow from something we can't see into something we can see. We might not be able to see them get into our bodies but once they do they can grow and divide.

2. **Figure 3** shows what happened when antibiotics were put in the dish with the bacteria. The white disc on the right was soaked in antibiotics and put in the dish. The white disc on the left was soaked in sterile water. The antibiotic can travel away from the disc in any direction. The white/yellow streaks are bacteria.

Remember, if you can see it with your eye it means there are many bacteria clumped together. **Why is there an area around the disc with no bacteria? Choose the best answer from the choices below.**

A. The bacteria haven't grown on the dish yet in that spot - give them enough time and they will cover that area too.

B. Antibiotics kill bacteria and the white disc has antibiotics on it. They spread out from the disc and kill the bacteria. There might still be some bacteria there, but not enough to look like dots to our eyes.

C. When the antibiotic disc was placed in the dish, the bacteria near it all moved away as a physical response. The number of bacteria in the dish is the same as before, they are just bunched up more in different spaces now.

3. The bacteria were allowed to grow a little longer. And some colonies (dots) did grow near the antibiotic as seen in **Figure 4**. **How are the bacteria colonies that are now growing near the antibiotic disc different from the bacteria that were killed by the antibiotic?**

A. The bacteria developed antibiotic resistance when they saw the antibiotics.

B. The bacteria have a trait that keeps the antibiotic from killing them.

C. The bacteria are a different species than the bacteria that were all killed.

D. They are not different from the bacteria that were there originally, they just took more time to grow.

4. Antibiotic resistance is a heritable trait. Some bacteria have genes that code for proteins that cause the bacteria to be resistant to being killed by antibiotics. Bacteria reproduce through a process of cell division similar to mitosis. The bacteria grows, replicates its DNA and divides (**Figure 5**). The resulting cell is genetically identical to the original cell. **Predict what you think would happen over time if the bacterial cells that grew with the antibiotic were given unlimited nutrients.**

If the bacterial cells had unlimited nutrients they would grow and divide. The new bacteria would have the same traits for resistance as the original.

5. Scientists studying antibiotic resistance investigated the relationship between antibiotic resistance and antibiotic use. **Figure 6** shows how antibiotic use has changed over time and **Figure 7** shows how antibiotic resistance has changed over time. **Explain what you think the relationship is between antibiotic use and antibiotic resistance.**

There is a positive relationship between antibiotic use and antibiotic resistance. They both increase over time.

6. To understand more about the relationship between antibiotic use and antibiotic resistance in bacteria, scientists identified the gene that codes for resistance and measured how many individuals in the population had that gene. Then, they exposed one population to antibiotics while the other population was not exposed to antibiotics. They reproduce every 20 minutes so they let the bacteria grow and divide for several days.

Complete the table below by adding what percent of each population you would expect to be either resistant or nonresistant, wherever you see blank areas in the table.

A.

	Exposed to antibiotics		Not exposed to antibiotics	
	Percent of population nonresistant	Percent of population resistant	Percent of population nonresistant	Percent of population resistant
Day 1	80%	20%	80%	20%
Day 2	60%	40%	80%	20%
Day 3	40%	60%	80%	20%
Day 4	15%	85%	80%	20%
Day 5	5%	95%	80%	20%

B. How does the proportion of the population with the trait for antibiotic resistance change over time in the two different conditions?

When exposed to antibiotics the percent resistance increases. When not exposed they stay the same.

C. Write an explanation using the data above as evidence to support the claim that antibiotic use causes antibiotic resistance.

See rubric below:

7. Reports from the Centers for Disease Control indicate that antibiotics are frequently overprescribed or used incorrectly. Some people concerned with antibiotic resistance advocate for a reduction in the use of antibiotics. **Explain how a reduction in the use of antibiotics could have the potential to reduce the amount of antibiotic resistance we see in the future.**

If the selection pressure of the antibiotics is removed then the resistant bacteria will not increase in proportion over time. They would still be in the population but at lower numbers because they would not have an advantage.

	Foundational Pieces	Linked Understanding	Organized Understanding
3D Elements	In this explanation, look for: Student explains how antibiotics cause bacteria with an advantageous heritable trait to differentially survive and reproduce, making all individuals in the population resistant to the antibiotic.	In this explanation, look for: Student explanation is based on evidence for how antibiotics cause bacteria with an advantageous heritable trait to differentially survive and reproduce, changing the proportion of individuals in the population that are resistant to the antibiotic.	In this explanation, look for: Student explanation is based on empirical evidence from a variety of sources for how antibiotics cause only bacteria with an advantageous heritable trait to differentially survive and reproduce, changing the proportion of individuals in the population that are resistant to the antibiotic.
Example	The increased use of antibiotics is changing the environment bacteria live in. This new environment is selecting for bacteria with antibiotic resistance. Only the bacteria with genes that give the bacteria resistance to the antibiotics are able to survive and reproduce. Over time, all bacteria become resistant to the antibiotic.	The increased use of antibiotics is changing the environment bacteria live in. This new environment is selecting for different traits within the bacteria populations. One of those traits is antibiotic resistance. Only the bacteria with genes that give the bacteria resistance to the antibiotics are able to survive and reproduce. Over time, because reproduction results in new bacteria with the same genes, the number of bacteria with antibiotic resistance genes within the population increases.	The increased use of antibiotics is changing the environment bacteria live in. This new environment is selecting for different traits within the bacteria populations. One of those traits is antibiotic resistance. Only the bacteria with genes that give the bacteria resistance to the antibiotics are able to survive and reproduce. Over time, because reproduction results in new bacteria with the same genes, the proportion/frequency of bacteria with antibiotic resistance genes within the population increases. The population not exposed to antibiotics did not have a change in the proportion of individuals with the resistance trait in the population because there was no selection pressure making it advantageous to survival/reproduction.

Feedback/ What to Do	<i>Linking:</i>	<i>Organizing:</i>	<i>Extending:</i>
	Ask students to use the results from the tables or graph to explain how the number of bacteria changes gradually over time. Ask students to revise their ideas after review.	Ask students to explain why the population that is not exposed to antibiotics did not change. Ask students to revise their ideas after review.	Ask students to explain why different bacteria require treatment with different types of antibiotics.

Ideas for Instruction	Foundational Understanding	Linked Understanding	Organized Understanding
	- Support students in reading the graphs and tables. - Review the model of evolution by natural selection your class developed and apply it to novel examples.	- Refer back to lesson 3 and discuss how the allele for poison resistance spread before poison as a selection pressure was introduced. - Review the model of evolution by natural selection your class developed and apply it to novel examples.	Ask students how they think research for treatments against bacteria will need to proceed in the future to stay ahead of antibiotic resistance.

References

- CDC. Antibiotic Resistance Threats in the United States, 2019. Atlanta, GA: U.S. Department of Health and Human Services, CDC; 2019.
- Thapa, D., Pyakurel, S., Thapa, S. et al. Staphylococcus aureus with inducible clindamycin resistance and methicillin resistance in a tertiary hospital in Nepal. Trop Med Health 49, 99 (2021). <https://doi.org/10.1186/s41182-021-00392-2>

Model Instructions/Key

Follow these instructions to support the introduction of the investigative model on day 1 and modifications on day 2.

Prepare for Day 1:

Organize the materials so each group gets a sealed plastic-storage container of about 120–150 beads with 6 colors with roughly equal amounts of each color. They should also get 2 additional small containers.

- Keep a large supply of extra beads available for students to exchange colors as needed.
- If you teach more than one section, make sure students return all beads at the end of class and mix them before scooping beads into containers for the next section.
- Storage containers should hold roughly 2 cups so students can mix beads without losing them and get their fingers in the containers easily to pick up beads.
- The two extra storage containers are useful for getting additional beads as necessary and for creating new gene pools.

