



Curriculum Units by Fellows of the National Initiative
2018 Volume V: Manipulating Biology: Costs, Benefits and Controversies

Endangered Species, De-Extinction and MANipulation

Curriculum Unit 18.05.09, published September 2018

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Objectives

“As educators and conservators of endangered species, all we can do is shine a light on the beauty and majesty of these animals in hopes to spark a love and a need to keep them from vanishing from our planet.” – Amanda O’Donoughue, a former zookeeper¹

While researching, I came upon O’Donoughue’s editorial in response of the death of Harambe, a 17-year old silverback gorilla that was shot in the Cincinnati Zoo to protect a young child who had fallen into the enclosure. O’Donoughue’s quote captures the essence of what I hope students will gain from this curriculum unit.

The curriculum unit will focus on past human action, the present problem, and how to save species in the future. I plan to very briefly explore trends in evolution/extinction and the current evidence that a sixth mass extinction is occurring. Many organisms are endangered and it is important for young students to understand the causes, the present problem, and possible ways to mitigate the causes and save the species in the future. According to Peter Vitousek, a Stanford University professor, et al, “There is no clearer illustration of the extent of human dominance of Earth than the fact that maintaining the diversity of ‘wild’ species and the functioning of ‘wild’ ecosystems will require increasing human involvement.”²

The lack of knowledge of typical urbanites is a hinderance to conservation efforts. There is an even greater lack of knowledge when it comes to understanding human impacts on the local habitat. The young people are the future and it really will be up to them to help save the species and to take care of our planet Earth. This unit will explore ways to manipulate biology in order to save an endangered species or to potentially de-extinct a species.

As a way to hook my students, the unit will use the movie *Jurassic Park* to set the stage. The film is a classic science-fiction movie based on the novel by Michael Crichton. The movie was released in 1993, but his book preceded it in 1990. In the movie, scientists use dinosaur DNA from the bloodmeals of fossilized mosquitoes to resurrect the dinosaurs. In the movie the dinosaurs are in a theme park, much like Disney World, however due to unintended consequences things spin out of control. The movie will not only excite my students about the

idea of de-extincting a species but will also portray some of the ethical issues.

Who the Unit Serves

Currently, I teach fourth grade in an urban school district. This curriculum unit is for science class. Science gets limited time and attention due to the emphasis on reading, math, and social studies linked to state testing. This unit combines cutting-edge science, critical thinking, ethics, and hands-on learning to truly engage my students with some of the tough topics facing our world.

Background Content Knowledge

According to Anthony D. Barnosky, a professor at UC Berkeley, et al, "Paleontologists characterize mass extinction as times when Earth loses more than three quarters of its species in a geologically short interval, as happened only five times in the past 540 million years or so."³

Some scientists believe that humans are causing the sixth mass extinction, which would be the first one to occur with humans present as a species. According to science writer, Emily Monosson, there are 21,000 species at-risk for extinction across the globe.⁴ Barnosky et al describe the situation in this way, "The huge difference between where we are now, and where we could easily be within a few generations, reveals the urgency of relieving the pressures that are pushing today's species towards extinction."⁵

Some of the ways humans are causing the mass extinction include: land transformation/habitat fragmentation, transporting invasive species, toxic pollution, ocean acidification, overharvesting, climate change, and direct killing of species.

Land Transformation

Vitousek defines land transformation as the altering of land to produce goods and services. Farming, forestry and urbanization are the main ways the land is transformed. According to Vitousek, "39-50% of the land has been transformed."⁶ Additional land has been fragmented which also impacts species and ecosystems. Land transformation and fragmentation not only alter ecosystems, but also the way organisms interact with their environment. Land transformation is the single greatest cause of extinction, and if it continues at the current rate, many more species will become extinct.

Oceans

The impact of humans is harder to determine in the oceans. With 60% of humans living within 100 km of the coasts, the ocean's productive coastal areas have been significantly impacted by humans. Vitousek states, "Moreover, a recent analysis suggested that although humans use about 8% of the primary production of the oceans, that fraction grows to more than 25% for upwelling areas and to 35% for temperate continental shelf areas."⁷

There are unintended consequences of harvesting this "primary production." Many of the species harvested are top predators and removing them has a greater effect on the balance of the ecosystem. Also, some of the methods of fishing damage the habitat, such as a dredge that is dragged along the bottom of the ocean floor.

