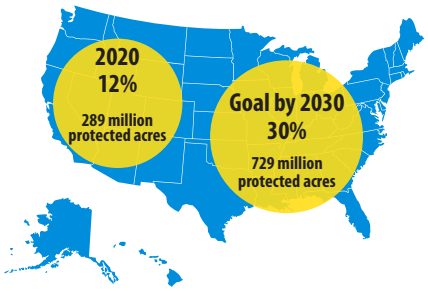
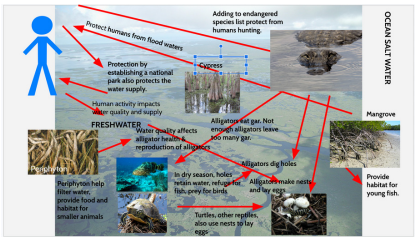
Unit Storyline

Lesson Set 1: How do populations interact with components of ecosystems?

LESSON 1

Why do ecosystems need protection, and how are they protected?

Anchoring Phenomenon 4 days

Phenomenon or design problem	What we do and figure out	How we represent it
Lands and waters are protected in different ways based on different criteria. 	We hear about a plan called the 30 by 30 Initiative designed to preserve land and water in the US and beyond. We brainstorm a list of criteria that motivate conservation. We look at examples of conservation and develop initial models of what happened in these places over time. We build a Driving Question Board and generate ideas for investigation. We figure out: • In the US and other countries, there is a plan to conserve 30% of lands and waters by 2030. • Humans have different reasons for conserving lands and waters. • Each system is composed of unique components and interactions that are affected by human interactions. • We can look at ecosystems that have been protected to understand how to protect systems in the future.	 National Park Service

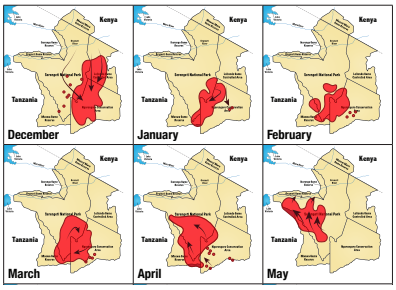
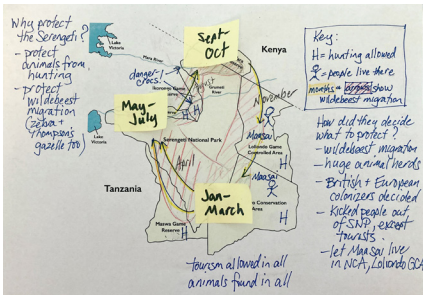
Navigation to Next Lesson: We figured out that people conserve places, lands, and waters for many different reasons and in many different ways. We wonder how we can use what we figured out about multiple ecosystems to understand how to conserve lands and waters across the US.

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LESSON 2

What can other cases of conservation help us understand about ecosystems and conservation?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Serengeti National Park was created to protect the great animal migration route and has a history of complicated human interactions. 	We watch a video and look at maps of the Serengeti ecosystem and read about the history of its conservation. We collect more information in a scavenger hunt. We create a consensus model and short explanation of why Serengeti National Park and surrounding reserves were created. We figure out: • The Serengeti is a unique ecosystem with high biodiversity, a unique large mammal migration, and endemic and endangered species. • The great migration is unique, and the park was established in part to protect it. • The great migration is dangerous, but the animals do it anyway. • As a protected space, human decision-making about the Serengeti ecosystem has been motivated by many different points of view and priorities.	

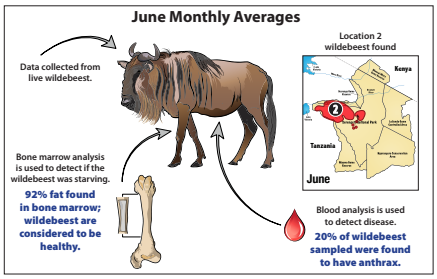
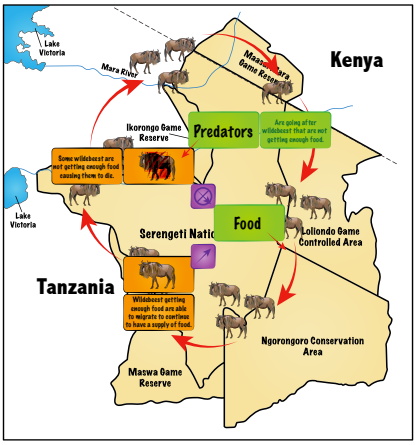
Navigation to Next Lesson: We figure out that Serengeti National Park and surrounding reserves were created to protect the migration of the wildebeest. We wonder why wildebeest go through such a long, dangerous migration.

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LESSON 3

Why do the animals in the Serengeti migrate?

Investigation 2 days

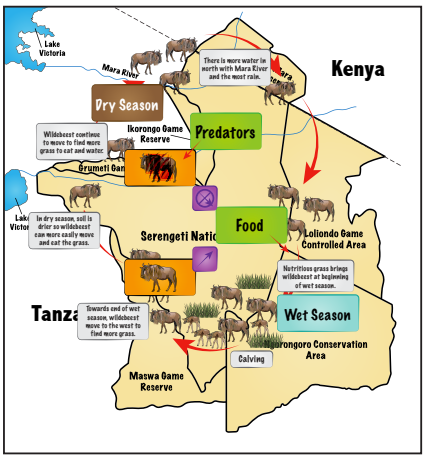
Phenomenon or design problem	What we do and figure out	
Wildebeest field data can be organized to find patterns to explain their migration.  	We reflect on wildebeest migration and brainstorm why wildebeest migrate. We hear from a scientist about what he figured out from studying wildebeest. We look closer at wildebeest field data and organize it to look for patterns to explain wildebeest migration. We communicate what we figure out on data displays and co-construct a classroom consensus model to explain what we figured out about wildebeest migration. We figure out: • Some wildebeest are killed by predators, but most wildebeest die of starvation. • Food is the main factor that motivates the migration pattern.	

Navigation to Next Lesson: We figure out that there is evidence that the wildebeest migration is caused by food. We have a lot of questions about this connection between food and wildebeest moving from location to location.

LESSON 4

How is food driving the wildebeest migration?

Investigation 3 days

Phenomenon or design problem	What we do and figure out	How we represent it
Factors such as rain affect wildebeest migration in the Serengeti.  Daniel Rosengren	We decide to investigate how food drives the migration. We hear from a scientist that rain is a good way to understand food, because it is a limiting factor that affects how much grass there can be. We figure out: • There is a wet and a dry season in the Serengeti. • Rain is related to location some of the time. • Other factors limit wildebeest location at different times of the year.	

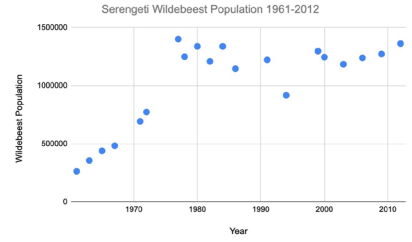
Navigation to Next Lesson: We figure out what limiting factors are driving wildebeest migration, which makes us wonder about the large wildebeest population and how it can be so big.

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LESSON 5

How does food affect the population size?

Investigation **2 days**

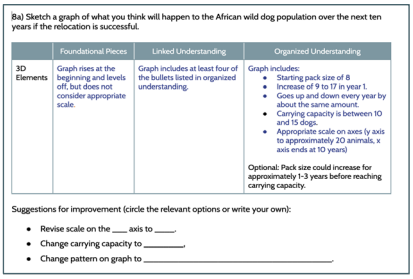
Phenomenon or design problem	What we do and figure out	How we represent it
The population of wildebeest is large when there is a lot of access to food (grass).  Anthony R.E. Sinclair	We decide to use a kinesthetic model to simulate what is happening with food and wildebeest in the Serengeti. We make sense of the data we collect to determine that the amount of food regulates how many wildebeest can survive. We conclude that more food is available because the wildebeest migrate. We figure out: • Food availability is the main limiting factor that regulates the wildebeest population; when they run out of food they move or die. • Migration increases the carrying capacity of the Serengeti ecosystem for wildebeest.	 Data Source: Hopcraft, G. et al. (2015)

Navigation to Next Lesson: We figure out more food is available to wildebeest when they migrate. We wonder if we can apply everything we have figured out so far back to our conservation profiles.

LESSON 6

Can we apply what we figured out about limiting factors and carrying capacity to a new scenario?

Putting Pieces Together **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Scientists want to reintroduce African wild dogs from South Africa to a new national park in Malawi.  Andy Morffew, CC BY-2.0	We apply the concepts of limiting factors and carrying capacity to a new scenario as we learn how to complete transfer tasks. We revisit the Driving Question Board to determine what else we need to know about the Serengeti ecosystem to learn how ecosystems work and protect them. We figure out: • Space, food, and predation can be limiting factors for wild dogs. • Data about limiting factors can be used to determine carrying capacity. • Liwonde National Park can support one pack of African wild dogs. • We need more information about the role of predators in the Serengeti ecosystem.	

Navigation to Next Lesson: We determine that we understand some of the limiting factors for the wildebeest, but we do not completely understand the role of their predators in the Serengeti ecosystem.

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Lesson Set 2: How do all the living and non-living components interact in an ecosystem?

LESSON 7

How do predators interact with the wildebeest migration?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Predators such as lions and spotted hyena interact with the wildebeest migration.  Diana Robinson, CC BY-NC-ND 2.0	We investigate the role of predators in the migration. We read about the behaviors of wildebeest and their predators and relate them to rules in an agent-based modeling game. We play the game and analyze our data to determine that group behaviors increase survival for predators and prey. We realize our model is limited because we only investigated a few components and wonder how we can include more of the components. We figure out: • Behaviors in wildebeest and their predators can inform initial conditions and rules in a model. • Mathematical models, such as algorithms, provide evidence to explain interactions. • There is a pattern of group behavior increasing survival across multiple species. • Models have limits that can affect the kinds of conclusions we can make from our data.	*If* an **individual wildebeest** interacts with **any predator**, *then* the wildebeest is **successful 29% of the time**. inputs: wildebeest, predator interaction outputs: lives (0), dies (-1) *If* **wildebeest = 1** and **predator = 1 and 2**, *then* wildebeest 0 (.29) OR *If* **wildebeest = 1** and **predator = 1 and 2**, *then* wildebeest -1 (.71)

Navigation to Next Lesson: We figure out that group behaviors increase survival and wonder about the rest of the components of the Serengeti system.

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LESSON 8

What other components of the Serengeti system interact with the migration?

Investigation **2 days**

Phenomenon or design problem

The Serengeti successfully supports many different organisms.



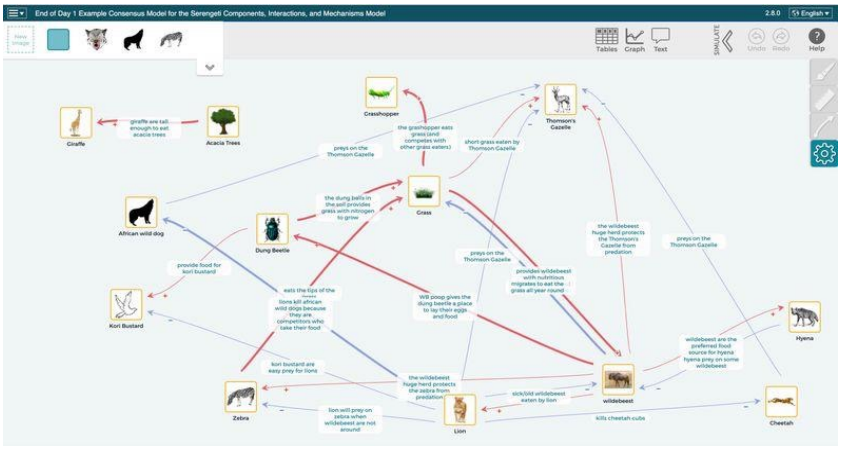
Mathis Jrdl, Unsplash

What we do and figure out

We investigate other components of the Serengeti ecosystem. We gather information to develop a model that includes mechanisms and mathematical representations of relationships. We use our models to predict outcomes of disturbances and figure out that biodiversity can support resilience in the system. We update our Progress Trackers and the DQB and complete an exit ticket to show what we have learned. We figure out:

- Many components of the ecosystem connect to the wildebeest migration.
- The mechanisms of their interactions include predator/prey, group behavior, and competition.
- Wildebeest are a keystone species, and their migration supports biodiversity across the entire Serengeti.
- Biodiversity leads to greater stability within the ecosystem because with more species, a drop in population size of one species can be balanced by an increase in the population of another.
- Biodiversity contributes to ecosystem resilience when a disturbance occurs.