For students who cannot distinguish colors, a possible alternative to beads are blank scrabble tiles with stickers of different shapes such as hearts, rectangles, circles, ovals, diamonds, etc. It is better to use a standard shaped item to avoid bias when randomly choosing pairs. Students who cannot distinguish color could also take on the role of selecting beads because they will be less biased in their selection.

In class on day 1:

Demonstrate steps 1–3 on *Fragmentation Investigation* and record your results on a large data table on the board where students can easily view it. Make sure there are enough rows in the table for each group to add in their own allele frequencies. Instruct all students to fill out the top row of their data table in *Fragmentation Investigation* in the same color.

Remind students that bead selection and mate choice should be random in this activity.

Prepare for Day 2:

Review the exit tickets at the end of day 1 and choose 3–4 of the most commonly suggested selection pressures to update **slide J**. Update the rules on **slide K** as needed to match the bead colors available to your class.

In addition to the day 1 materials, each group will also need a 4-sided die and blank piece of paper on day 2.

In class on day 2:

Display slide J. Explain that you compiled the ideas from the exit ticket to create the list on the slide. Each group will begin today by setting up the 6 panthers from generation 1 using the 12 allele beads they left off with in the last class. As a class, choose two selection pressures from the list to investigate. Assign half the groups to investigate each one. **Display slide K** and assign one selection pressure the class chose to rule A and the other to rule B. See the table below for examples. Explain that these rules govern fitness for that selection pressure. Point out the location on *Fragmentation Investigation* to write down the selection pressure and rule. Use **slides L–O** to explain instruction steps 1–4 for day 2 from *Fragmentation Investigation*. Emphasize that students should not change the pairs they begin with to match the rule they were assigned.

Key to Student Responses

Day 1

1. How does your generation 1 gene pool compare with populations from other groups?

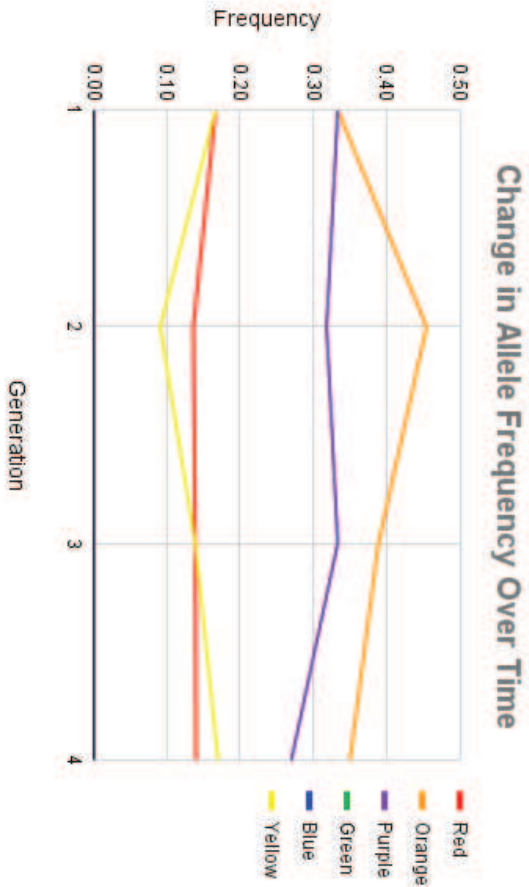
Answers will vary. Students should describe which color alleles they do or do not have compared with others and any unusual random frequencies they have compared to others.

2. What is the effect of fragmentation on the first generation of panthers?

Having a smaller population means you may not get all of the alleles in one population. The genetic diversity of a small population is random.

Day 2

1. Sample final graph if students collect 4 generations of data (only 3 required). These will vary significantly from group to group. Comparing and discussing why the graphs are different between groups based on random chance and the effect of the selection pressure will be critical to building understanding.



2. Sample answers. Answers will vary based on selection pressure and rule.

Possible Selection pressures	Rule	Sample question 2 responses
fear of people	Rule A • If no yellow, 1 offspring per pair • If one individual has yellow, then 2 offspring • If both have yellow, then 3 offspring	Yellow alleles became more common in the gene pool. Yellow allele suppresses production of CORT, making panthers less stressed around people so they can live and hunt in cities and get food. More copies means more offspring.
changing food source	Rule A • If no yellow, 1 offspring per pair • If one individual has yellow, then 2 offspring • If both have yellow, then 3 offspring	We did not have any yellow alleles in our population so there was no selection for that trait so the allele frequency did not change. We imagine that the yellow allele provides an anatomical advantage to catch a new food source. If both parents have it they both eat better and are more fit for reproduction.
pollution	Rule B • If no red, 3 offspring per pair • If one individual has red, then 2 offspring • If both have red, then 1 offspring	The pairs without red reproduced more, so the frequency of red went down in the population. Red codes for a protein that makes you more susceptible to poison. Both parents are less healthy if they both have the allele.

disease	Rule B • If no red, 3 offspring per pair • If one individual has red, then 2 offspring • If both have red, then 1 offspring	We did not have any red alleles, so the frequency did not change. We imagine that red codes for a protein that makes you more susceptible to disease. Both parents are less healthy if they both have the allele.
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3. What do you predict will happen to your panther population over the next few generations if the selection pressure is the same? Why?

Answers will vary but should follow the pattern on the graph. As the population grows, more alleles should be retained in the population. The frequency of an advantageous allele may increase and the frequency of a harmful allele may drop.

Some students should recognize that panthers do not die with this model and that is not realistic.

4. Would the fitness of the population have been different if it had not been fragmented? Why?

Answers will vary. Students who did not have the allele associated with the rule in their fragmented population should expect it to be in an unfragmented population, which would change allele frequencies and fitness levels.

5. Will your population be stable (or resilient) if faced with a new selection pressure with a new rule? Why?

Students should recognize that stability will depend on what the new selection pressure is and whether their population has that advantageous or harmful allele. Allele frequencies and fitness levels will change based on those variables.

6. Compare and contrast the change in allele frequency and fitness from your model to those from another group. What do you notice and wonder?

Students should compare the allele frequency graphs and change in population size between the two groups. They should note how the selection pressure caused change based on the random alleles each fragmented population had when generation 1 reproduced. Different rules cause different effects as well.

Name: _____

Date: _____

Lesson 9: Answer Key 1

Fish Data Excursion Key

Directions: With your group, use the following tinyURL to access the Fish Data Set in CODAP. Answer the questions as you go through each of the following steps.

CODAP LINK: <https://www.openscienced.org/european-bullhead-data-excursion/>

Is there a relationship between patch size and number of alleles (genetic diversity)?

Step A: Identify which of the following columns in the chart is the independent variable and which is the dependent variable.

- Patch size (independent variable)
- Number of alleles (genetic diversity) (dependent variable)

Step B: Click on the graph icon in the upper left corner of the screen to open a new graph window.

Step C: Drag the column heading that you identified as the independent variable and drop it on the X-axis in the graph.

Step D: Drag the column heading you identified as the dependent variable from the table and drop it on the Y-axis in the graph.

Step E: Click on the ruler next to the graph. Then select the "Least Square Line" box. (Drag the corner of the graph to make it bigger if you cannot see the r^2 =value in the yellow box.)

1. Looking at the overall data. Circle the relationship that best fits the data.

- a. Positive Relationship
- b. No Relationship
- c. Negative Relationship

2. The mean number of alleles is a measure for genetic diversity. Describe the relationship in words. (As patch size increases, genetic diversity...)

As patch size increases, the genetic diversity also increases.

3. CODAP will provide you with an r^2 value on the graph. Use a calculator and take the square root of that number to find r , the correlation coefficient. The correlation coefficient will tell you how strong the relationship is between the patch size and genetic diversity.

r^2 value = 0.628

r value = 0.00

r value = 0.50

r value = 1.00



4. Summarize in words the relative strength of the relationship between patch size and genetic diversity using the correlation coefficient, r value.

The correlation coefficient shows that there is a strong relationship, meaning that the amount of genetic diversity can be explained by the patch size.