Other consequences are that non-targeted species are unintentionally captured and species get caught in nets left behind as in Figure 1.



Figure 1: A sea turtle entangled in a fishing net.

Creative Commons NOAA

A massive amount of plastic, with some estimates of few hundred billion pounds, float around the earth's oceans.⁸ This garbage jeopardizes organisms when they become entrapped and when the plastic is ingested. Recently a dead pilot whale was found in Thailand with 17 pounds of plastic in its stomach!⁹

Invasive species

Approximately 335 million years ago, the continents were all connected into a single land mass called Pangea. The massive continent started to break apart about 175 million years ago. Darwin noted that even though parts of South America, Africa, and Australia shared a similar topography and climate, the plants and animals were not so similar. Darwin believed that because the species evolved separately in isolated areas, the result was differing adaptations to local condition that led to greater species biodiversity.

Since the Industrial Revolution and the invention of the steamship, technology has been advancing rapidly. Today the globe is crisscrossed with tanker ships and airplanes; in addition to cargo and passengers this causes other species to be inadvertently moved around the globe depositing them in foreign environments. Upon arrival, sometimes they have no natural predators or parasites and they can become invasive, and

possibly displace the local species. Transporting species and the resulting “biological invasion” is the second-greatest cause of extinction. Some invasions take over the native species, thus decreasing the biodiversity.¹⁰ According to Kolbert, in one day about 10,000 species are moved around the world in ballast water alone. Due to the remixing of the species in some parts of the world, non-native flora and fauna outnumber native ones.¹¹ While the remixing of species may increase the biodiversity locally, it will lead to a decrease globally.¹²

Some scientists refer to this phenomenon as New Pangea. The world is once again “connected.” While the world is not physically connected, species from one continent are able to hitch a ride to another continent. “Thus, a single tanker (or for that matter, a jet passenger) can undo millions of years of geographic separation.¹³

One specific example is the Burmese python which has invaded the Everglades in Florida. Like other invasive species it has no known predators. But, to make matters worse, it is an apex predator. It is easy to find a video online of a python battling with a large alligator, a native apex predator. There is much concern about the impact the pythons are having on the Florida ecosystem as many of the small mammals are disappearing.¹⁴

Toxic Pollutants

For hundreds of years, human activity has altered the Earth’s atmosphere. Beginning with the Industrial Revolution, “Humans have burned through enough fossil fuels – coal, oil, and natural gas to add some 365 billion metric tons of carbon to the atmosphere.”¹⁵ Kolbert goes on to describe the effect of deforestation. By cutting down forests, trees that normally put oxygen in the air are removed. The result is another 180 billion tons of carbon in the atmosphere. Today the air has four hundred ppm (parts per million) of carbon dioxide in the air which is the highest amount in the last eight hundred thousand years.¹⁶ According to science writer, Carl Zimmer, “By the end of the twenty-first century, humans had raised the level of carbon dioxide in the atmosphere to its highest level in millions of years.”¹⁷ The changes to the atmosphere have a larger impact on the Earth as they are causing climate change.

Ocean Acidification

When the gases in the atmosphere and the ocean become lopsided, the ocean will absorb more carbon. Kolbert describes the change, “In effect: Every American pumps seven pounds of carbon into the sea.”¹⁸ She goes on to state that the ocean’s pH is expected to reach 7.8 in 2100. When the pH reaches this level, organisms disappear.¹⁹ Ulf Riebesell, a professor at GEOMAR Helmholtz Centre for Ocean Research Kiel, describes how highly tolerant organisms will become more abundant, but the biodiversity will decrease. Ocean acidification was a factor in at least two of the five mass extinctions, and possibly in a third.²⁰

Climate Change

The increased levels of CO₂ are projected to increase the Earth’s temperatures by as much as seven degrees Fahrenheit by 2050, which would eliminate the remaining glaciers.²¹ The rise in temperature and the melting of the glaciers will raise the level of oceans. The rise in temperature is similar to moving the climate bands poleward by 30 feet each day.²²

Killing Species

Humans kill species for a variety of reasons, including as food sources, for black market sale of animal

products such as ivory, to remove agricultural threats, for cultural beliefs, and for sport.