How we represent it



Navigation to Next Lesson: We figure out that interactions between components based on the combined influences of competition, predation, and group behavior create biodiversity, which can lead to stability of the overall number of organisms in an ecosystem and resilience to disturbances. We wonder about the long-term effects of establishing Serengeti National Park affecting the resilience of the ecosystem.

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Lesson Set 3: How can we use what we learned about ecosystems to protect them?

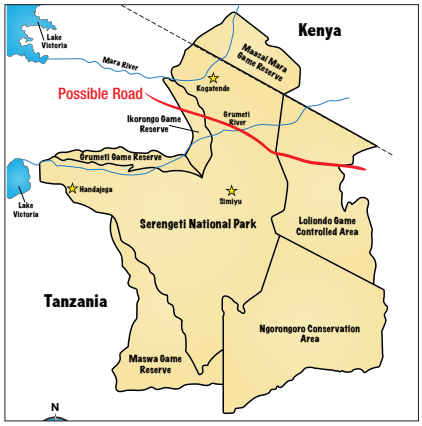
LESSON 9

How do humans interact with the Serengeti ecosystem?

Investigation **2 days**

Phenomenon or design problem

Tanzanians are considering building a road in the Serengeti.

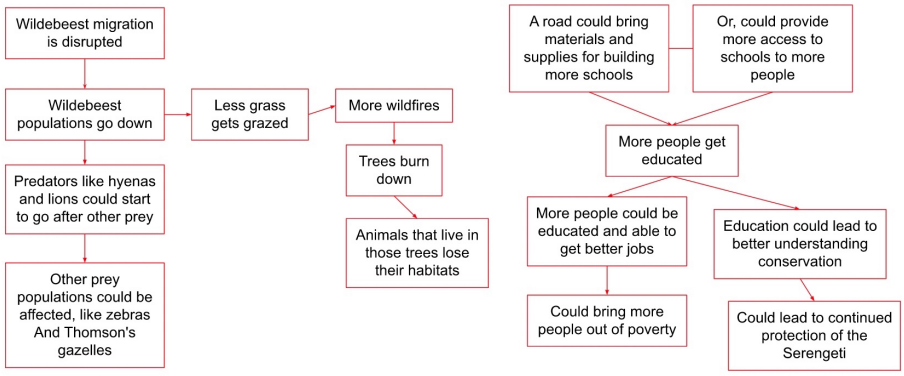


What we do and figure out

We explore how human interest holders interact with the Serengeti ecosystem and we add them to our models. We use our model to evaluate the Serengeti conservation plan and decide that it was successful in achieving its goals. We wonder what will happen in the future and investigate a proposal to build a road in the Serengeti. We evaluate road proposals and make a recommendation about the Serengeti conservation plan. We figure out:

- Creating the park protected the wildebeest migration and the stability of the system.
- Some interest holders benefit, but others are harmed, and not all human connections in the system are stable.
- Successful conservation that supports a stable ecosystem also involves relationships between the conservation managers and the broader community.
- There are numerous short- and long-term consequences that interest holders need to consider when making conservation decisions.

How we represent it



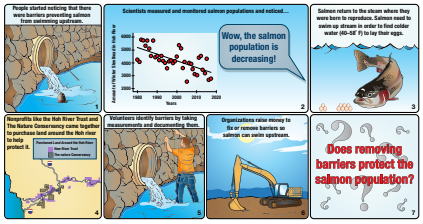
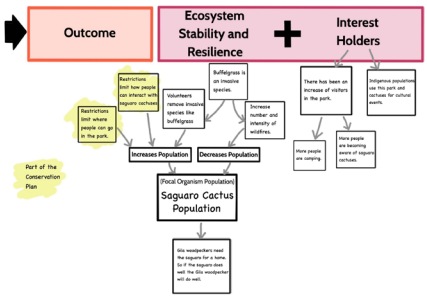
Navigation to Next Lesson: We figured out how a possible road could affect humans and nonhumans in Serengeti National Park. We wonder about how we could protect ecosystems more broadly.

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LESSON 10

How do we evaluate if a conservation effort is working?

Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Conservation success relies on the plan's goals being met while supporting ecosystem resilience and minimizing any negative impacts on interest holders. 	We return to our conservation profiles from Lesson 1. We evaluate the conservation plans in those systems by considering the impact the plan would have on organisms, the ecosystem overall, and other interest holders. We build understanding about what it means for conservation to be successful and how we can use what we learned to protect more lands and waters. We figure out: • Conservation success relies on the plan's goals being met while supporting ecosystem resilience and minimizing any negative impacts on interest holders. • Interest holders have different goals, and the criteria they judge success by may be different from the overall plan. • We can learn how to protect more places in the future by looking at conservation happening now.	

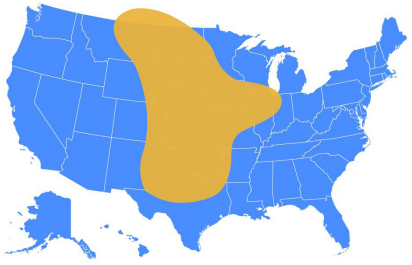
Navigation to Next Lesson: We figure out that conservation success relies on the plan's goals being met while supporting ecosystem resilience and minimizing any negative impacts on interest holders. This makes us wonder if we can apply everything we figured out to new conservation plans from the 30 by 30 Initiative.

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LESSON 11

Can we use everything we have figured out about ecosystems and conservation to expand conservation to new lands and waters?

Putting Pieces Together 1 day

Phenomenon or design problem	What we do and figure out	How we represent it
The American Prairie Reserve aims to add new protected lands.  Brian Greenblatt, CC BY-SA 3.0	We complete a transfer task about the American Prairie Preserve to demonstrate what we figured out throughout the unit about how ecosystems work and how understanding them can help us protect them. We figure out: • Human-caused changes can cause disruptions that change an ecosystem. • Some changes have greater or lesser effects and impact the stability of the system. • A change to a keystone species can affect the biodiversity of the system. • Humans consider many criteria when making decisions about conserving or using the natural world.	 Zntrip, GPL

Navigation to Next Lesson: There is no next lesson.

Lessons 1–11 **26 Days Total**

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Unit Storyline

Lesson Set 1: What causes zombie fires to burn under the ice and what are the consequences?

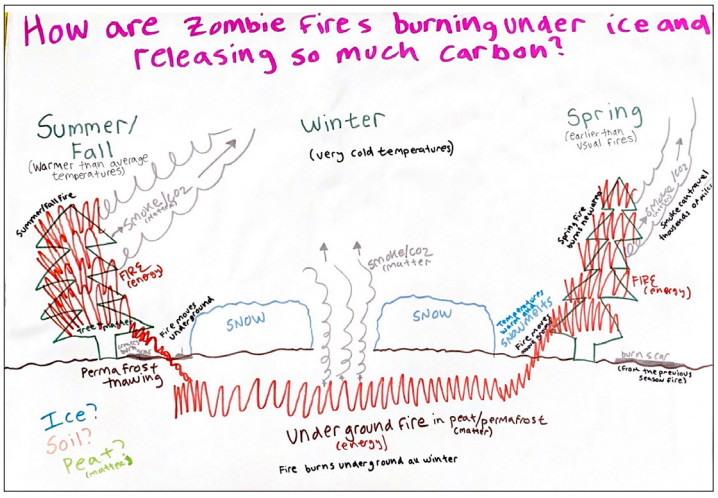
LESSON 1

How can fires burn under ice and release so much energy and matter?

Anchoring Phenomenon **3 days**

Phenomenon or design problem	What we do and figure out
Fires in the Arctic are burning under ice. 	We do a visual inquiry to investigate zombie fires. We share our experiences and ideas about how our lives are connected to fires. We develop initial models to explain the interactions in the zombie fire system and how they release so much carbon. We develop a DQB and decide to investigate how zombie fires could be burning under the ice. We figure out: • Zombie fires burn under ice throughout the winter. • In zombie fires, peat is burning in the thawing permafrost. • Lots of carbon is put into the air when these zombie fires burn. • Zombie fires are not very common but are becoming more common.

How we represent it



Navigation to Next Lesson: We figured out zombie fires burn under ice and release carbon. We wonder what is happening with the matter and energy in the peat/permafrost that allows fires to burn under ice.

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LESSON 2

What is peat and why does it burn so much?

Investigation **2 days**

Phenomenon or design problem

Burning peat and other fuels releases carbon dioxide and energy.



What we do and figure out

We decide to investigate what is burning in zombie fires. We observe and burn peat and other fuels for fire. We read about the relationships between permafrost and peat and notice and wonder about why peat formed. We figure out:

- We can explain puzzling observations using energy and matter concepts.
- Peat, made from ancient plants, is widespread and used as fuel.
- Peat is carbon-based and releases CO_2 when burned.
- Peat burns slowly, emitting much CO_2 and energy.
- Permafrost is ground that stays frozen for years, even centuries.
- Arctic permafrost thaw reveals peat.

How we represent it

		Peat	Wood	Leaves
Energy	Fuel Temp Before	25.7 °C	26.1 °C	25.5 °C
	Fuel Temp After	41.3 °C	30 °C	25.9 °C
	Surroundings Temp Before	25.3 °C	25.4 °C	22.5 °C
	Surroundings Temp After	26.8 °C	26.8 °C	25.8 °C
	Burning Time	10 min +	4 min	30 seconds
	Other observations	Hard to light. No visible flame, just a glowing ember at the beginning	Difficult to keep lit. Short, bright orange flame, went out before lid was on.	Easy to light. Tall bright yellow flame. Burned for 30 seconds.
Matter	Mass before	0.48 grams	0.48 grams	0.48 grams
	Mass after	0.04 grams	0.23 grams	0.28 grams
	BTB before	Blue	Blue	Blue
	BTB after	Green / Yellow	Blue / Yellow	Blue / Yellow
	Other observations	Lots of smoke, condensation. Glass cover became cloudy and covered in droplets. Sample continued burning while taking mass after. Before was black, turned into a gray white ash.	Was brown then turned black, then gray white. After about 8 minutes the smoke seemed to clear out of the glass container.	Brown, then black. Very little smoke because the fire went out quickly.

Navigation to Next Lesson: We figured out peat is made of layers of dead plants and releases CO_2 when it burns. We wonder why those plants did not break down and what happens when peat forms.

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LESSON 3

Why is there so much peat that has not decomposed in the permafrost?

Investigation **4 days**

Phenomenon or design problem

Peat does not decompose very much in permafrost.

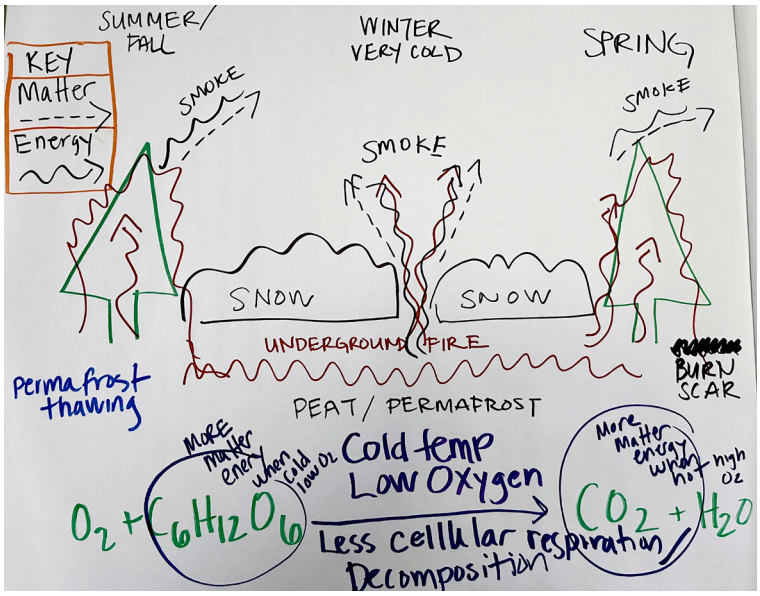


What we do and figure out

We look at images, develop models, and investigate how temperature affects decomposition rate. We plan and carry out an investigation, using yeast to generate evidence for an explanation about why there is so much peat. We figure out:

- Energy and matter from plants are typically returned to the atmosphere by decomposers.
- Conditions such as temperature and oxygen levels affect the rate of decomposition.
- Decomposition happens through a process called cellular respiration, where energy and matter are transferred.
- Energy from sugar is transferred to yeast and other decomposers during cellular respiration.
- Matter from sugar is transformed during cellular respiration to grow more yeast and produce carbon dioxide and water.
- In the permafrost/peat system, cold temperatures and low oxygen levels slow the rate of decomposition and cellular respiration.
- When rates of decomposition are low, the matter and energy do not flow out of the permafrost/peat system, making a carbon sink.