Conclusions

5. Patch size is a measure for the size of continuous habitat. If we apply the results of this study to other nonhuman populations, how does reducing fragmentation and connecting habitat help make

populations more resilient?

As habitats are more connected, the amount of habitat for nonhuman populations increases. This allows for larger populations that have greater genetic diversity.

Reference

Knaepkens, G., Bervoets, L., Verheyen, E., & Eens, M. (2003). Relationship between population size and genetic diversity in endangered populations of the European bullhead (*Cottus Gobio*): Implications for conservation. *Biological Conservation*, 115(3), 403–410. [https://doi.org/10.1016/S0006-3207\(03\)00156-3](https://doi.org/10.1016/S0006-3207(03)00156-3)

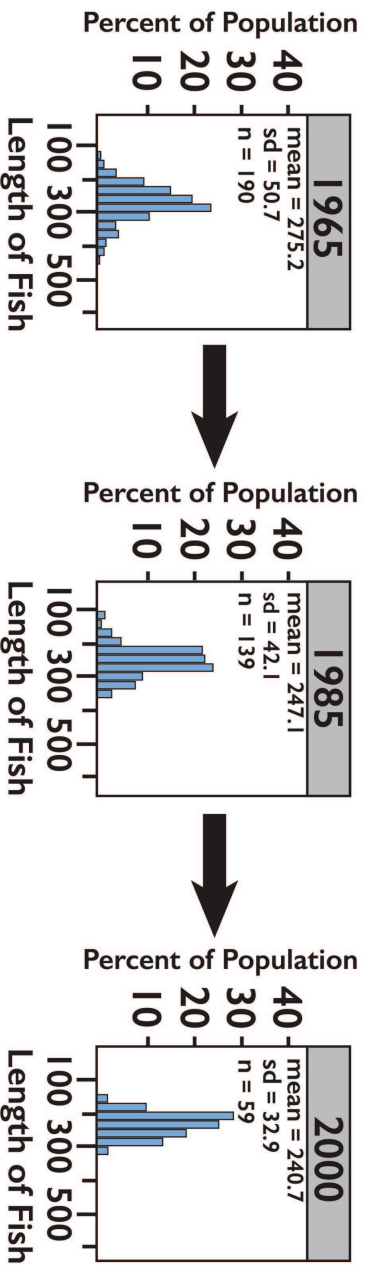
Electronic Exit Ticket Key

9.A. Apply statistics to determine how designed systems with connected habitats change the distribution of traits in nonhuman populations when conditions change. (SEP: 4.2; DCI: LS4C.3; CCC: 2.3)

Where these elements are addressed in this assessment.	4.2 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.	LS4.C.3: Adaptation Adaptation also means that the distribution of traits in a population can change when conditions change.	2.3 Cause and Effect Systems can be designed to cause a desired effect.
Q1	X	X	
Q2		X	X
Q3			
Q4	X		X
Q5	X		
Q6			X
Q7			

Question 1

Distribution of the length of fish within a population over the years



Data Source: Haugen et al. (2008)

Use the graphs above and choose the best response: Imagine you caught 100 fish in 1965 then caught 100 fish in 2000. How would you expect the **variety of lengths** in **the fish** to be **different** between the 2 years?

- The 100 fish caught in 2000 would be no different in length than the 100 fish caught in 1965.
- The 100 fish caught in 2000 would be more similar in length than the 100 fish caught in 1965.
- The 100 fish caught in 2000 would be more similar in length than the 100 fish caught in 1965.
- The 100 fish caught in 2000 are all longer than the 100 fish caught in 1965.

Correct response:

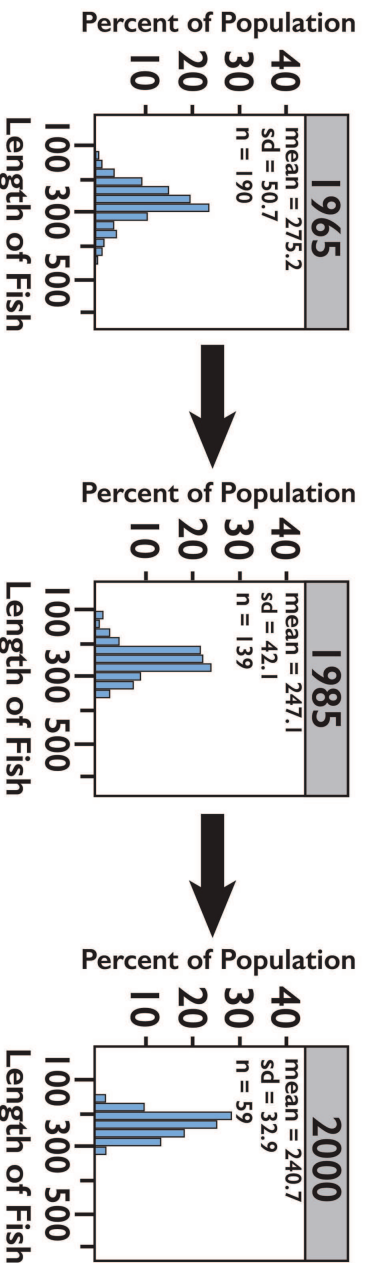
The 100 fish caught in 2000 would be more similar in length than the 100 fish caught in 1965.

Rationale for correct response: Standard deviation (sd) is a measurement that looks at how spread out the data points are from the mean (average). These graphs show that standard deviation (sd) is decreasing over time, meaning that there is less variation in fish length.

What to do: If students interpret these graphs as showing opposing information, ask students to articulate and explain what part of the graph shows the variety of fish lengths. Students should either refer to the standard deviation (sd) numerical value or could look at the fish length x-axis. Using the X-axis students could describe how the data in the 1965 graph is wider than the width of the data in the 2000 graph. If students say that all fish in 2000 are shorter than all fish in 1965, ask them to focus on the term "all." The question is not asking about the mean but the variation.

Question 2

Distribution of the length of fish within a population over the years



Data Source: Haugen et al. (2008)

The goal of the fish ladder was to connect populations, increase genetic diversity, and therefore broaden the range of lengths in fish. Based on the data, did this happen?

- No, the standard deviation (sd) decreased over time because the fish ladder selected for fish that are shorter in length.
- No, the mean length decreased because the fish ladder caused fish to be weaker.
- Yes, overall we see that the percentage of longer-length fish increased over time.
- Yes, the standard deviation (sd) increased over time because the fish ladder selected for fish that are longer in length.

Correct response:

- No, the standard deviation decreased over time because the fish ladder selected for fish that are shorter in length.

Rationale: Looking at the standard deviation, the opposite of the goal happened. Standard deviation is a measurement that looks at how spread out the data points are from the mean (average). The standard deviation (sd) shows that the distribution of traits for fish length decreased from 1965–2000.

What to do: If they answered that the mean length decreased because the fish ladder caused the fish to be weaker, ask students if they have any evidence from the graph for why fish are weaker because of fish ladders. If they answered yes the standard deviation (sd) increased over time, ask what information from the graph shows the standard deviation increasing. Ask them to consider what would we expect to see over time if genetic diversity increased, causing more fish of different lengths.

Question 3

What is a system that people designed that did not work as intended (at home, at school, in sports, in politics, etc.)?

What to look for in response:

Accept all responses. Validating these responses engages students in activating the **relevance** and **interest** in these issues, which can motivate future questions.

What to do:

If students are struggling to think about something that did not work as intended, provide students with an example from your own life where a product you bought did not work as intended or a new process was not effective as you originally thought.

Question 4

Why is it important to know both the mean and standard deviation for fish lengths rather than only the mean if you are trying to determine if the fish ladder caused an increase in genetic diversity and lengths in the fish population?