The passenger pigeon is an example of a species that was both hunted for meat and was killed because it posed an agricultural threat to farmers' crops (Figure 2). The pigeons were an easy target since their flocks were so large; the flocks were so numerous that they would turn the sky dark. These massive flocks posed a threat to farmers' crops, so farmers shot them. According to Stewart Brand's TED Talk on de-extinction, the population of passenger pigeons went from five billion to zero in just a few decades.²³



Figure 2: Passenger pigeon flock being hunted in Louisiana. The Illustrated Shooting and Dramatic News. (Public domain)

Elephants and rhinoceros are poached for the ivory in their horns. Even though laws exist to protect these creatures, the value of their ivory horns and tusks drives the black market.

Overharvesting

Many species are endangered or extinct due to humans overharvesting them. This is true of many marine invertebrates, fish, mammals, birds, reptiles, and amphibians. Some have been overharvested for food, medicine, skin, and body parts. Tigers, the passenger pigeon, the Carolina parakeet, and certain primates are a few examples of species that have been overharvested.²⁴ Overfishing is also a prevalent problem. Paul

Crutzen, a professor at the Scripps Institution of Oceanography, University of California, San Diego, states, “Fisheries remove more than 25% of the primary production in upwelling ocean regions and 35% in the temperate continental shelf.”²⁵

Possible Solutions

Just as there are many reasons why the sixth mass extinction is upon us, there are a variety of ways to potentially prevent another mass extinction. Rachel Carson, an environmentalist and author, who began the conservation movement with her 1962 book *Silent Spring* said, “One way to open your eyes is to ask yourself, “What if I had never seen this before? What if I knew I would never see it again?”²⁶ I want my students to not only understand methods to help endangered species, but also to think critically about the pros and cons of each method.

Through my reading and research, it is clear that people believe biodiversity is a good thing. During the seminar that led to this curriculum unit, Yale University professor, Paul Turner posed the question, “Why is biodiversity good?” Is it because people want to see a variety of species? Is it beneficial to have more species? Will one produce a lifesaving medicine? Do people just enjoy a greater variety of bird calls when walking through the park?

Biodiversity seems to be a common way to examine the health of an ecosystem. The stability of an ecosystem depends on biodiversity. In an ecosystem, each species has a special role or a niche that it fills. Let’s say organism A is a food source for organism B. If organism A is reduced or disappears, then organism B will have to find another food source. As a result, organism B may become less healthy since it is not adhering to its regular diet, in addition to possible competition with other organisms for the same food source. As a result, neither organism may have enough to eat. These species may become weaker or even die. The ripple effect continues through the ecosystem. Thus, this process can reduce the health of the ecosystem and potentially decrease the biodiversity within the ecosystem.

Controlling invasive species

Research seems to indicate that preventing the introduction or establishment of non-native species is the best way to limit their impact on an ecosystem.²⁷ Quarantining is one strategy used to prevent the establishment of an invasive species. An example is the story of the citrus long-horned beetle in Washington. The beetle was discovered in a nursery in 2001, and the owner brought a specimen to the U.S. Department of Agriculture Plant Inspection Station at Sea Tac Airport, where the beetle was identified as a threat. The Washington Department of Agriculture was alerted and was able to isolate the source of the infestation. It was discovered that several beetles had escaped. Fortunately, this particular beetle is slow to reproduce. In an effort to prevent the establishment of the citrus long-horned beetle, trees were cut down, pesticides administered, an education plan was launched to residents, and restoration was funded by the Department of Forestry. In 2006, the quarantine was lifted after data collected over several years indicated favorable results.²⁸ This particular example exemplifies the quick action, the cooperation of a variety of agencies, the understanding of the threat, and the education of the public that was necessary to eradicate the citrus long-horned beetle before it could become an established non-native species. Controlling invasive species is costly in terms of money and resources, but the consequences of failing to control invasive species are costlier.