How we represent it



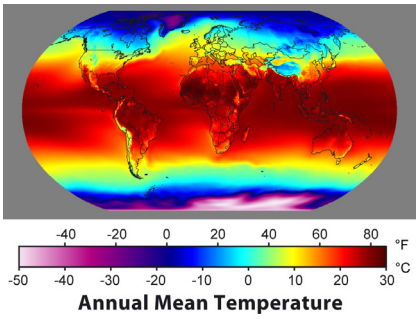
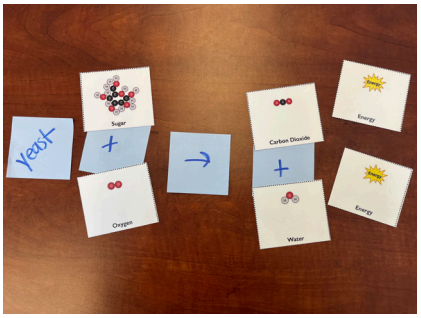
Navigation to Next Lesson: We figured out that carbon and energy are trapped in permafrost/peat due to slow decomposition/respiration. We wonder why there were so many plants in the Arctic that made peat if it is so cold.

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LESSON 4

How did so much plant energy and matter get into the peat in the zombie fire system?

Problematizing, Investigation **1 day**

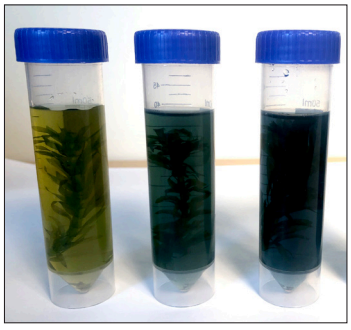
Phenomenon or design problem	What we do and figure out	How we represent it
Solar energy in the Arctic provides energy for photosynthesis. 	We investigate how so much plant matter was stored as peat under the permafrost. We read about Earth's conditions thousands of years ago that allowed for the formation of all that peat. We figure out: • Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds through photosynthesis. • As solar radiation in the Arctic decreased, many plants died, and peat and permafrost were formed.	

Navigation to Next Lesson: Now that we see that there is a relationship between solar radiation and photosynthesis, we need to investigate this. We need data!

LESSON 5

Could changes in the Earth's tilt cause more energy and matter to be stored in plants?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Plants make different amounts of starch when the light angle changes. 	We plan and carry out an investigation to determine how differences in available solar energy impact how much carbon dioxide is captured and stored as chemical energy in plants. We figure out: • Through photosynthesis, plants convert carbon dioxide and water into sugar and release oxygen. • More solar energy means more carbon dioxide is captured and stored by plants as sugar and oxygen. • Plants convert excess sugar into larger carbon-based molecules, such as starch. • Increased solar radiation in the Arctic increased the potential for plants to capture and store chemical energy in carbon-based compounds. • As solar radiation in the Arctic decreased, plants died, and peat and permafrost were formed.	

	Uncovered		Covered	
	Before	After	Before	After
Indirect Light	Yellow	Green/ Blue	Yellow	Yellow
Direct Light	Yellow	Dark Blue	Yellow	Yellow

Navigation to Next Lesson: We figured out that changes in solar energy based on differences in the Earth's tilt are responsible for the matter and energy stored in peat under the permafrost. We think we have figured out enough to try to explain how zombie fires can burn under ice and release so much carbon.

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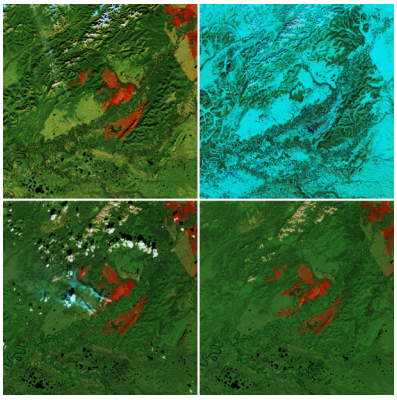
LESSON 6

How do zombie fires disrupt the flow of energy and cycle of matter in Arctic ecosystems?

Putting Pieces Together 2 days

Phenomenon or design problem

An infrared image shows the heat energy of a zombie fire burning underground.



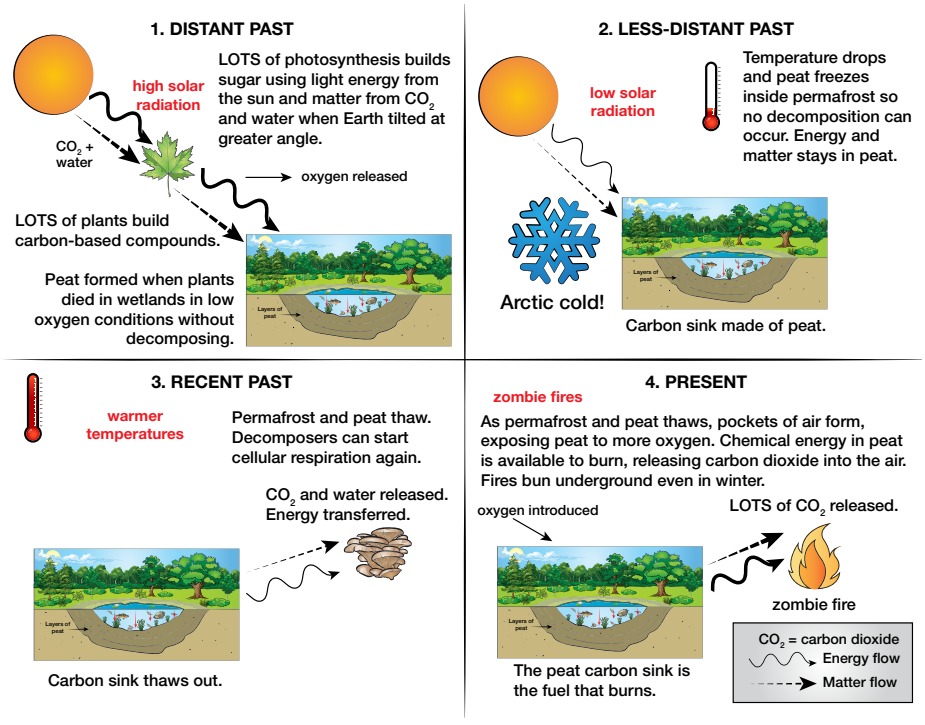
NASA's Earth Observatory, Joshua Stevens Public Domain

What we do and figure out

We develop our class consensus model based on evidence we collected to construct an explanation for zombie fires. We return to our DQB to update our questions and revise our Driving Question: What causes fires in ecosystems to burn and how should we manage them? We figure out:

- Photosynthesis captures energy from sunlight and converts it to chemical energy in carbon-based glucose fuel, taking carbon out of the air and into the plants. Plants with extra energy and matter assemble glucose into larger molecules.
- Plants in the Arctic die and get submerged where it is too cold for decomposition to happen quickly. Generations of plants die on top of one another, resulting in more and more matter and energy remaining under water/ice.
- Peat is layers of partially decomposed plants. When permafrost thaws, peat is exposed. Peat can now decompose and burn.
- Zombie fires burn carbon sinks in the peat/permafrost system, releasing tons of carbon dioxide into the air.
- In the recent past peat was frozen in permafrost, keeping matter and energy, but if in the future more permafrost thaws, then more matter and energy will be available.

How we represent it



Navigation to Next Lesson: We figured out how zombie fires are burning in the Arctic, but we wonder if there are other ecosystems with carbon sinks burning and what makes them vulnerable to burning.

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Lesson Set 2: How is global carbon cycling affected by fires?

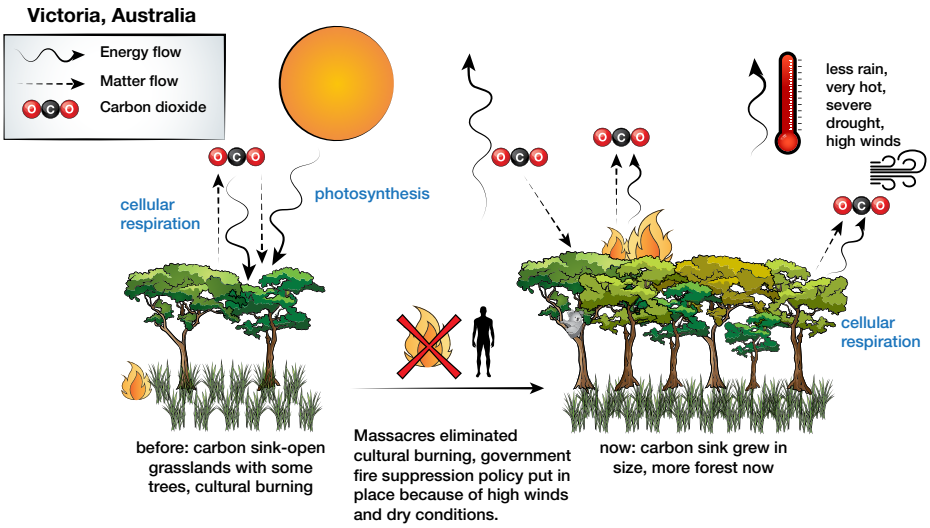
LESSON 7

What is happening to carbon sinks in other ecosystems?

Investigation 2 days

Phenomenon or design problem	What we do and figure out
Fires are burning in carbon sinks around the world. 	We use case studies to investigate places, lands, and waters where global carbon sinks are burning with more frequency. We analyze how energy and matter are moving through each system and discuss the historical events and decisions that contributed to the current conditions that make each carbon sink more likely to burn. We develop small-group models to help us come to consensus on the conditions that make carbon sinks more likely to burn. We wonder what the consequences and large-scale impacts are of fires from all these ecosystems. We also wonder about ways to manage fires into the future. We figure out: • Many different ecosystems have carbon sinks created from the flow of energy and matter into plants by photosynthesis. • There are common climate-related and human-caused factors in ecosystems that make the energy and matter in carbon sinks more likely to burn. • Fire increases the flow of matter and energy from the biosphere to the atmosphere.

How we represent it



The carbon sink is grass and eucalyptus forest. Photosynthesis transferred energy and carbon into the plants to create the sink. Today, very dry grasses and less rain makes carbon sink highly flammable. Bans on cultural burning, fire suppression that would have thinned out grasses and wood does not happen anymore making big, intense fires very likely.

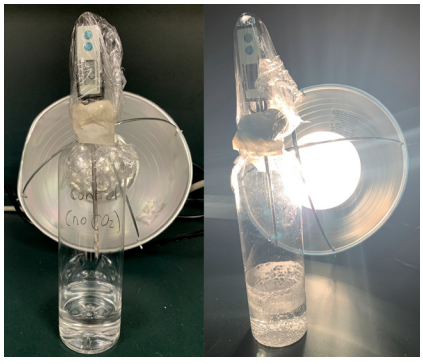
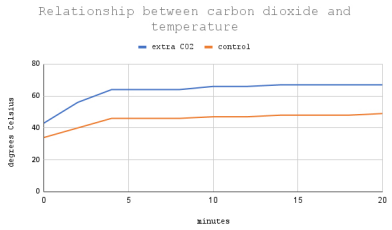
Navigation to Next Lesson: We figured out carbon sinks are burning due to drought, rising temperatures, land use changes, and fire suppression. We wonder about the larger consequences of these fires.

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LESSON 8

Why should we be concerned that carbon sinks around the world are burning?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Carbon dioxide from fires in the atmosphere is causing the temperature to increase. 	We investigate the effect of increased carbon dioxide on temperature, develop directional hypotheses, and collect evidence to support our hypotheses. We revise our hypotheses to explain the relationship between atmospheric carbon dioxide and temperature at the global scale and investigate data collected by scientists. We figure out: • Increased carbon dioxide in the air causes increased air temperature. • A directional hypothesis explains the effect of carbon dioxide concentration on temperature in a simulated system. • Global data indicates the relationship we figured out in our investigation system is similar to the relationship at the global scale.	

Navigation to Next Lesson: We figured out that increasing atmospheric carbon dioxide increases temperature and wonder how the relationship between carbon dioxide and temperature affects other systems.

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LESSON 9

What are the global effects of increased carbon dioxide from fires?

Investigation, Putting Pieces Together 2 days

Phenomenon or design problem

Fire influences how carbon and energy cycle through Earth's systems differently than in the past.