- Because the mean only tells us about the variation in the fish, whereas the standard deviation shows us the average size of the fish.
- **Because the mean only shows us the average size of the fish, whereas the standard deviation tells us about the variation in the fish.**
- Because the mean only tells us about the range in size for the population of fish, whereas the standard deviation tells us about the variation in fish.
- Because the mean only tells us about the variation in the fish, whereas the standard deviation tells us about the range in size for the population of fish.

Correct response:

- **Because the mean only shows us the average size of the fish, whereas the standard deviation tells us about the variation in the fish.**

Rationale: The mean is a mathematical tool that helps us understand the average fish length. The standard deviation is a mathematical tool that helps us understand how spread apart the data was from the mean. The standard deviation showed us how the fish ladder changed the genetic diversity, or variety of alleles, in the fish population. Together both of these mathematical tools helped us see that the overall size of fish decreased in size and that the fish within the population were more similar in size.

What to do:

Ask students to think about what each of the different mathematical tools can tell us about data. Then have students explain how both tools are useful in analyzing data to determine if fish ladders or other wildlife corridors are working as intended.

Question 5

How did using correlation coefficient, or r value, help you make sense of the relationship between patch size and number of alleles (genetic diversity)?

What to look for in response:

- Confirm that the correlation coefficient allowed students to determine the relative strength of the positive relationship between patch size and number of alleles (genetic diversity).

What to do:

Encourage students to think about the overall relationship between patch size and number of alleles. Use framing such as: as patch size increases what would you expect would happen to the number of alleles? How were we able to determine this relationship?

Question 6

How did **cause and effect relationships** help you decide if **designed corridor systems** are working as intended?

What to look for in response:

- We know that a more connected habitat with more opportunity for sexual reproduction in a large population should allow populations to be more stable because it sustains a greater genetic diversity. If we install a corridor and it causes genetic diversity to decrease, we know the corridor did not have the desired effect.

What to do:

Ask students to consider what would happen to populations that experienced habitat fragmentation because they did not have wildlife corridors. Then have students consider what they think would happen to these populations if wildlife corridors connecting habitat were introduced.

Question 7

Name one way you helped the class make progress on the lesson question today.

What to look for in response:

- Students identify how they helped another student or groups of students during the investigations.
- Students articulate how they contributed to helping the class achieve their goals for the lesson.

What to do: Depending on student responses, it may be beneficial to revisit the Community Agreements.

- If many students do not identify how they helped, spend time revisiting the Community Agreements to ensure that students are using the agreements as they work together to make progress on figuring out science and engineering ideas.
- If many students do articulate how they contributed, revisit the Community Agreements and celebrate their contributions. Encourage students to think about additional agreements they could work on to continue being helpful for Lesson 10.

Lesson 9: Answer Key 3

Statistics Extension Key

Directions: With your group, use the following tinyURL to access the Fish Data Set in CODAP. Answer the questions as you go through each of the following steps.

CODAP LINK: <https://www.openscienced.org/european-bullhead-data-excursion/>

Part 1: Is there a **relationship between patch size and the size of the population**?

Step A: Identify which of the following columns in the chart is the independent variable and which is the dependent variable.

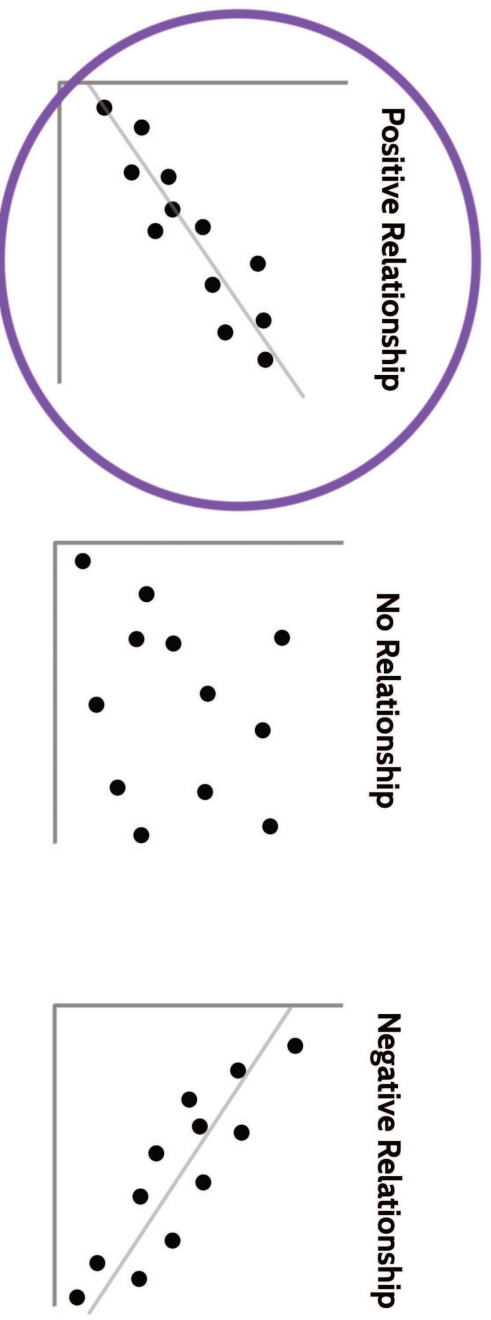
- Effective Population Size (dependent variable)
- Patch Size (independent variable)

Step B: Drag the column heading that you identified as the independent variable and drop it on the X-axis in the graph.

Step C: Drag the column heading you identified as the dependent variable from the table and drop it on the Y-axis in the graph.

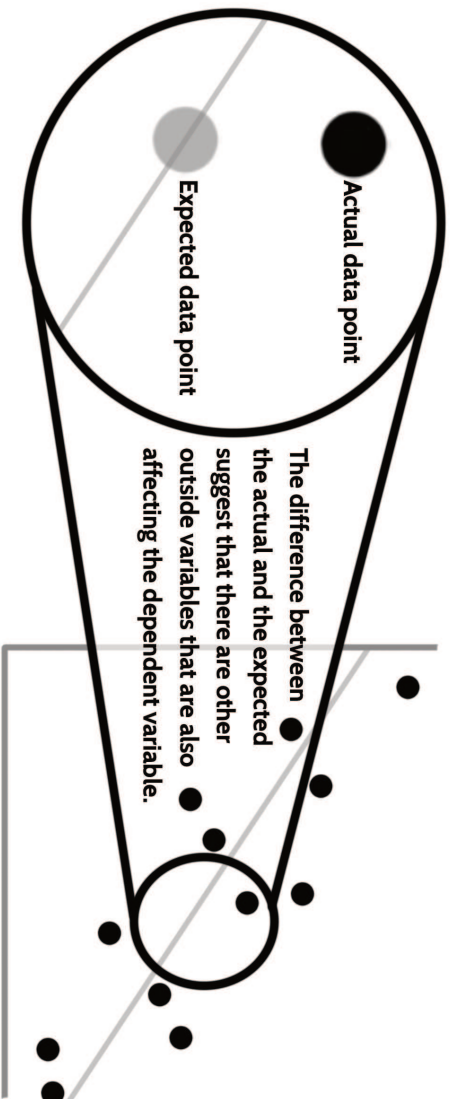
Step D: Click on the ruler next to the graph. Then select the “Least Square Line” box.