Reintroduce species

Another technique to increase biodiversity is to reintroduce species. The story of the Florida panther, *Puma concolor coryi* portrays this technique. The Florida panther was endangered due to humans hunting deer, which was their food source and reducing their habitat with development. After searching, a small population of panthers was discovered. The population was isolated and genetically similar, which are characteristics of inbreeding. The panthers exhibited poor physical fitness, many kittens were dying, and males were reproductively compromised. The panthers were projected to go extinct within forty years.²⁹ A group of scientists met to develop a plan. The group determined that the best course of action would be to bring wild panthers from another location to Florida, to increase the size and variation of the gene pool. So, in 1995, eight panthers from a different subspecies, *Puma concolor stanleyana*, were captured in Texas and released into the wild in Florida.

Apparently, there is some debate over the different subspecies of the North American panthers. It involves the number of subspecies and whether or not the species in Florida really is a different subspecies from the one in Texas. Some believe they are all the same, *Puma concolor cougar*.³⁰

Regardless, the goal was to increase the genetic variation and improve the survival rate of panthers in Florida. The plan worked! Of the eight female cougars introduced, three died before producing offspring. The other five however, produced 20 kittens. None of the eight translocated panthers remain in the Florida population today. Two more died, and the remaining three were moved to captivity once a significant number of offspring was produced. Based on a report from February 2017, it is estimated that there are about 120-230 adult and subadult panthers, which is an increase from 100-180 adult and subadults in 2014.³¹ These counts do not include kittens still dependent on their mothers. Today, Florida has the only known breeding population of panthers on the east coast.

Habitat Preservation

While the Florida panthers' population is on the rise, the fact that their habitat is so limited is concerning. They are relegated to a small sliver of their former habitat and are surrounded by an ever-increasing population of people. "Although conservation efforts focused on individual endangered species have yielded some successes, they are expensive – and the protection and restoration of whole ecosystems often represents the most effective way to sustain genetic, population, and species diversity."³²

Kolbert raises an important question, "How can humans coexist with species in the modern world when our existence and their survival are pitted against each other?"³³ This idea is the crux of the problem. Panthers once roamed from South Carolina to Louisiana, but currently live in less than five percent of their historic range in southern Florida.³⁴

Humans want to help the animals, but as a species, humans are quite narcissistic. While humans may want to help preserve ecosystems, I don't believe many humans are willing to prioritize saving the environment above their own needs. I don't think humans are concerned enough to preserve large swaths of land, when it can be used for homes, factories, shopping malls, office buildings, roads, and other capitalistic ventures that make life easier.

The human population is projected to reach nine billion people within the next 30 years. Thus, increasing our need for housing, food, and goods and services, which will only compound our inability to preserve natural

habitats for the earth's flora and fauna. The best strategy for saving a species is to protect them in their native habitat. This strategy is called *in situ* conservation.

Captive Breeding and Reintroduction

The next method, captive breeding, is one type of *ex situ* conservation. This is when an endangered species is taken out of its natural habitat. With *ex situ* conservation, the species could be moved to another habitat in the wild, a zoo, or a preserve. Captive breeding programs are a last-ditch effort to keep a species that is in imminent danger from going extinct. The goal is to eventually re-establish a wild population. "An estimated 4,000 to 6,000 vertebrate species will need captive breeding over the next 200 years in order to mitigate extinction threats."³⁵

Captive breeding programs face several challenges. They are not always successful with the intent to have individuals mate and breed and can face a lack of genetic variation due to inbreeding among close-relatives. In some cases, zoos are able to relocate a suitable mate to increase genetic variation for breeding purposes. Once raised in captivity, survival in the wild becomes more challenging. Training is necessary to teach species the survival skills prior to their release into the wild. In the case of the California condor, some died once they were released as a result of crashing into power lines. Subsequently, California condors were trained to avoid the power lines.³⁶

The California condor, the black-footed ferret, the golden lion tamarin, and the red wolf are some species that were recent successes of captive breeding programs. Captive breeding is expensive as 35 million dollars was spent between 1987 and 2009 to reintroduce the California condor.³⁷ Another success story is with great apes. In captive breeding programs, great apes experience good health, readily reproduce, and live 10 or more years longer than their peers that are not raised in captivity.³⁸

Education

Educating my students about the importance not only of caring for endangered species, but also of taking care of the earth is important so they will hopefully become good stewards of the earth. With the sixth mass extinction underway, time is of the essence. My students may one day play a vital role in the future of endangered species and the possible de-extinction of species.