Atmosphere

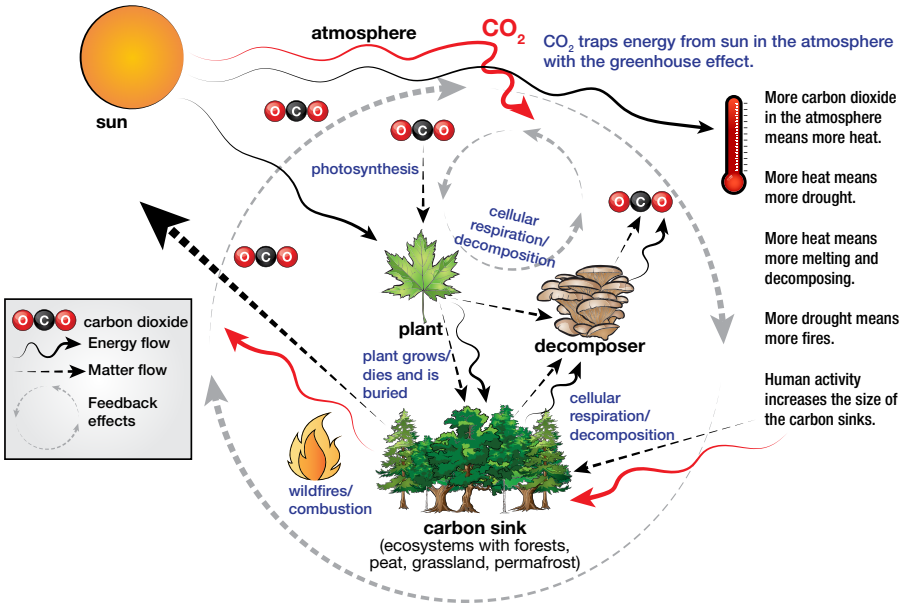
Die roll	What happens?	Where to next?
1 2 3	You remain in the atmosphere as a molecule of carbon dioxide, CO_2 (matter). **Energy remains in the same arrangement of atoms.** Record this action and roll again.	Atmosphere
4	You enter the ocean as carbon dioxide, CO_2, and are dissolved in the water (matter). **Energy flows to a new system in the same arrangement of atoms.**	Ocean
5 6	You are taken in by a producer as carbon dioxide, CO_2. The producer uses energy from sunlight and water to rearrange you into molecules used to build biomass (matter) of the producer. **Energy flows to a new system AND the atoms are rearranged.**	Producers

What we do and figure out

We use a quantitative model to simulate how carbon and energy flow through Earth's systems. We develop a model to determine if carbon dioxide levels and temperature will continue to grow as more carbon sinks burn. We figure out:

- Human actions caused the burning of carbon sinks, which shifted the balance of carbon (matter) and energy in the Earth system, releasing energy and matter from plant-based carbon sinks from the biosphere into the atmosphere.
- A (positive) feedback effect is created as increased carbon dioxide causes increased temperature and increased temperature causes more drought, which leads to more wildfires that release additional carbon dioxide into the atmosphere.

How we represent it



Navigation to Next Lesson: We figured out that burning carbon sinks create a positive feedback effect between carbon dioxide and temperature, and we wonder if we can reduce this by managing carbon sinks better.

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Lesson Set 3: How do we design solutions to manage the impacts of fires?

LESSON 10

How can we help manage the matter and energy in fire systems?

Investigation **3 days**

Phenomenon or design problem

Successful management of carbon sinks to prevent large wildfires uses a variety of methods that affect the flow of carbon and energy in ecosystems.

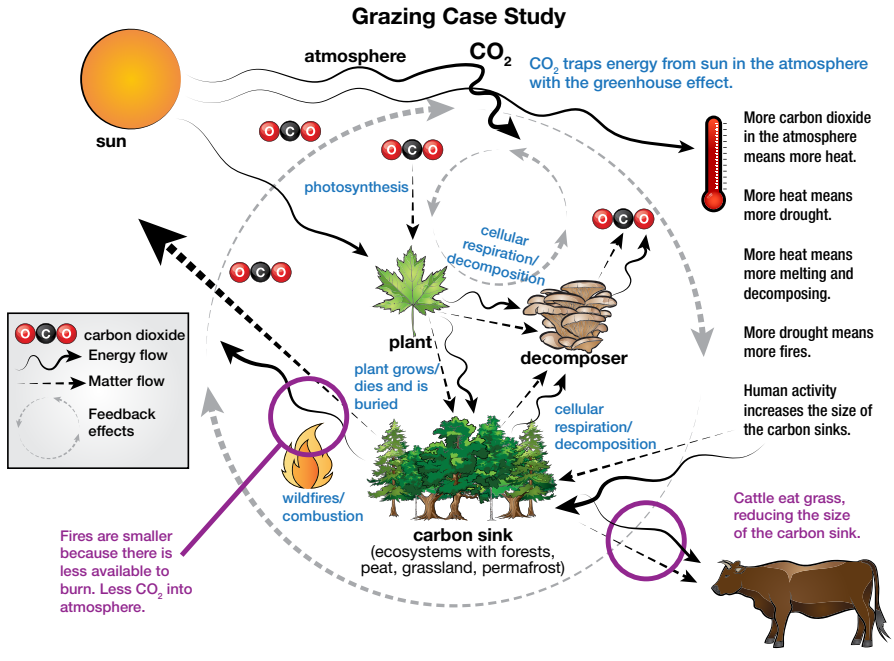


What we do and figure out

We investigate four case studies of successful fire management. We read about how prescribed burning, cultural burning, restoring grazer populations, and replanting forests help manage the amount of available carbon and energy that burn in wildfires. We use a mathematical representation to explain how these techniques could help fire management in ecosystems. We investigate fire risk in our own community and ways to reduce that risk. We figure out:

- Managing the amount of fuel available to burn in carbon sinks through prescribed burns, cultural burns, and grazing helps reduce an overabundance of built-up energy and matter.
- Planting trees can remove carbon dioxide from the atmosphere and has the potential to reduce atmospheric temperature.
- Energy and matter flow through each level of a food web through producers, consumers, and decomposers.
- Fire management decisions have short- and long-term consequences for both social and ecological structures and systems.

How we represent it



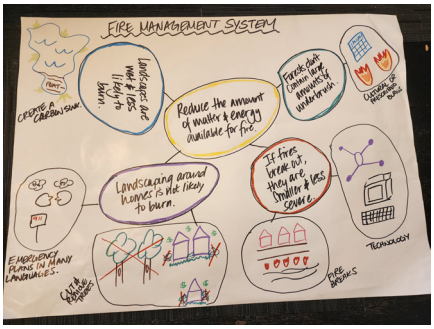
Navigation to Next Lesson: We figured out successful fire management includes a balance of plants and animals. We wonder how we can protect the places, lands, and waters we care about.

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LESSON 11

What decisions can we make to help manage fire in communities we care about?

Putting Pieces Together **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Fire management systems must meet criteria, constraints, and community needs. 	We create fire, matter, and energy management systems for reducing carbon emissions for places, lands, and waters we care about. We acknowledge species, kinds, and behaviors at different scales of the ecosystem we want to protect. We break down fire management criteria into simpler criteria. We share and seek knowledge from our community members. We share and revise fire matter and energy management systems, putting pieces together from the unit connected to five dimensions of complex socio-ecological systems. We figure out: • Criteria need to be broken down into simpler ones to manage fire to see who will be impacted (human and nonhuman) by our decisions. • Making decisions involves and impacts people at many levels in the systems we care about. • The places, lands, and waters we care about are complex, and decisions about the priority of certain criteria over others (trade-offs) may be needed. • We can answer many questions on our DQB.	

Navigation to Next Lesson: We figured out it is helpful to break down criteria when designing fire management systems. We wonder if we can apply what we figured out to a new phenomenon.

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LESSON 12

Can we use everything we have figured out about fires to explain a new phenomenon?

Putting Pieces Together 1 day

Phenomenon or design problem

Massive fish kills happen in the Gulf of Mexico.

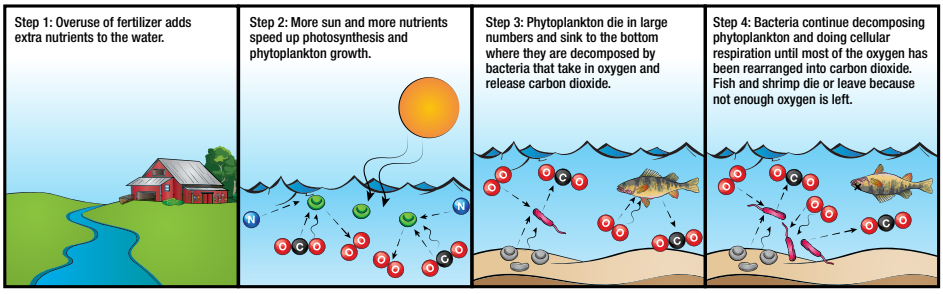


What we do and figure out

We complete a Transfer Task about eutrophication in marine ecosystems to demonstrate how what we figured out throughout the unit about the flow of energy and matter applies to other systems. We figure out:

- Carbon and oxygen cycle in systems such as the Gulf of Mexico, including the hydrosphere, atmosphere, and biosphere.
- Factors such as temperature and nutrient availability affect components of the system and can be observed through inputs and outputs of photosynthesis and carbon dioxide.

How we represent it



Navigation to Next Lesson: There is the last lesson of the unit.

Lessons 1–12 **28 Days Total**

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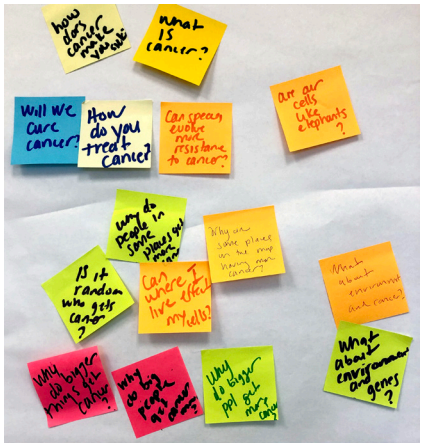
Unit Storyline

Lesson Set 1: What is cancer?

LESSON 1

Who gets cancer and why?

Anchoring Phenomenon **3 days**

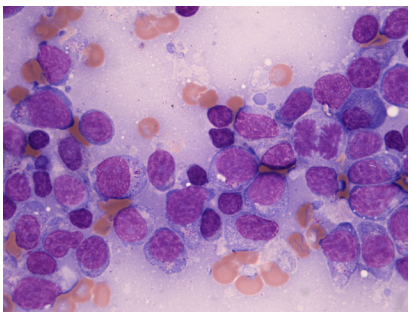
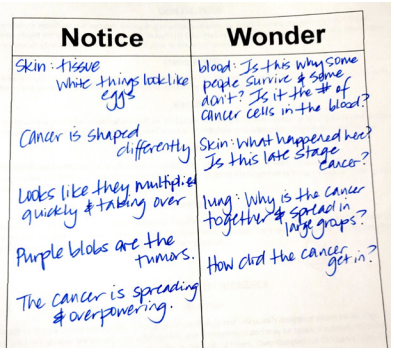
Phenomenon or design problem	What we do and figure out	How we represent it
Humans and nonhuman animals get cancer at different rates due to a number of factors.  Adapted from: National Cancer Institute, Unsplash	We explore cancer data and factors that might affect who gets cancer, such as geographic location and genetics. We figure out: • Cancer affects all of us through our relationships. • There are differences between the most commonly diagnosed and most commonly fatal cancers. • Cancer incidence differs by geographic location. • For humans, taller and older individuals have higher rates of cancer. • Scientists expected this to be true for other mammals, but it is not. • There is a gene called p53 that protects some animals from cancer.	

Navigation to Next Lesson: We decide we need to know more about what cancer is and how cancer cells are different from non-cancer cells.

LESSON 2

What is cancer?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Cancer cells look different from non-cancer cells.  William R. Geddie, CC0 1.0 Universal	We look at pictures of cancer and non-cancer cells and read about what happens when cancer cells stick together. We figure out: • How cancer cells look different from non-cancer cells. • Cancer cells have irregular shapes and tend to stick together. • When cancer cells stick together they can form tumors, which can invade tissues, disrupt system function, and make us sick.	 Illustrations created by OpenSciEd in BioRender

Navigation to Next Lesson: We figure out that cancer cells are different from non-cancer cells in important ways and that they can disrupt system function and make us sick. We wonder how non-cancer cells become cancer cells.