1. Looking at the overall data, circle the relationship that best fits the data.

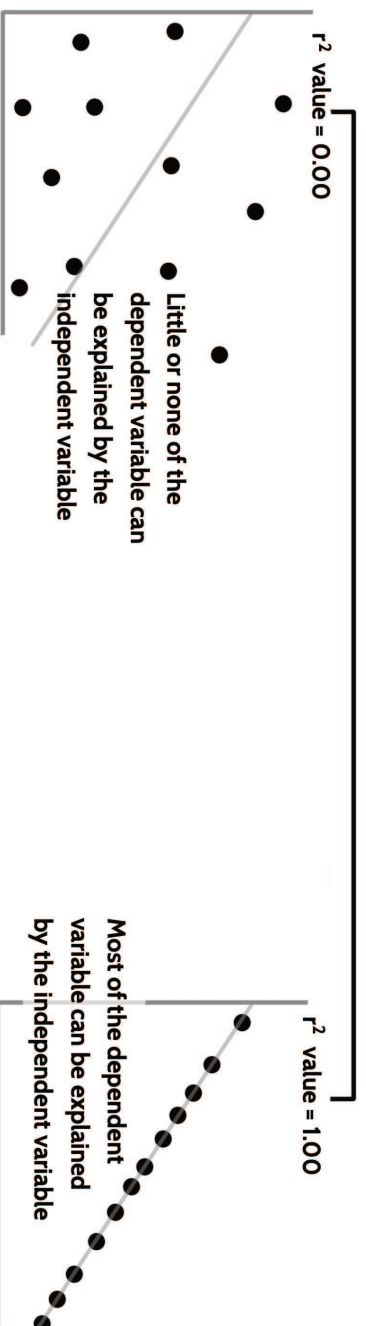


2. Describe the relationship in words. (As patch size increases, the effective population size...)
As the patch size increases, the effective population size increases.

3. There are a lot of different variables that can affect an individual data point. The “ r^2 ” value is used to describe how much the variable on the X-axis affects the variable on the Y-axis.



The r^2 value is based on a continuum. It is a mathematical and statistical tool that shows how much of the dependent variable can be explained by the independent variable.



Use the r^2 value on the graph to mark on the continuum how strongly patch size affects the population size.



4. Summarize in words the relative strength of the relationship between patch size and effective population size using the r^2 value.

About half of a population's size can be explained by the patch size, but there are other variables besides patch size that also are affecting population size.

Part 2: If there is a relationship in part 1, is there a relationship between patch size and number of alleles (genetic diversity)?

Step A: Identify which of the following columns in the chart is the independent variable and which is the dependent variable.

- Patch size (independent variable)
- Number of alleles (genetic diversity) (dependent variable)

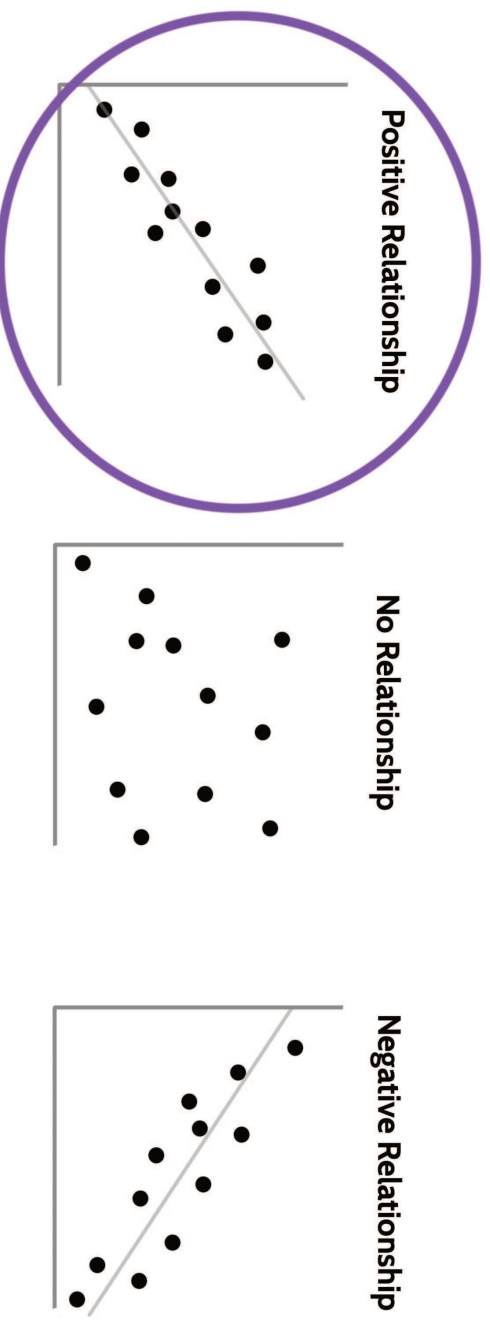
Step A: Click on the graph icon in the upper left corner of the screen to open a new graph window.

Step B: Drag the column heading that you identified as the independent variable and drop it on the X-axis in the graph.

Step C: Drag the column heading you identified as the dependent variable from the table and drop it on the Y-axis in the graph.

Step D: Click on the ruler next to the graph. Then select the "Least Square Line" box.

5. Looking at the overall data, circle the relationship graph that best fits the data.



6. The mean number of alleles is a measure for genetic diversity. Describe the relationship in words. (As patch size increases, genetic diversity...)

As patch size increases, the genetic diversity also increases.

7. Use the r^2 value on the graph to mark on the continuum how strongly patch size affects genetic diversity.



8. Summarize in words the relative strength of the relationship between patch size and genetic diversity using the r^2 value.

Over half of the genetic diversity can be explained by the patch size, but there are other variables besides patch size that also are affecting genetic diversity.

Conclusions

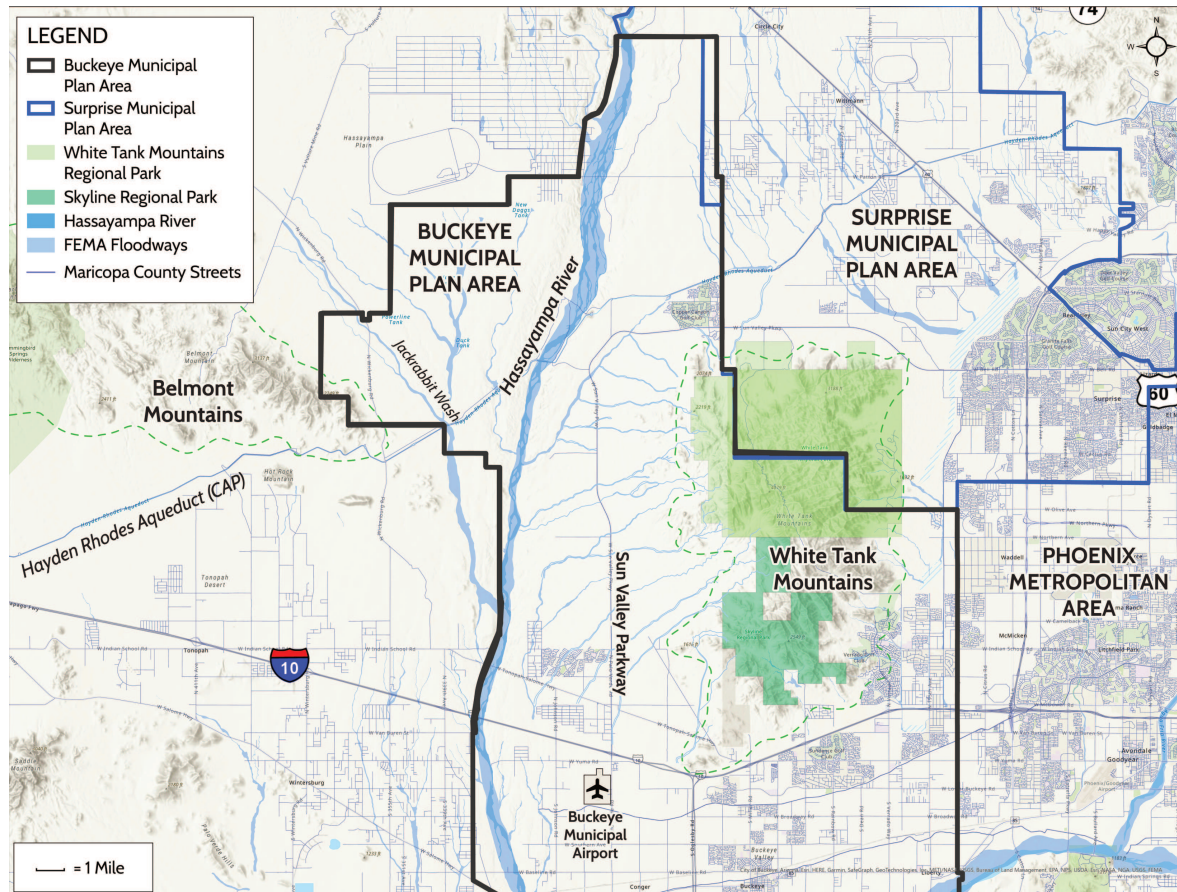
9. Patch size is a measure for the size of continuous habitat. According to this study, how does reducing fragmentation and connecting habitat help make populations more resilient? As habitats are more connected, the amount of habitat for nonhuman populations increases. This allows for larger populations that have greater genetic diversity.