My students need to be made aware of the role genes and the genome will play in the future of science. I recently caught up with an old friend. As I described my curriculum unit, he shared with me a latent effect of *Jurassic Park*. Upon further research, I discovered an NPR story that says fossil-evidence of a new dinosaur species is discovered every ten days. Some of the *Jurassic Park* generation are graduating from Ph.D. programs and bringing their talents to the field. Ari Shapiro, the host of the NPR segment, says, "Many people who work in paleontology think what's happening today is tied to a summer blockbuster that hit movie theaters 25 years ago."³⁹

After reading a chapter in *The Rise of the Necrofauna*, a book by Britt Wray about reviving extinct species, I took note when she mentioned that two production companies had approached her about turning the book into a film. She also mentioned other films that are in the works related to species resurrection. Perhaps my curriculum unit and future films will inspire the next generation of scientists to study genes and the genome.

Science changes rapidly. The ability to map genomes continues to become more readily available and less expensive. Colin Tudge states in his book, *The Impact of the Gene*, "We need to know which species are most

endangered and in the greatest need of immediate help. We can't make that judgement without knowledge of genes."⁴⁰ His idea connects education and the next four methods of supporting endangered species and the possible de-extinction of species.

Genetic Assistance, Gene Editing, CRISPR, and Cryo

Going back to *Jurassic Park*, the idea of genetically engineering dinosaurs seemed far-fetched in the 1990's, but today the concept of resurrecting more-recently extinct fauna is moving closer to becoming a real possibility. I want my students to realize that we already live in a genetically modified world. Much of our food, manufacturing of medical products such as insulin, and even our pets are obtained from genetic modification.

Genetic assistance relates to techniques used to rescue endangered species. Britt Wray describes genetic assistance as three layers. The first layer is the discovery of what is going on with the species. Researchers collect and analyze genetic information in an effort to determine what is making the species vulnerable and susceptible.

The second layer involves editing the genome to reduce the vulnerability. One example would be a species that is susceptible to a particular disease, and the possibility of replacing the compromised gene with one that has pathogen-resistance. This is one way that gene editing could be used to help save endangered species before they disappear.

The third layer is essentially the resurrection of an extinct species. The idea is to take genes that define the species and put them into the genome of the closest living relative. Ben Novak, a scientist at a company called *Revive and Restore*, is working to resurrect the passenger pigeon. He sequenced its genome and analyzed it to determine the key aspects that distinguish a passenger pigeon from its closest living relative, the band-tailed pigeon. The passenger pigeon was a keystone species. Robert Paine, an ecologist who worked at the University of Washington in Seattle, first coined the term keystone species in 1966. According to a National Geographic website, "A keystone species is an organism that helps define an entire ecosystem. Without its keystone species, the ecosystem would be dramatically different or cease to exist altogether."⁴¹ National Geographic then explains that the ecosystem is unable to fill the niche when a keystone species disappears.

The woolly mammoth is a keystone species that Professor George Church from Harvard University is working to resurrect. As I spoke to people regarding my ideas for the curriculum unit and the notion of bringing back the woolly mammoth, people seem a little shocked. I get the sense they were thinking, "Why would we want to do that?" The thought of bringing back a prehistoric beast does seem more daunting to me than resurrecting a passenger pigeon, which was more recently driven extinct. As I searched around trying to find out more about keystone species, I found the answer.