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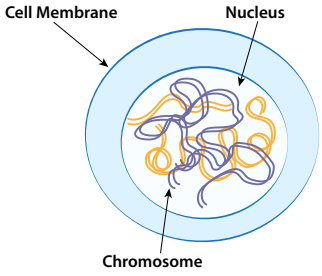
LESSON 3

How do non-cancer cells become cancer cells?

Investigation **3 days**

Phenomenon or design problem

The cell cycle has several steps with checkpoints and controls that govern whether cell division occurs. In cancer, these checkpoints and controls work differently.

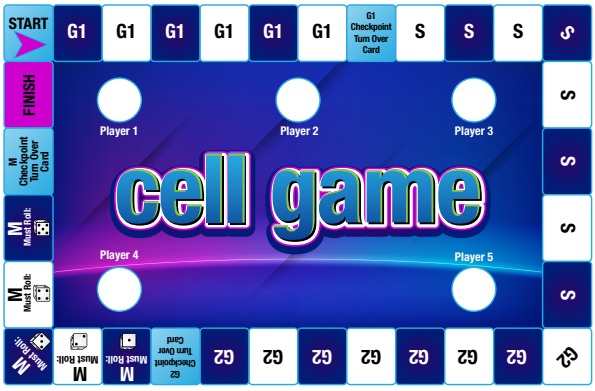


What we do and figure out

We use a Cell Game and scientific model to investigate how non-cancer cells can make cancer cells. We figure out:

- Cell division happens in all cells through a series of phases, ending with mitosis when one cell forms two new cells.
- The formation of new cells is typically regulated by p53, which provides feedback at specific checkpoints to ensure that a cell does not proceed until sufficient resources are acquired.
- When p53 fails to regulate cell division, non-cancer cells may form cancer cells.
- Cancer cells differ from non-cancer cells in that there are differences in their chromosomes.

How we represent it



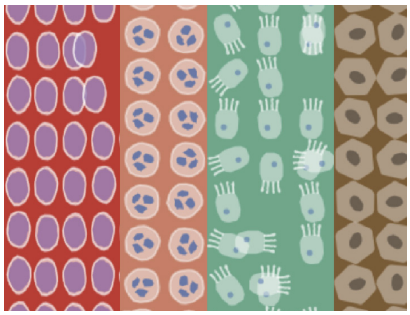
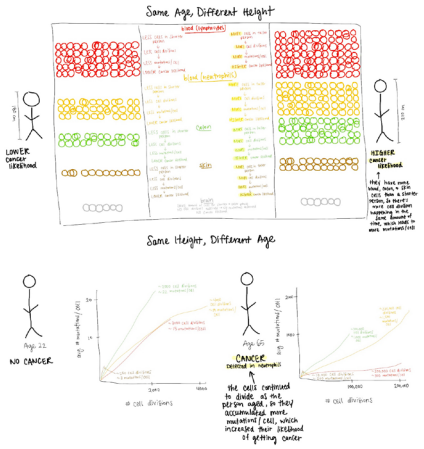
Navigation to Next Lesson: We figure out that cell division is regulated by p53 through a series of checkpoints and that sometimes cells can pass the checkpoints without everything they need and have differences in their chromosomes. We wonder how they got those differences.

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LESSON 4

Why are some kinds of cancer more common than others in older and taller people?

Investigation 1 day

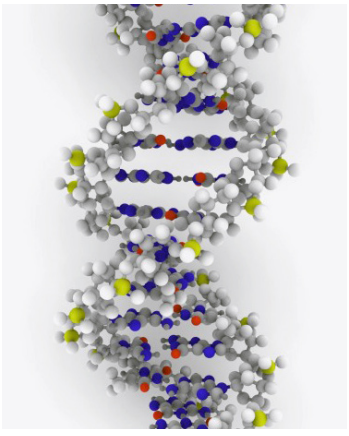
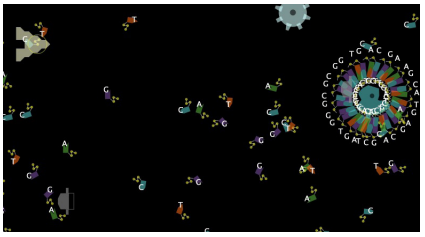
Phenomenon or design problem	What we do and figure out	How we represent it
Cell division happens at different rates, which affects cancer rates, especially in older and taller people.  Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.	We use a simulation to investigate the relationship between cell division rates and the likelihood of cancer. We model these relationships for different cell types and how they impact older and taller people. We figure out: • Some cell types divide more than others. • The longer you live, the more your cells divide. • The taller you are, the more your cells divide. • The more divisions there are, the more chances for mutations to happen. • The more mutations a person has, the higher their likelihood of getting cancer.	

Navigation to Next Lesson: We figure out that different types of cells divide at different rates and that the cell division rate is directly related to the number of mutations present in cells, which leads to greater or lesser likelihood of cancer. But we know that there are other ways that people get cancer. We wonder why cancer seems to run in some families.

LESSON 5

How do cancer cells end up with differences in their chromosomes and what is the role of p53 in preventing the differences?

Investigation 2 days

Phenomenon or design problem	What we do and figure out	How we represent it
DNA replication can result in differences in DNA, which can lead to cancer. 	We interact with a computer simulation and a reading to understand how DNA replication happens and where the mutations that cause cancer come from. We figure out: • Genes are regions of DNA containing information that determines traits. • DNA is organized in chromosomes. • During DNA replication, mutations can occur. • These mutations can change chromosomes. • p53 can correct those errors, but it does not always work. • Non-cancer cells have identical chromosomes, but the chromosomes in cancer cells are different.	 Wilensky, U. 1999. NetLogo. http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL.

Navigation to Next Lesson: We will investigate why there are different versions of p53 and how we get them.

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LESSON 6

How do we make p53, and why is it different sometimes?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
DNA codes for proteins, and protein shape affects function.  Photo by Braňo on Unsplash	We work with a kinesthetic model and a reading to make sense of gene expression. We figure out: • DNA is organized into genes in chromosomes. • Each gene codes for a protein through a process called gene expression. • Mutations in genes can lead to different structures and functions in proteins. • If the code in DNA is different, the sequence of amino acids and the protein may be different. • Additional mutations can occur during gene expression. • Not all DNA codes for proteins.	

Navigation to Next Lesson: We figure out how gene expression works and pause to acknowledge how many ideas we have worked with in Lesson Set 1.

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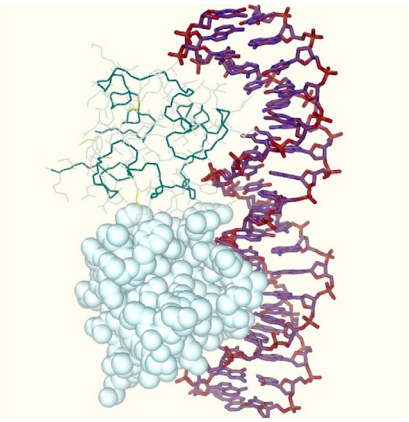
LESSON 7

What is the genetic basis of cancer?

Putting Pieces Together **1 day**

Phenomenon or design problem

Mutations in the p53 gene can lead to proteins that function differently, which eventually can lead to cancer.



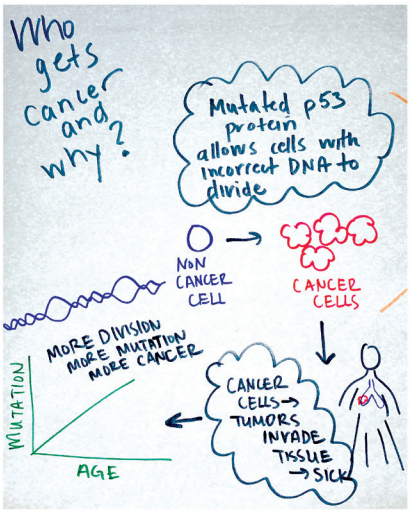
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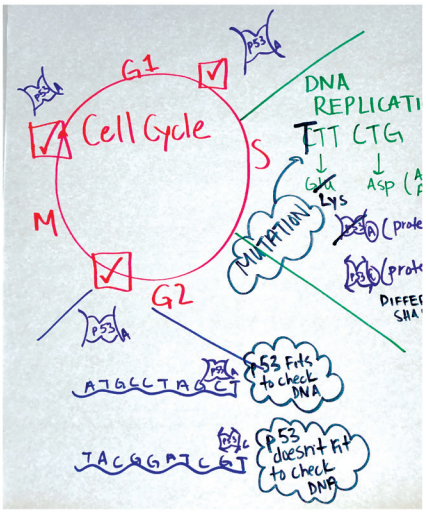
What we do and figure out

We develop our class consensus model to connect ideas from Lesson Set 1. We return to our Driving Question Board to update our questions and prioritize next steps. We figure out:

- Cells are part of a hierarchical organization system of organisms' tissues, organs, and systems.
- When cancer cells stick together, they can form tumors that can invade tissues, disrupt systems, and make us sick.
- Cancer cells form when p53 is not working.
- Cell division happens in all cells through a series of phases, ending with mitosis when one cell forms two new cells with identical chromosomes.
- Cancer cells have differences in their chromosomes.
- Chromosomes are made of DNA copied during DNA replication when mutations occur.
- p53 can correct those errors, but not all versions of p53 work the same.
- Each gene codes for a protein through a process called gene expression.
- Mutations in genes can lead to different structures and functions in proteins.

How we represent it





Navigation to Next Lesson: We wonder about how being taller and older increases the likelihood that you will get cancer.

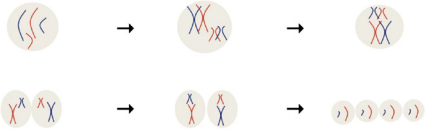
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Lesson Set 2: What are the causes of cancer?

LESSON 8

Why do some cancers appear to run in families?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
p53 mutations can be inherited in families. 	We watch videos about two young individuals, Lakita and Lauren, who survived multiple cancers. We model Lakita's family in a pedigree and use a second model to try to understand more about Lauren's family. We figure out how mutations that increase the risk of cancer can be inherited in families. We decide to investigate mutations due to the environment next. We figure out: • People with Li-Fraumeni syndrome have an increased risk of developing cancer because of an inherited p53 allele. • Pedigrees show the occurrence of traits in families and can help model inheritance. • During meiosis, chromosome pairs can swap regions of DNA in a process called crossing over. • Crossing over can result in new combinations of alleles along a chromosome and thus more genetic variation.	

Navigation to Next Lesson: We figured out some cancers can be caused by inherited mutations. We wonder how the environment leads to other cancers.

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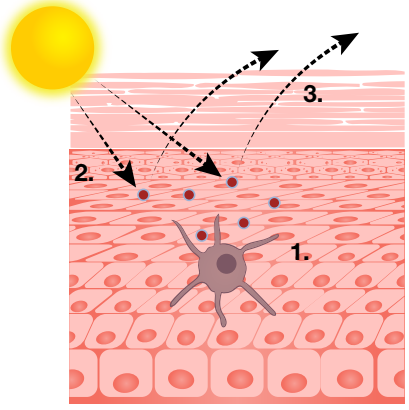
LESSON 9

How do genes interact with the environment to affect who gets cancer?

Investigation **3 days**

Phenomenon or design problem

UV radiation affects the structure of DNA and the function of proteins.

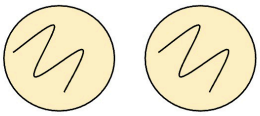
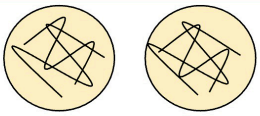


What we do and figure out

We read about the mechanism of UV radiation causing mutations in our cells and about a protective mechanism in our skin. We investigate scientific data related to incidence of skin cancer and design and carry out our own investigations. We figure out:

- UV radiation can cause mutations in DNA.
- Those mutations can cause changes in protein structure and function and lead to cancer.
- Skin has a protective mechanism against damaging UV radiation that is governed by a protein called melanin.
- Variations in exposure to UV radiation and variations in melanin production lead to different levels of risk in the human population.

How we represent it

Group	Drawing of Petri Dish	Observations
1		Some growth all over the dish. A medium amount compared to others.
2		Extensive all over the dish. A high amount compared to others.

Navigation to Next Lesson: We figure out how environmental factors such as UV radiation can cause mutations that lead to cancer. We decide to figure out more about why people in different groups and places get cancer at different rates.

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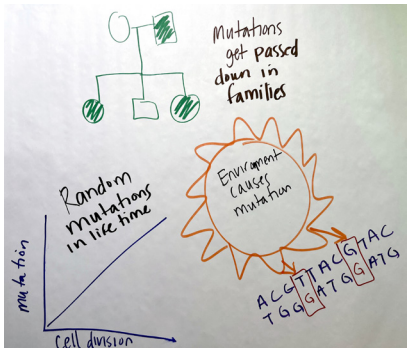
LESSON 10

Who gets cancer and why?