References

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Lesson 10 Teacher Reference

Buckeye Area Map



Adapted from: White Tank Mountains Conservancy, (2021). Data Source: Maricopa County [Arizona]. Streets, Maricopa County Recorder GIS Department. GIS data release, Arizona Geographic Information Council. Accessed 29 Apr. 2020.

Buckeye Plan Evaluation Tool Key

10.A.2 Evaluate competing design solutions in a real, complex **expanding urban** system based on scientific ideas related to creating **more stable populations and ecosystems** and relevant factors **including a range of constraints**. (SEP 7.6; **DCI: ETS1.B.1, LS4.D.2; CCC: 7.4**)

3D Elements Addressed in this Assessment		
SEP	Evaluate competing design solutions to a real-world problem based on scientific ideas and principles, empirical evidence, and/or logical arguments regarding relevant factors (e.g. economic, societal, environmental, ethical considerations).	
DCI	Humans depend on the living world for the resources and other benefits provided by biodiversity. But human activity is also having adverse impacts on biodiversity through overpopulation, overexploitation, habitat destruction, pollution, introduction of invasive species, and climate change. Thus, sustaining biodiversity so that ecosystem functioning and productivity are maintained is essential to supporting and enhancing life on Earth. Sustaining biodiversity also aids humanity by preserving landscapes of recreational or inspirational value.	
	When evaluating solutions, it is important to take into account a range of constraints, including cost, safety, reliability, and aesthetics and to consider social, cultural, and environmental impacts.	
CCC	Systems can be designed for greater or lesser stability.	

Thinking about the long term stability of nonhuman populations in Buckeye, what should be the goal of the design? What should we see in a design that would help us accomplish that goal?

Our goal is to make sure the populations do not get fragmented so there is adequate gene flow to maintain genetic diversity over the long term. Nonhuman populations should be part of a resilient ecosystem with many interconnected populations. We should see a strategy or structure in the design that prevents fragmentation of populations, like a corridor over a highway or something connecting areas or a decision not to develop in a certain area.

Use the tables below to help compare and evaluate the competing arguments or different design solutions.

Design #1		Design #2	
Part 1: Summarize the designs			
Summarize the main idea of the design.	The design includes two wide corridors (½ mile-1 mile wide) that run from the White Tank Mountains to the Belmont Mountains. It requires the purchase of private land to build the corridors. Bike and walking paths will run along the corridors.	This design builds a series of narrow corridors (200-400 ft wide including buffers) along existing floodways from the White Tank Mountains to the Hassayampa River and I-10. It provides bike and walking paths throughout the new development area.	

Design #1		Design #2
Part 2: Identify the Key Science Ideas and Supporting Evidence		
How does this design prevent populations from becoming fragmented? How does it promote gene flow? Use data to support or refute your answer where possible.	It creates 2 wide corridors that are wide enough for mountain lions (need 100-300 ft) and mule deer (need 800-2400 feet, max of 0.45 miles). Nonhuman populations will move along this corridor, allowing for gene flow between the White Tank Mountains and Belmont Mountains.	The corridors are too narrow for mule deer that are afraid of humans and need corridors that are at least 800 feet wide. However, they are wide enough for mountain lions. There are probably fewer mountain lions than deer so it helps that population with gene flow. The corridors do not cross the Hassayampa River, however, so animals are not protected if they want to get all the way to the Belmont Mountains unless maybe they do not develop the washes.
How does this design support biodiversity?	It provides corridors for many species (at least 11) and also supports genetic diversity by preventing fragmentation.	It allows species to move to the Hassayampa River and along the I-10 corridor so they have more space. Native plants in the corridors will provide habitat for a variety of species. The genetic diversity of mule deer and mountain lions may not be reduced because they cannot cross to the Belmont Mountains.

Compare your two evaluations. Which design is best from a **science perspective**, and why? Proposal 1 is better. It provides wide enough corridors for mountain lions, mule deer and likely many other species to move between the White Tank Mountains and Belmont Mountains, allowing for gene flow and maintaining high biodiversity in the ecosystem. Proposal 2 causes fragmentation. It does not protect the mule deer with wide enough corridors, which mountain lions need to eat. If something happens to the mule deer, the mountain lions may starve.

	Design #1	Design #2
Part 3: Consider the Impact on People and their Communities		
How does this design fit with the criteria and constraints proposed by the City of Buckeye?	It provides bike and walking paths for people for recreation in the northern part of the city. It is safer for cars because it provides wildlife crossings that keep animals off the roads and prevents crashes. It preserves the desert ecosystem and natural beauty at the corridors and protects the Hassayampa River and JackRabbit Wash. It may not provide enough housing if they cannot develop the area in the wide corridors. Prevents some development near major roads, which criteria calls for.	It provides bike and walking paths for people for recreation. Those paths are distributed equitably throughout the city. It is safer for cars because it provides wildlife crossings that keep animals off the roads and prevents crashes. It preserves the desert ecosystem and natural beauty in the corridors. It limits costs because the corridors are built where they need to protect from flooding anyway. Development can happen near major roads like the SVP and I-11.

What ideas are being prioritized/most valued in this design? (for example cost, recreation, safety, housing, wildlife, people, etc.)	It prioritizes the needs of the nonhuman populations. It provides recreation for people as well, but does not prioritize equitable access to these areas.	It prioritizes lower cost corridor options that allow for equitable development throughout the area. Housing needs and housing prices are valued. Equitable access to recreation.
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Compare your two evaluations. Which design is best from the **perspective of people and their communities**, and why?

Design 2 is better for people who want equitable housing and access to natural areas for recreation and beauty. It also saves the city money because it serves the dual purpose of protecting areas from flooding and creating wildlife corridors. Design 1 is more expensive and difficult to complete because the city needs to buy private land and convince people to sell to them. Design 1 also requires a corridor under or over the I-11, which will be expensive to build.

Part 4: Analyze Both the Science and Human Perspectives

When considering BOTH the science ideas AND the impacts of the designs on people and their communities, which design do you think is best? Support your answer with evidence.

See rubric below

What revisions would you make to the design to address any issues discovered in your evaluation?