Some scientists think that resurrecting the woolly mammoth may help to revive the "mammoth steppe," a grassland-tundra ecosystem which played a key role in driving climate. Modern steppe ecosystems have already been created in Sweden and the Siberian Arctic, with the idea that these ecosystems could help lessen the effects of global warming.⁴² Church explains, "Today they (tundras) are melting, and if that process continues, they could release more greenhouse gas than all the world's forests would if they burned to the ground."⁴³ Church and his lab are working on editing some woolly mammoth traits into Asian elephants. The main traits to edit-in are subcutaneous fat, woolly hair, and sebaceous glands. These are the traits that help the mammoth to survive in the cold climate. The theory is that the woolly mammoth will eat the dead grass

which will foster the growth of spring grass. The spring grass will help prevent erosion with its deep roots. The woolly mammoth will take down trees thus increasing the amount of reflected light. Also, the woolly mammoth will poke holes in the ice allowing freezing air to reach the soil which will enable deeper freezing of the permafrost layer (Figure 3). The increased grasslands will better insulate the permafrost layer in the summer thus preventing emissions of greenhouse gases.⁴⁴



Figure 3: Woolly mammoths near the Somme River, American Museum of Natural History mural. (Public domain)

CRISPR

CRISPR is an acronym for Clustered Regularly Interspaced Short Palindromic Repeats. CRISPR is a cutting-edge gene editing technology. In my research, I read the book *A Crack in Creation* by Jennifer A. Doudna and Samuel H. Sternberg. It is basically a memoir telling the story of how Doudna first learned about CRISPR and her journey to become one of the leading scientists studying CRISPR today.

Jennifer Doudna, a professor at the University of California Berkeley, describes her feelings early in her journey. She said, “These bits of information sent a little shiver of intrigue down my spine; if CRISPR was present in so many different species, there was a good chance that nature was using it to do something important.”⁴⁵

As Doudna worked more with CRISPR and other top scientists around the world, she came to understand and explain in her book that CRISPR basically is the equivalent of an immune system that allows bacterial cells to fight bacteriophages, or bacteria-specific viruses. Doudna had been working on Type I CRISPR when she was introduced to Emmanuelle Charpentier, a French biologist, who was working with Type II CRISPR which uses the Cas9 protein. Basically, CRISPR finds the target sequence in the DNA, the Cas9 protein cuts the DNA, and then the new DNA sequence is inserted. As of now, CRISPR can edit genes and turn off genes. The recent discoveries with CRISPR make it feasible for this technology to help in efforts for resurrecting species such as the passenger pigeon and the woolly mammoth. So Doudna, Emmanuelle, Martin Jinek and Michi Hauer from Doudna’s lab and Krzysztof Chylinski who had previously worked in Emmanuelle’s lab began collaborating across the globe. Bit by bit they figured out more of the CRISPR puzzle.

Doudna described the feeling, “How incredible that bacteria had found a way to program a warrior protein to seek and destroy viral DNA! And how miraculous, how fortunate, that we could repurpose this fundamental property for an entirely different use.”⁴⁶

Cryo

There are about a dozen locations around the world that are freezing cells and DNA of endangered species. They have various names such as: The Frozen Zoo at the San Diego Zoo, the Cryobiobank at the Cincinnati Zoo, the Frozen Ark at the University of Nottingham in England, and the Ambrose Monell Cryo Collection at the American Museum of Natural History (AMNH) in New York City. The AMNH has one of the largest collections of frozen tissues. The idea is that this is like a lending library and the samples can be sent to any scientist anywhere in the world. From the literature I read, cryo repositories are an attempt to catalogue as many species from around the world so that future generations potentially can figure out what to do with them. Embedded in the mission statement of the Ambrose Monnell Cryo Collection it states, “In a time of massive species loss, such efforts are essential in order to preserve as comprehensive a record as possible of the earth’s biodiversity.”⁴⁷

With the development of CRISPR and gene editing technology, the “future” of using the cells and DNA stored in the cryo banks is literally right around the corner. Fortunately, scientists had the foresight to plan for the future. One question that will continue to be debated is whether a woolly mammoth or a passenger pigeon is really the same species if it did not develop in its natural habitat.