Putting Pieces Together **2 days**

Phenomenon or design problem

Mutations can be inherited, come from exposure to the environment, or can occur randomly to affect a person's cancer risk.

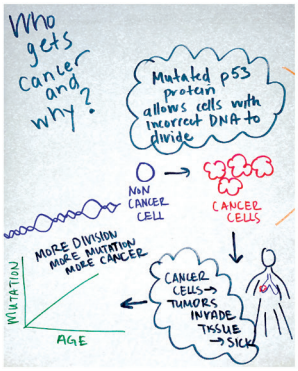


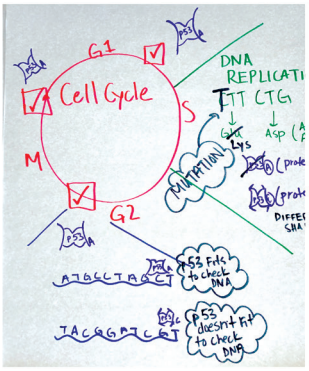
What we do and figure out

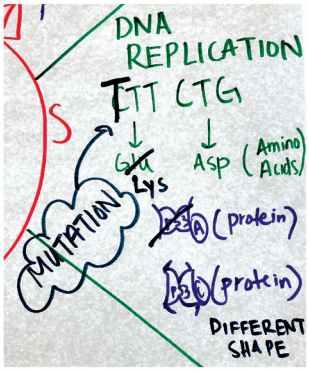
We develop our consensus model that puts together all of the ideas that we figured out about random mutations, inheritance, and environmental factors. We acknowledge that we have made a lot of progress since the last consensus model and pause to put these new ideas together. We decide that we need to figure out if our ideas would hold up in a different context and complete a transfer task to continue to make progress on figuring out who gets cancer and why. We figure out:

- The more your cells divide, the greater the chance of accumulating mutations.
- Li-Fraumeni syndrome is an inherited condition.
- Meiosis is a process where a cell undergoes two divisions to produce gametes.
- During meiosis, chromosome pairs can swap regions of DNA in a process called crossing over.
- UV radiation and other environmental factors can cause mutations in DNA.

How we represent it







Navigation to Next Lesson: We wonder how cancer is treated.

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Lesson Set 3: What can we do about cancer?

LESSON 11

How do cancer treatments work?

Investigation **2 day**

Phenomenon or design problem	What we do and figure out	How we represent it
Cancer treatment options affect cancer and non-cancer cells.  Bill Branson (Photographer) and National Cancer Institute	We consider what we already know about cancer treatment options and hear about different treatments that Lakita and Lauren experienced. We explore how different treatments work and revise our Cell Game model to predict the relationship between treatment and the cell cycle. We wonder about access to treatment in different places. We figure out: • Chemotherapy, radiation, surgery, and immunotherapy are common cancer treatments. • These treatments affect cancer cells and non-cancer cells and can disrupt body systems. • There are a number of constraints that affect decisions about cancer treatment.	

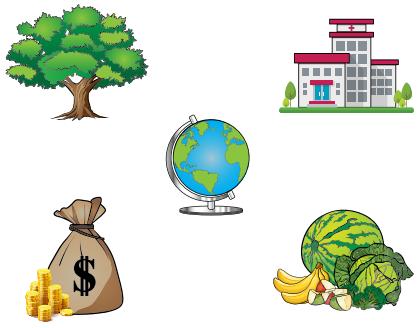
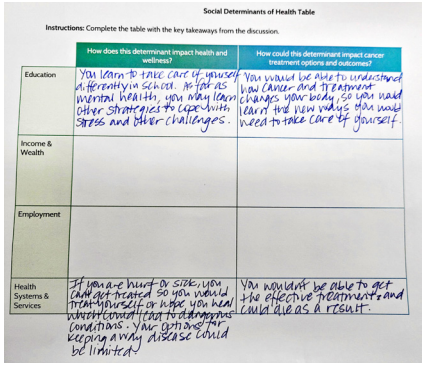
Navigation to Next Lesson: We figured out how cancer treatments work, and we wonder why not everyone gets the same treatments.

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LESSON 12

What can we do to support people in our communities who have cancer?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Social determinants of health are additional factors that affect cancer incidence and mortality. 	We decide to further investigate cancer incidence and mortality data and conclude that both are affected by geography and access to health services. We learn about social determinants of health and the impact they have on access to treatment. We hear about advocates called health navigators who can support friends and family in cancer treatment and develop an interview protocol as a resource. We figure out: • There were differences in national cancer incidence and mortality data. • Social determinants impact health and wellness, and we may not have control over them. • There is specific evidence about how distance from cancer specialists and changes in health insurance impact health outcomes. • Even as students, there are ways that we can be a solution in co-constructing equitable and effective treatment plans.	

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

Lessons 1–12 **26 Days Total**

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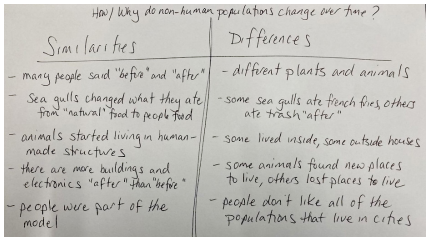
Unit Storyline

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

LESSON 1

What is the effect of increasing urbanization on nonhuman populations?

Anchoring Phenomenon **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Students see evidence of increasing urbanization and are introduced to examples of populations impacted by those environments.  Nita Knott	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: hawksbeard, 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 nonurban areas. • Some rat populations in urban areas have resistance to poisons. • Some junco populations moved to urban areas and are bolder than those in nonurban areas. • We have questions about the causes of the differences between urban and nonurban nonhuman populations.	

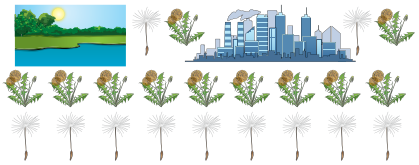
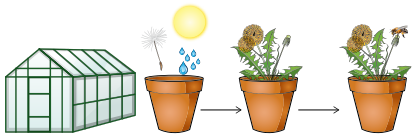
Navigation to Next Lesson: We decide to investigate why hawksbeard make fewer feathery seeds in cities.

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LESSON 2

Why does hawksbeard make fewer feathery seeds in cities?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Fragmentation of urban areas impacts seed dispersal strategies in plant populations.  cheptou	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 setup.** 1. Collect seeds with feathers from 11 locations.  2. Raise 30 plants from each location in a greenhouse.  3. Count the number of feathery and nonfeathery seeds on two seed heads from each plant. 

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

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LESSON 3

Is poison a selection pressure?

Investigation 3 days

Phenomenon or design problem	What we do and figure out	
80% of rats in Tokyo, Japan are resistant to poison.  Denitsa Kireva, Pexels	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.	Name: _____ Date: _____ **Rat Poison Explanation** **Part 1: Revising Explanation with New Data** **Instructions:** Use words 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. 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 _____.

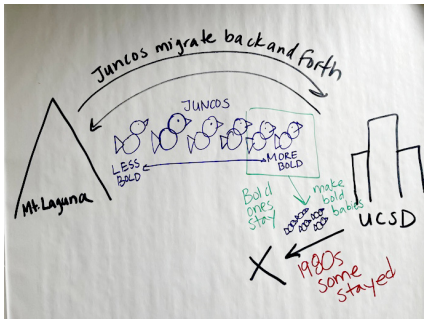
Navigation to Next Lesson: We figured out that rat poison is a selection pressure for physiological adaptations, which made us wonder what else we need to figure out on our initial class consensus model.

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LESSON 4

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

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Juncos in an urban environment are bolder than juncos in the nonurban 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 bolder birds 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. • Over time, juncos that are bolder are more likely to survive and reproduce in the urban environment, resulting in a greater proportion of bolder juncos in the city population.	

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

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LESSON 5

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

Putting Pieces Together 2 days

Phenomenon or design problem

Urbanization can affect the distribution of traits in multiple species.



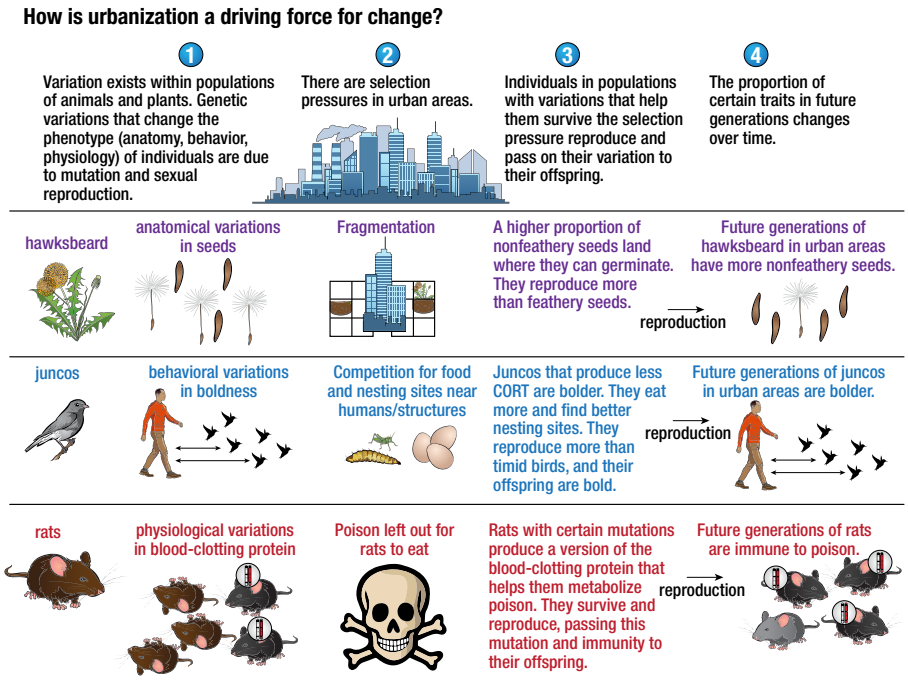
Clémence Delmas, CC BY 3.0

What we do and figure out

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

How we represent it



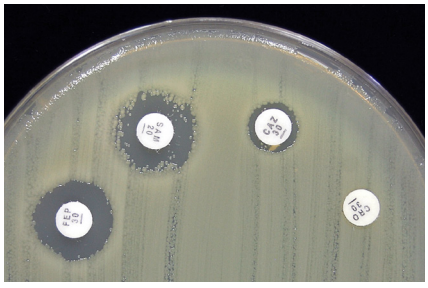
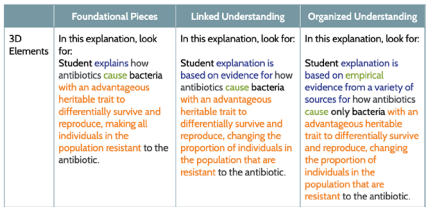
Navigation to Next Lesson: We apply our model of evolution by natural selection to a new phenomenon.

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LESSON 6

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

Putting Pieces Together **1 day**

Phenomenon or design problem	What we do and figure out	How we represent it
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.	

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

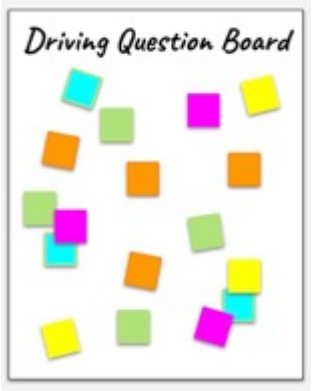
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Lesson Set 2: How can we use what we know about natural selection to design cities that support resilient populations and ecosystems?

LESSON 7

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

Problematizing 2 days

Phenomenon or design problem	What we do and figure out	How we represent it
Species can be negatively affected by urbanization. New development can plan to reduce negative effects.  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 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.	

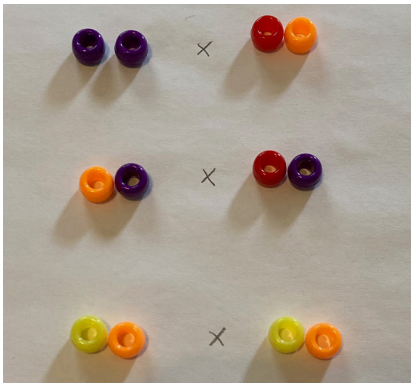
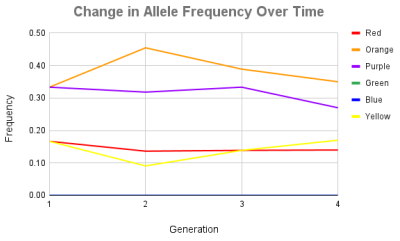
Navigation to Next Lesson: We investigate a new case of the Florida panther and see new urbanization in Buckeye, AZ..