See rubric below

Foundational Pieces	Linked Understanding	Organized Understanding
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3D Elements	Look for:	Look for:	Look for:
	Students explain how one design solution is better for the genetic diversity of nonhuman populations to prevent fragmentation in urban areas. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4) AND Students balance the protection of nonhuman and human needs related to urbanization. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2) AND Students make suggestions that blend ideas from both proposals that accommodate the needs of human and nonhuman populations. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2)	Students explain using evidence how one design solution better stabilizes the genetic diversity of nonhuman populations through the use of wildlife corridors to prevent fragmentation in urban areas. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4) AND Students balance the protection of genetic diversity with a human need related to urbanization. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2) AND Students make suggestions that blend ideas from both proposals that accommodate the needs of human and nonhuman populations, to create more equitable access to recreation and/or natural beauty. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2)	Students explain using evidence how one design solution better stabilizes the genetic diversity of nonhuman populations through the use of wildlife corridors to prevent fragmentation in urban areas. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2; CCC: 7.4) AND Students balance the protection of biodiversity with multiple human needs related to urbanization. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2) AND Students make detailed suggestions that blend ideas from both proposals with more distributed, medium-width corridors that accommodate the needs of human and nonhuman populations, or adding an additional corridor all the way to the Belmont Mountains to proposal 2, or combining corridors from both proposals to create more equitable access to recreation and/or natural beauty. (SEP 7.6; DCI: ETS1.B.1, LS4.D.2)

Example	I think design 1 is better because it includes corridors that run from the White Tank Mountains to the Belmont Mountains, whereas design 2 stops at the river. This prevents fragmentation. Even though the design is more expensive. I think it is really important to help the populations get all the way to the Belmont Mountains. AND I would combine parts of design 1 and 2 so both humans and nonhumans get what they need.	I think design 1 is better because it includes two wide corridors (½ mile-1 mile wide) that run from the White Tank Mountains to the Belmont Mountains that are wide enough for both mule deer and mountain lions to use, whereas design 2 stops at the river. This prevents fragmentation and supports gene flow in both populations, which will keep them stable and able to adapt to future changes in the environment. Even though the design is more expensive. I think it is really important to help the populations get all the way to the Belmont mountains. AND I would add on the floodway corridors from design 2 to design 1 to provide people who live in Buckeye more equitable access to recreation and beautiful areas.	I think design 1 is better because it includes two wide corridors (½ mile-1 mile wide) that run from the White Tank Mountains to the Belmont Mountains that are wide enough for both mule deer and mountain lions to use, whereas design 2 stops at the river. This prevents fragmentation and supports gene flow in both populations, which will keep them stable and able to adapt to future changes in the environment. Even though the design 1 is more expensive because they have to buy private land, I think it is really important to help the populations get all the way to the Belmont mountains. The wide corridors will also provide places for a wide variety of nonhuman populations to live, creating a resilient ecosystem and supporting biodiversity in general. AND I would add on the floodway corridors from design 2 to design 1 to provide people who live in Buckeye more equitable access to recreation and beautiful areas. It would also provide additional native plantings for smaller nonhuman populations to protect biodiversity.
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		NOTE: Students could effectively argue for Proposal 2 if equitable access to recreation, more housing with access to existing infrastructure, and lower costs are strong concerns.
Feedback /What to Do	Linking: Ask students if the corridors in design 1 or 2 meets the needs of the mountain lion and mule deer as described in the Visual Inquiry. Provide sentence starters from the equity callout.	Organizing: Ask if the designs meet all criteria for maintaining biodiversity and resilient ecosystems that are discussed in Lessons 7 and 9. Refer students to the criteria and constraints presented in <i>Buckeye Criteria and Constraints</i>.
		Extending: Refer students to the criteria and constraints presented in <i>Buckeye Criteria and Constraints</i> and ask them to consider ways a design could meet additional criteria within given constraints. Ask them if one of the other possible solutions proposed in the 3D row of this rubric would be a viable option.

Part 5: Apply what you learned to a place that matters to you.

Think of a place you care about that is threatened by urbanization. How would you apply what you know from this unit to protect the nonhuman populations or biodiversity of that place? Describe at least one concrete action you could take that would make a difference.

Answers will vary. Answers may include lobbying for money to protect a park or wildlife corridor, helping people put in native plantings in gardens, installing green roofs, moving a development away from an area key to wildlife movement.

Transfer Task Key

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. [Clarification Statement: Emphasis is on analyzing shifts in numerical distribution of traits and using these shifts as evidence to support explanations.] [Assessment Boundary: *Assessment is limited to basic statistical and graphical analysis. Assessment does not include allele frequency calculations.*]

3D Elements Addressed in this Assessment		1	2	3	4	5	6	7
SEPs	4.2 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.		X		X	X		X
DCIs	LS4.B.1 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-LS4-2),(HS-LS4-3)	X		X	X	X		X
	LS4.B.2 The traits that positively affect survival are more likely to be reproduced and thus are more common in the population. (HS-LS4-3)		X			X	X	X
	LS4.C.2 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)		X				X	X
	LS4.C.3 Adaptation also means that the distribution of traits in a population can change when conditions change. (HS-LS4-3)	X				X		X
CCCs	1.1 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.	X					X	X

Can Humans Save the Banana?

The banana is the most popular fruit in the world, currently making up almost half of all global production of fruit. Every banana you buy at the store is genetically identical to the one next to it! This is because the banana only reproduces by creating clones of itself.

Most bananas grow in tropical climates between the equator and 30 degrees south of the equator. In the wild, bananas sexually reproduce like other plants. In farmed bananas, farmers do not allow the bananas to sexually reproduce. They clone the variety of plants that is best for commercial growing, harvest, and shipping to locations around the world.

Before the 1950s, the world's choice of banana was the Gros Michel variety because it was creamier, sweeter, and easier to transport than other bananas (they had thick peels, which protected the bananas from bruising). However, between 1890 and 1950, the banana crop in Latin America was almost entirely destroyed. The culprit was a fungus called *Fusarium oxysporum*. The fungus lives in the soil and infects the roots of the banana plant. It slowly works its way up the plant, eventually choking the plant of nutrients and killing it. Because all Gros Michel individuals were genetically identical, the disease devastated their populations.

Analyze the maps illustrating the Gros Michel populations in Latin America before 1890 and after 1950:

1. Why do you think the Gros Michel banana populations were so vulnerable to a single fungus? How could one fungus almost kill off entire populations?

They lack genetic diversity, so if a fungus kills one plant, it will kill all of them because they have the same defenses or lack of defense because they are all exactly the same genetically.

Switching to the Cavendish

After almost all the Gros Michel bananas were gone, farmers switched to a different banana variety that was resistant to the *Fusarium oxysporum* fungus. Right now 99% of all global banana exports are made up of one variety—the Cavendish banana. But the Cavendish banana might be in danger as well!

A New Environmental Pressure

Now bananas are facing a new threat. Increasing numbers of Cavendish bananas across Asia, Australia, and Africa are becoming infected by a new fungus. The tropical race 4 (TR4) fungus is unaffected by pesticides and kills Cavendish banana plants. Analyze the graph (Figure 2) from a case study of TR4 fungus infestation in Taiwan from 1967–1999.

2. Banana farmers are trying to understand the urgency of this problem with the TR4 fungus.

- What kind of relationship (positive, negative, or no correlation) can you identify between the area infected with TR4 and the number of years passed? Use evidence from Figure 2 to support your claim.

Positive, the area infested increases with time.

- Based on this data, what do you predict will happen to the Cavendish banana in the future?

The Cavendish will be devastated like the Gros Michel.

A Possible Solution to the Banana Crisis

Currently, there are no banana varieties that are resistant to the TR4 fungus, so banana farmers are looking for another solution to their problem.

A scientist named James Dale found a wild banana called *Musa acuminata malaccensis* that is resistant to TR4, but it has hard seeds that make it difficult to eat. Dale was able to isolate the gene for resistance, RGA2, from the wild banana and insert it into the Cavendish banana plant. This created what is called a *genetically modified* variety. Dale created 6 versions.

Dale conducted a three-year trial on a banana plantation in Australia where TR4 infection was common and most Cavendish bananas had been killed by the fungus. He planted all Cavendish bananas—a typical variety that was not genetically modified and five genetically modified varieties of the RGA2 resistance gene from the *Musa acuminata malaccensis*, called RGA2-2, RGA2-3, RGA2-4, RGA2-5, and RGA2-7. The Cavendish and 5 genetically modified varieties lived together as a single population and were all grown in the same area, exposed equally to the TR4 fungus.

Analyze the data from his study using the questions below:

3. How do expression levels for the RGA2 gene differ between banana variations?
There is a difference in expression between the banana varieties. The gene is expressed most in RGA2-2 and 2-3 and least in Cavendish and RGA 202-7.