Once again, I will return to *Jurassic Park*, now that the gene-editing techniques have been explained. I may even replay the clip where the scientists go out and find the dinosaur eggs which was a supposed impossibility because the dinosaurs were designed to be incapable of reproduction. This will encourage my students to consider possible intended and unintended consequences of bringing back the passenger pigeon or other extinct species when the consequences are not known.

Introducing a de-extinct species could have the same effect as an invasive species. So, while it could initially increase the biodiversity, in the long term it may actually decrease it. As discussed in our seminar, another consequence is we really do not know what will happen if we start tinkering with the genome. While we do not fully understand how all genes work, we are figuring out that many genes can play a role in a single trait, such as height in humans.⁴⁸ Another concern is that if a gene is turned off, others may turn on to make up for it. What effect will replacing genes in a species have on the species, on other species, or on the environment over time? If we use gene editing to help an endangered species be more resistant to a pathogen, will another more virulent pathogen replace the pathogen?

Strategies

I plan to use a variety of strategies throughout the curriculum unit to actively engage my students.

Movie clips

The unit will kick off with a clip of *Jurassic Park*, to captivate their attention. After watching the video clip the students will write their reflections which we will share as a part of a class discussion. Other clips will be employed throughout the curriculum unit to touch on various topics as we work through the curriculum unit. The students will continue to reflect and discuss each time.

Hands-on simulations

The students will engage in numerous hands-on simulations designed to represent scientific concepts. The simulations will be staggered throughout the unit and will model how invasive species take over an environment, how invasive species reduce global biodiversity, and how CRISPR works.

Philosophical discourse

I want my students to participate in philosophical discourse. They will discuss a related scenario from the time of Aristotle which will lead into the section on de-extinction. Without much explanation as to the purpose of the activity, the students may wonder how this fits with the unit. I hope this will inspire their curiosity to figure out the connection.

Case studies

Case studies will be analyzed so students will think critically and apply their knowledge. The first case study will be presented after they learn about CRISPR, and another will be part of a cumulative project where they have to decide how to preserve an endangered species and justify their choice.

Mapping Endangered Species

As an extension to the unit, the students will investigate an endangered species in the state of Virginia. However, this strategy could be used for any U.S. state or country around the world. The students will discover the geographical area where these species live. This strategy should engage the students in some research and makes a more local connection.

Activities

Day 1: Introduce background knowledge about the sixth mass extinction and show *Jurassic Park* clip (24:00-27:00) of how scientists resurrect dinosaurs.

Day 2: Explain the background knowledge about land transformation, oceans, and invasive species. Plant some native species and also an invasive species. Students will observe over time.

Day 3: Go over toxic pollutants, ocean acidification, climate change, killing species and overharvesting. Students will create mini-poster showcasing three problems that are threatening species.

Day 4: Activity 1

Day 5: Teach the possible solutions (controlling invasive species, reintroduce species, and habitat preservation)

Day 6: Teach the possible solutions (Captive breeding and reintroduction and education)

Day 7: Activity 2

Day 8: Activity 2 part 2, then teach possible solutions (Genetic assistance, gene editing, CRISPR, Cryo)

Day 9: Activity 3 (ongoing)

Day 10: Activity 4 and lesson on de-extinction

Day 11: My students will research endangered species state-wide and determine in which of the five regions the species live. As a class, we will work on electronically mapping local species by dropping pins and having species information pop up.

Day 12: Complete local species mapping

Day 13: Activity 5

Day 14: Research for activity 5

Day 15: Work on activity 5 and share.

Activity 1: Biodiversity Hands-on Simulation

My students will put 1 L of water in each of four identical containers. Then they will add three drops of food coloring to each (red, blue, green, and purple – a combo of red and blue). Each day a student will use an eye dropper to add five mL of a color from one container and add it to all other colors. The process will continue each day until all four containers appear to be the same color. This will model the idea of homogenization of species that is occurring as invasive species are moving around the world and decreasing global biodiversity.