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LESSON 8

How can fragmentation lead to lower genetic diversity?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
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.	

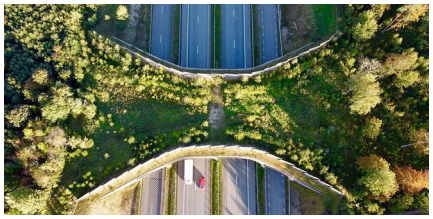
Navigation to Next Lesson: We review wonderings that remain about possible solutions for preventing fragmentation and the loss of genetic diversity in urban areas from our Progress Tracker.

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LESSON 9

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

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	How we represent it
Wildlife corridors affect population stability and genetic diversity in nonhuman populations.  Sillerkiil, CC BY-SA 4.0	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** • Nonhuman populations do not get fragmented • Provides good habitats 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 **Interest Holder's Criteria** • Housing for all of the people who will live there. • Places to hike and bike • Roads to commute on, deliver materials on, etc. • Costs to build all the protections for animals cannot exceed the budget • 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

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

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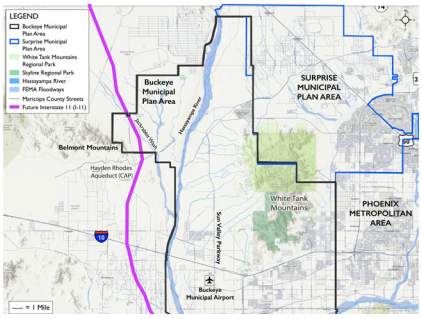
LESSON 10

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

Putting Pieces Together **2 days**

Phenomenon or design problem

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



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.

What we do and figure out

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.

How we represent it

Name: _____ Date: _____

Buckeye Plan Evaluation Tool

1. 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?

2. 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.

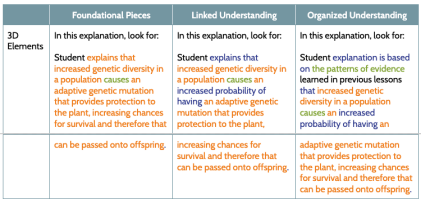
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LESSON 11

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

Putting Pieces Together 1 day



Phenomenon or design problem	What we do and figure out	How we represent it
Banana populations are devastated by fungal infections.  Frank Vincentz, CC BY-SA 3.0	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**

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Unit Storyline

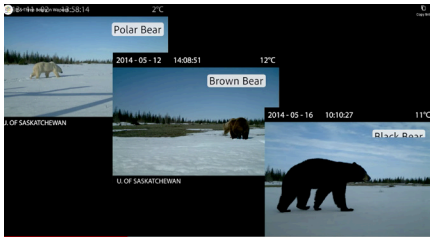
Lesson Set 1: What is happening with Arctic bear populations?

LESSON 1

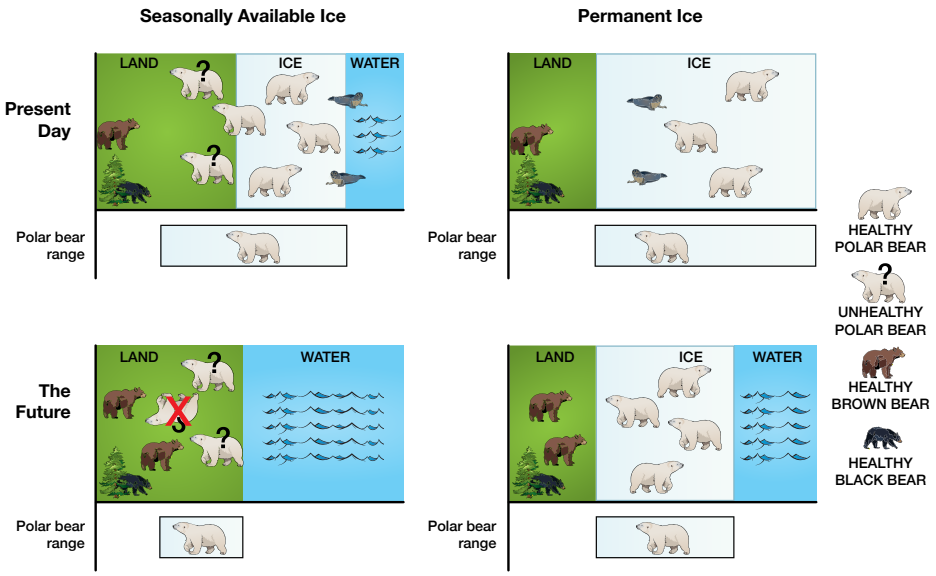
How do changes in climate affect bear species coming together for the first time in the Arctic?

Anchoring Phenomenon **3 days**

Phenomenon or design problem	What we do and figure out
The sighting of three bear species in one location in Canada for the first time may be related to the effects of climate change.	We investigate changing Arctic environmental conditions and their relationship to Arctic bear populations. We read about polar, brown, and black bears and consider how they may adapt to changing conditions. We investigate the stability of Arctic bear populations in different regions of the Arctic. We develop and share initial models about the future of different polar bear populations. We develop our DQB and figure out: • The coverage and duration of Arctic sea ice is changing, leading to less sea ice habitat for polar bears in areas with seasonally available ice. • Polar bears are adapted to the Arctic ecosystem and rely on Arctic sea ice. • Based on their adaptations, the polar bears are most at risk for population declines as the environment changes. • Based on their adaptations, brown bears may expand their range as the Arctic warms. • Polar and brown bears are likely to interact more as the environment changes.



How we represent it



Navigation to Next Lesson: We decide to investigate how polar, brown, and black bears interact because changes in climate may make that more likely to occur in the future.

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LESSON 2

How and why are bear species interacting and why might brown bears dominate?

Investigation **2 days**

Phenomenon or design problem

Arctic bear population interactions are complex.



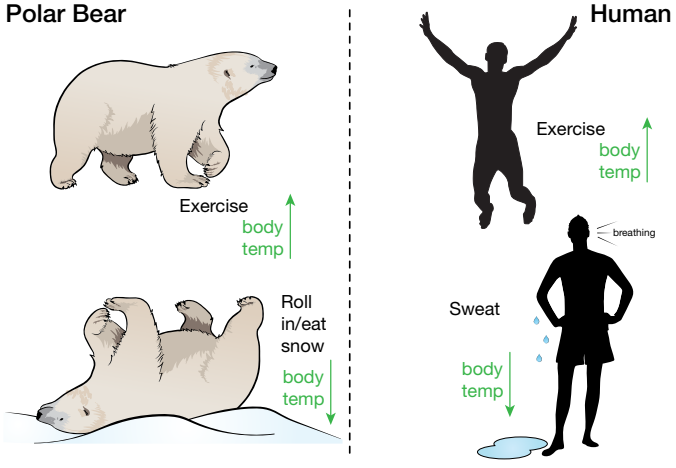
Andreas Weith, CC BY-SA 4.0; Robert F. Tobler, CC BY-SA 4.0

What we do and figure out

We decide to investigate interactions between black, brown, and polar bears. We investigate thermoregulation to figure out why polar bears might run away from brown bears. We construct claims about what will happen in polar and brown bear interactions in the future. We wonder about other similarities and differences between the bears. We figure out:

- In interactions with brown bears around food, polar bears run away.
- When polar bears exercise, they overheat easily.
- Polar bear adaptations, including a variation of the NOS3 gene, cause polar bears to get hot.
- Other mammals, like humans, can regulate heat through sweating and other mechanisms.
- Polar bears can cool off when there is snow, but without it they get too hot and pass out.
- Genetic differences in thermoregulation may lead to brown bears dominating over polar bears in a warming Arctic.

How we represent it



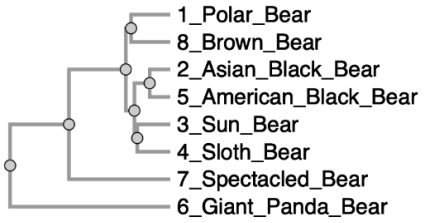
Navigation to Next Lesson: We will investigate how similar/different the three species of bears are with anatomical and DNA evidence to build a tree to see that polar bears are most similar to brown bears and that they share a recent common ancestor.

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LESSON 3

How similar/different are the polar, brown, and black bears?

Investigation **2 days**

Phenomenon or design problem	What we do and figure out	
Some bear species are more closely related to each other than others. 	We decide to investigate how similar/different the three species of bears are. We investigate similarities and differences in anatomical evidence and realize it is hard to figure out how the bears are related. We decide to use DNA evidence and build a tree of the polar, brown, and black bears with five other bear species. We figure out that polar bears are most similar to brown bears and that they shared a more recent common ancestor than they do with other bears. We figure out: • We have evidence that polar, brown, and black bears have a lot of similarities and differences based on anatomy and behavior. • We can use trees to communicate our hypotheses about relationships among bear species. • Polar bears and brown bears are more genetically similar to each other than they are to any other bear species. • Polar bears and brown bears share a more recent common ancestor than they do with other bears.	

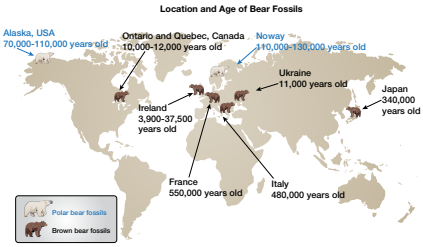
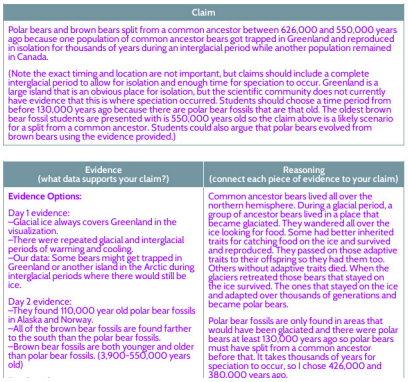
Navigation to Next Lesson: We will look at evidence from glacial and interglacial periods, fossils, and genetics to construct an argument to explain why polar bears and brown bears split from their common ancestor.

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LESSON 4

How did polar and brown bears become different species?

Investigation **3 days**

Phenomenon or design problem	What we do and figure out	How we represent it
The Arctic has undergone cycles of glaciation.  Data sources: Cahill, et al. (2018); Harington et al. (2014); Marciszak et al. (2015); Segawa et al. (2021); Villalba de Alvarado et al. (2022); Wang et al. (2022)	We review the mechanism of evolution by natural selection, which motivates us to learn more about selection pressures caused by glacial and interglacial periods that may have caused polar bears and brown bears to split from their common ancestor. We connect these geologic events with fossil evidence of bears and genetic variations found in polar and brown bears. We construct and revise arguments about what could have caused polar and brown bears to become distinct species as we look at each type of evidence. We decide to leverage what we have figured out about bear speciation in the past to figure out what will happen to polar bears in the future. We figure out: • The Arctic has undergone glacial and interglacial periods, creating selective pressures for bears. • Small bear populations may have been isolated in areas that kept ice year-round during interglacial periods. • Natural selection acted on genetic variations present in isolated populations of bears over thousands of generations. • Speciation occurred in the common ancestor bear after thousands of generations, leading to polar bears that are adapted to polar environments and brown bears that are adapted to nonpolar environments.	 **Claim** Polar bears and brown bears split from a common ancestor between 626,000 and 550,000 years ago because one population of common ancestor bears got trapped in Greenland and reproduced in isolation for thousands of years during an interglacial period while another population remained in Canada. (Note the exact timing and location are not important, but claims should include a complete interglacial period to allow for isolation and enough time for speciation to occur. Greenland is a large island that is an obvious place for isolation, but the scientific community does not currently have evidence that this is where speciation occurred. Students should choose a time period from before 130,000 years ago because there are polar bear fossils that are that old. The oldest brown bear fossil students are presented with is 550,000 years old so the claim above is a likely scenario for a split from a common ancestor. Students could also argue that polar bears evolved from brown bears using the evidence provided.) **Evidence** (what data supports your claim?) **Evidence Options:** Day 1 evidence: –Glacial ice always covers Greenland in the visualization. –There were repeated glacial and interglacial periods of warming and cooling. –Our data: Some bears might get trapped in Greenland or another island in the Arctic during interglacial periods where there would still be ice. Day 2 evidence: –They found 110,000 year old polar bear fossils in Alaska and Norway. –All of the brown bear fossils are found farther to the south than the polar bear fossils. –Brown bear fossils are both younger and older than polar bear fossils. (3,900-550,000 years old) **Reasoning** (connect each piece of evidence to your claim) Common ancestor bears lived all over the northern hemisphere. During a glacial period, a group of ancestor bears lived in a place that became glaciated. They wandered all over the ice looking for food. Some had better inherited traits for catching food on the ice and survived and reproduced. They passed on those adaptive traits to their offspring so they had them too. Others without adaptive traits died. When the glaciers retreated those bears that stayed on the ice survived. The ones that stayed on the ice and adapted over thousands of generations and became polar bears. Polar bear fossils are only found in areas that would have been glaciated and there were polar bears at least 130,000 years ago so polar bears must have split from a common ancestor before that. It takes thousands of years for speciation to occur, so I chose 426,000 and 380,000 years ago.