4.a. Using **Figure 5**, identify the banana variations that were most infected by the fungus. *Cavendish* and *RGAA2-7*

b. What relationship do you see between the *RGAA2* gene expression (Figure 4) and the percent infection (Figure 5)?

The more gene they express, the less they are infected. OR
The less gene they express, the more they are infected. OR

There is a negative relationship between infection and gene expression.

c. When scientists calculated the *r* value (correlation coefficient) for the relationship between percent infection and *RGAA2* expression, they got a value of 0.84. Is this a strong or weak relationship? **Strong**

d. Which variations have the greatest resistance to TR4 and will survive the best?
RGAA2-3, *2-2* and *2-4* are a close second.

5. Imagine after the TR4 infection that Dale left his experimental population to reproduce on its own and the environmental conditions did not change. If he came back in 20 years, predict whether each variety would increase or decrease in proportion in the population.

Variety	Cavendish	RGAA2-2	RGAA2-3	RGAA2-4	RGAA2-5	RGAA2-7
Starting proportion	.17	.17	.17	.17	.17	.17
Change in proportion	decrease	increase	increase	increase	increase	decrease

Can this GMO save the banana? Would this solve the problem?

6. Think about the pattern you read about in this task. Farmers grew a single variety—the Gros Michel banana—and it was devastated by *Fusarium oxysporum*. Cavendish is now being devastated by TR4. What do you think will happen if banana farmers switch to *RGAA2-3*? Will this pattern repeat? Explain.

I think the *RGAA2-3* will hold off the TS4 fungus for a while, but eventually the fungus will get a mutation that will let it work around the *RGAA2-3* defense and that mutation will spread in the population as the fungus reproduces through the mechanisms of natural selection as fast as it did in Figure 2. Eventually most fungus will be able to attack bananas again, and the banana population will be devastated like it was by *Fusarium oxysporum*.

OR

A new fungus will come along and attack bananas, and the crop will not have a defense. Since the bananas are all genetically identical, none of them will survive the new crop, and the new fungus will spread through the farms as quickly as Figure 2.

7. Although many farmers prefer to grow a single variety of banana with no genetic variation for commercial purposes, some scientists believe that banana farmers should grow multiple banana varieties that can sexually reproduce to prevent future outbreaks of disease that devastate whole populations. Use your understanding of natural selection to explain how this could protect the banana crop from disease. Support your response with evidence and patterns from different cases you have investigated in this unit.

Foundational Pieces	Linked Understanding	Organized Understanding
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3D Elements	In this explanation, look for: Student explains that increased genetic diversity in a population causes an adaptive genetic mutation that provides protection to the plant, increasing chances for survival and therefore that can be passed onto offspring.	In this explanation, look for: Student explains that increased genetic diversity in a population causes an increased probability of having an adaptive genetic mutation that provides protection to the plant, increasing chances for survival, and therefore that can be passed onto offspring.	In this explanation, look for: Student explanation is based on the patterns of evidence learned in previous lessons that increased genetic diversity in a population causes an increased probability of having an adaptive genetic mutation that provides protection to the plant, increasing chances for survival, and therefore that can be passed onto offspring.
Example	If farmers have multiple varieties of banana, there is more genetic variation in their farm population. These different varieties can mix genes when they reproduce, so if a new disease comes along, at least some of the individual banana plants in the population will have resistance, and then they can reproduce and share those favorable adaptations with their offspring. Those genes can then spread through the banana population.	If farmers have multiple varieties of banana, there is more genetic variation in their farm population. These different varieties can mix genes when they reproduce sexually, so if a new disease comes along, at least some of the individual banana plants in the population will have resistance, and then they can reproduce and share those favorable adaptations with their offspring. Those genes can then spread through the banana population. It's a matter of probability: larger populations with a larger amount of allele diversity provide more opportunities for adaptation when new selection pressures come along.	See below
Feedback /What to Do	<i>Linking:</i> Provide students with pony beads to represent the patterns they think will happen in clonal vs. sexually reproducing populations. Ask students to revise their models after review.	<i>Organizing:</i> Ask students to connect what is happening in the bananas to one of the other case studies from the unit. Ask students how they know this pattern is likely. Ask students to revise their models after review.	<i>Extending:</i> Ask students what disadvantages may come from farmers growing bananas that reproduce sexually.

Organized understanding example: If farmers have multiple varieties of banana, there is more genetic variation in their farm population. These different varieties can mix genes when they reproduce sexually, so if a new disease comes along, at least some of the individual banana plants in the population will have resistance, and then they can reproduce and share those favorable adaptations with their offspring. Those genes can then spread through the banana population. This is like the pattern we saw with the Florida panthers. When there are more of them, they have more allele diversity in their population, and when new selection pressures come along, there is a better chance that one of them will have the helpful allele that improves their fitness, and they can pass it on to their offspring. If the population is small and less diverse, they might not have the beneficial allele when it is needed. It's a matter of probability: larger populations with a larger amount of allele diversity provide more opportunities for adaptation when new selection pressures come along.

	Foundational Understanding	Linked Understanding	Organized Understanding
Ideas for Instruction	- Revisit Lesson 8 but use the alleles to represent variation in bananas, rather than panthers. Create a population with no variation and one with variation to model over generations. - Review the model of evolution by natural selection your class developed in lesson set 1.	Refer back to the progress tracker for Lessons 8 and 9. Ask students to review the cases studied in those lessons and ways the genetic diversity of populations were changed.	- Ask students to discuss what other agricultural crops, such as corn or soybeans, may face similar challenges based on the way they are grown, - Discuss why some groups, like seed savers or Indigenous groups, are protecting diverse seed stocks.

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Lesson 11: Answer Key 1

Progress Tracker Key

Driving Question

How is urbanization a driving force for change?

Lesson number	Lesson Question	What I Figured Out in Words, Pictures, and/or Symbols	Questions I Have
2	Why do hawksbeard make fewer feathery seeds in cities?	- Fragmentation is a selection pressure that makes it difficult for feathery seeds to land in a place they can germinate. - More nonfeathery seeds survive to germinate because they land next to their parent. - In urban areas, there is a higher proportion of plants with more nonfeathery seeds.	- How do the genetics work for hawksbeard? - Do plants from feathery and nonfeathery seeds always make the same proportion of seed types? - What other things can be selection pressures in urban environments?
4	What caused populations of city juncos to be more bold than mountain juncos?	- Boldness is a competitive advantage for obtaining food and nesting spaces. This leads to increased survival for birds that are more bold in city environments. - Juncos have inherited behavioral traits from their parents. - Elevated corticosterone (CORT) levels correspond to stress levels in juncos. This negatively affects how bold those birds are. - Over time, juncos that are more bold survive and reproduce, causing a greater proportion of juncos living in the city to be more bold.	- How is CORT inherited? - How did they stay at UCSD in the first place? - What will happen in the future?
8	How can fragmentation on lead to lower genetic diversity?	- Fragmentation can create smaller, isolated populations. - Fragmented populations become less fit if they lose individuals with alleles that provide a selective advantage. - Selection pressures and random chance can cause loss of allelic diversity in populations. - If populations lose genetic diversity, they cannot always adapt to a changing environment.	- Couldn't we just get a panther from somewhere else and bring it to our population? - Could we reconnect the populations somehow? - How could we prevent fragmentation?

9	How can we plan urban areas to protect genetic diversity in nonhuman populations?	• Keeping large populations in large areas maintains genetic diversity so populations can adapt to changing conditions. • We can maintain population resilience and genetic diversity by creating corridors to connect fragmented populations. • We can develop criteria for urbanization that sustains biodiversity that benefits humans and nonhuman populations. • Sometimes human and nonhuman needs may be in conflict.	• How are they planning to help the mountain lion? • Is the community of Buckeye considering urban designs to address habitat fragmentation? • Is it possible to make a design that is good for people and for animals? • How much do corridors cost to build?
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