Navigation to Next Lesson: Students use their understanding of how bear populations adapted to major changes in climate in the past to help them understand what might happen to Arctic bear populations in the future. We will create a class consensus model to put together the pieces we figured out so far in the unit and revisit the Driving Question Board to check on our progress.

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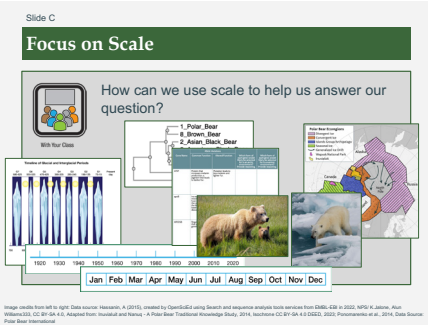
LESSON 5

What will happen to Arctic bear populations as their environment changes?

Putting Pieces Together 1 day

Phenomenon or design problem

Students put the pieces together and revise their model to explain what will happen to Arctic bear populations as their environment changes.

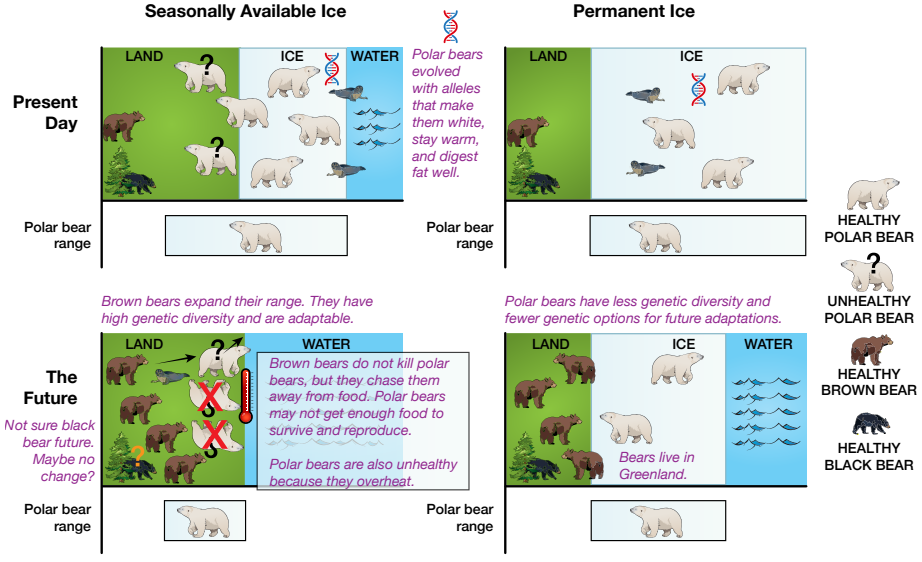


What we do and figure out

We develop a Gotta-Have-It Checklist and revise our initial consensus model using new evidence, putting together what we figured out from Lessons 2–4. We revisit our DQB and answer questions we have figured out, notice what questions are left unanswered, and add new questions. We figure out:

- Polar bear populations will decline in the future because they evolved with adaptations for Arctic environments. When removed from those habitats, they overheat and cannot outcompete brown bears for food.
- Arctic brown bear populations will increase in the future as there is less ice and they can use aggression and genetic diversity to find food, survive and reproduce in more areas on land in the Arctic.

How we represent it



Navigation to Next Lesson: We will investigate data and use a model to predict what will happen to polar bears as the climate changes and polar and brown bears interact in new ways.

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Lesson Set 2: What will happen to Arctic bear populations in the future?

LESSON 6

What will happen to bear species in the Arctic in the future?

Investigation **1 day**

Phenomenon or design problem

Polar and brown bears can mate and produce offspring.



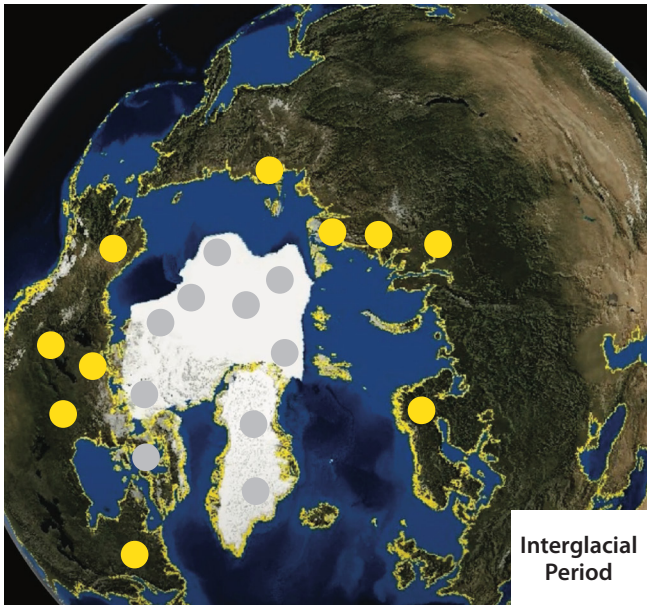
Corradox, CC BY-SA 3.0

What we do and figure out

We decide to investigate what will happen to polar bears in the future as the Arctic environment changes. We figure out the climate is likely changing too fast for polar bears to evolve and adapt to environmental changes. We wonder about other possibilities for polar bears and hear about a case where polar bears and brown bears mated and produced hybrid offspring. We use a model to generate evidence to help us predict hybrid fitness in the future. We wonder if polar bears could go extinct. We figure out:

- The Arctic climate is likely changing too quickly for polar bears to adapt.
- Polar and brown bears may interact and mate with each other.
- We can use a model to generate evidence to support predictions.
- If polar and brown bears mate, some polar bear genes may not be lost.

How we represent it



Interglacial Period

Navigation to Next Lesson: We wonder if polar bears could go extinct and will review how the changes to one species cascade through an ecosystem. We will investigate current extinction rates for the whole Earth and wonder how this compares with events in the geologic past. We will investigate the five mass extinctions in Earth's history, look for patterns in the evidence for the cause of those extinctions, and connect those ideas to what is happening today.

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LESSON 7

How do past patterns of extinction help us understand possible consequences of extinctions now and in the future?

Investigation **2 days**

Phenomenon or design problem

There are notable similarities between the five mass extinction events of the past and current extinctions.



Killdevil, GNU Free Documentation License

What we do and figure out

We investigate current extinction rates for the whole Earth and wonder how this compares with events in the geologic past. We investigate the five mass extinctions in Earth's history and figure out that in each, a major event precipitated a significant shift in climate. We connect what we learned in the past to what is happening today and update our Progress Trackers. We figure out:

- Five times in Earth's history, significant environmental changes that resulted in major shifts in global climate caused the extinction of at least 75% of all species.
- Extinction is a significant threat to biodiversity, which is necessary for ecosystem resistance.
- There are similarities between environmental conditions that caused the mass extinctions and Earth today.
- Unlike the previous five mass extinctions, current extinctions are primarily caused by human activities.

How we represent it

Extinction Event	Cause	Effects (on biosphere and other Earth systems)
Ordovician 444 MYA	Glacial period triggered by eroding mountains, which removed large amounts of CO_2 from the atmosphere	Reduced oxygen in ocean Extreme cold 86% species died (trilobites, coral, etc)
Devonian 359 MYA	Evolution of land plants. Used up carbon dioxide in the atmosphere.	Climate cooled Dead plants ran into oceans and decomposed, caused algae blooms. Oxygen left ocean, killing ocean life 75% species dies (armored fish, coral)
Permian 252 MYA	Volcano in Siberia released huge amount of CO_2 and sulfur dioxide	Acid rain, ocean acidification Global warming 96% species died (insects, coral, amphibians)
Triassic 201 MYA	Underwater volcano CO_2 levels rose	Global warming, sea level rise Ocean acidification Marine life died from change in ocean chemistry 80% species lost (reptile, coral, amphibians)
Cretaceous 66 MYA	Asteroid fell to earth	Blackened sky, blocked sun Rapid cooling Ocean acidification 76% species died (dinosaurs, plants, mammals)

Navigation to Next Lesson: We will research and evaluate different solutions people have used to protect species from extinction and present what we learn to our peers. We will discuss whether these solutions could work to protect the polar bear and if people should intervene to protect the polar bear from extinction.

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LESSON 8

What are our options for protecting species from extinction and should we implement them?

Investigation **3 days**

Phenomenon or design problem

People approach protection of species at risk of extinction in different ways.



Toby Hudson, CC BY-SA 3.0

What we do and figure out

We research and evaluate solutions people have used to protect species from extinction and present what we learn. We discuss if these solutions could work to protect the polar bear and if people should intervene. We write an individual argument with our position on whether we should do something to save polar bears from extinction. We figure out:

- Options for protecting endangered species from extinction include habitat conservation, breeding programs, species relocation, long-term storage of genetic material, and others.
- Not all species at risk of extinction can be protected in the same way.
- Protecting species from extinction requires huge inputs of time, money, resources, and collaboration.
- Protecting polar bears from extinction is difficult because they are large, long-lived, reproduce slowly, and cannot survive in warm climates.

How we represent it

	Choice 1	Choice 2	Choice 3 (optional)
Solution and case study What approach would you use? Which case study introduced it?	Manatee: pass laws to protect habitat and control human behavior.	Coral reef: save sperm and eggs and freeze them to create more individuals later.	
Evaluation Why would this solution work for the polar bear? What evidence supports this claim?	We could pass laws to cut down on greenhouse gasses to protect polar bear habitat. This is good for the polar bear because it is the only way to protect the loss of habitat. We have evidence that there is warming in the Arctic and that ice is melting faster than it ever has and we know there cannot be enough generations of polar bears to evolve to warmer temperatures in that time. Polar bears have a gene that makes them overheat. If we do not cool temperatures by reducing greenhouse gasses, they will go extinct.	Polar bears do not have high genetic diversity, we learned that in lesson 4. If we can harvest sperm and eggs from polar bears, we can protect the diversity we do have and help polar bears reproduce in the future. We may be able to screen for genes that do better in this warmer climate and create babies with better adaptations.	

Above you evaluated solutions that could prevent the extinction of the polar. Based on constraints and/or ethical considerations do you think people should put the solution you argued for above in place? Explain your thinking.

We should intervene because governments are already passing laws to reduce greenhouse gas emissions and people care about the polar bear so they would be willing to make sacrifices to use cars less and burn less fuels so we can save the species. I think if we collect sperm and eggs and screen them for genetic variations that are adaptive, we will be able to breed polar bears that can survive. We caused this crisis and it is our obligation to protect species from extinction.

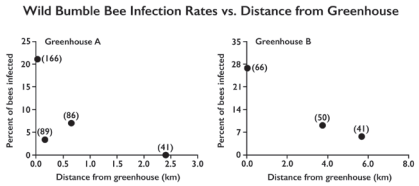
Navigation to Next Lesson:: We will complete a Transfer Task to evaluate claims about ways to protect endangered bumble bees to demonstrate how what we figured out throughout the unit about finding common ancestry, biological evolution, and extinction applies to other systems.

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LESSON 9

Can we use everything we have figured out about speciation to explain a new phenomenon?

Putting Pieces Together 2 days

Phenomenon or design problem	What we do and figure out	How we represent it
Bumble bees may be at risk of extinction.  USFWS Midwest Region from United States, CC BY 2.0	We complete a Transfer Task to evaluate claims about ways to protect endangered bumble bees to demonstrate how what we figured out throughout the unit about finding common ancestry, biological evolution, and extinction applies to other systems. We figure out: • Wild bumble bee populations are in danger from pathogens, pesticides, and climate change. • To protect the wild bee population, we need to eliminate the use of pesticides, reduce the number of managed honeybee hives, and maintain genetic diversity of bee populations.	

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

Lessons 1–9 **19 Days Total**

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