Activity 2: CRISPR

I want my students to understand the gist of how CRISPR works. The students will work in small groups and will construct a portion of the genetic code for a human with paper chain. Students will make the following chain: TACACTCACATTTTTTGCATATTATCTAGTCCCATGACATTA using the following color code: red for T, blue for A, yellow for C, and green for G. Each group will carefully check that they have made the code correctly. Then once the students leave for the day, I will make a few “mutations” to their DNA. I will switch out a few links of each chain. The next day, they will once again check that their DNA follows the pattern. If it is incorrect, they will correct it. I anticipate the students will remove the incorrect link and replace it with the correct color. Each group will explain how they fixed the problem. Then, the teacher will explain that that is a very simplified model of how CRISPR technology works. Once the students have made their model, I will explain the potential for CRISPR to help endangered species and to possibly de-extinct species.

Activity 3: Case Study- Bats

The students will read the case study, examine three pictures of hibernating bats, and view spread maps of white nose syndrome in bats. The pictures are available on page 215 in the book *The Sixth Extinction*. The maps are from the following website <https://www.whitenosesyndrome.org/static-page/wns-spread-maps>.

My students will work in small groups to discuss possible solutions, come up with their best solution, and share their solution with the class.

Bat Case Study

Bats may not be the cutest animal and many people may be afraid of them since they can get caught in your hair and their bites can carry the virus disease rabies. There is a threat to bats from New Hampshire to Virginia that could wipe out the entire population. The threat is a fungus disease called white-nose syndrome. It was first discovered in 2006 in New York and it spreads from cave to cave killing bats. Scientists have entered caves during the winter when bats hibernate. They find dead bats lying on the ground. In one cave in New Jersey the population went from 30,000 to 750 in just one year.⁴⁹ Bats protect human health and crops. Bats eat mosquitoes, beetles and moths. Mosquitoes carry diseases and beetles and moths harm many crops. One bat can eat 3,000 insects in one night.⁵⁰ Scientists discovered a type of bat, the greater mouse-eared bat in the Netherlands and Turkey. These bats have the white nose fungus, but it doesn't seem to harm them. Scientists believe they evolved with the fungus.⁵¹

Activity 4: Philosophical discussion about de-extinction

For this activity, the students will once again work in small groups. I plan to use the story of the ship of Theseus. The story is widely available online. The basic story is that Athenians put a ship in the harbor to honor the naval prowess of their king, Theseus. Over time the planks on the ship began to decay. Gradually the planks were replaced with new wood, until all of the planks had been replaced. The puzzle to debate is whether or not it is the same ship. Following this discussion, the class will discuss whether or not a species that lives in a zoo is the same species. Then the class will discuss whether or not a de-extinct species is the same as the original.

Activity 5

At the end of the curriculum unit, the students will use a second case study about the great apes. The final product will be to choose a strategy to help the endangered species, make a public service announcement, and justify the answer.

Mountain Gorillas Case Study

Mountain Gorillas are a critically endangered species. They live in Bwindi Forest National Park and Virunga Conservation Area in Rwanda, Uganda and Congo. Mountain gorillas cannot live in captivity. It is estimated that there are only 880 mountain gorillas left. Habitat loss is a main threat to the mountain gorilla. They are herbivores and eat plants and trees. Humans are taking over the land and cutting down the forests. Farming and firewood cause more deforestation, or cutting down the trees. Diseases also threaten the mountain gorillas. They are closely related to humans, and can catch illnesses from humans. Tourists that travel to see the gorillas carry illnesses which are easily spread within a gorilla family. If humans have a cold or the flu it can make the gorillas sick or kill them. Poaching, or hunting, is also a threat. Poachers set traps to catch other animals, but gorillas can get caught in the traps too. Gorillas can lose a limb or die from gangrene. Some people hunt gorillas for bush meat and others capture and sell baby gorillas as pets.⁵²

Appendix 1: Annotated District Standards

This curriculum primarily focuses on Virginia standards of learning for science, but also includes some language arts standards and a social studies standard. The science standards are 4.1, 4.4, 4.5, and 4.9. Beginning with science standard 4.1 which is scientific investigation and includes many different skills which are not intended to be taught in isolation, but embedded throughout the content of the other standards. This particular curriculum unit ties in nicely with the emphasis on scientific reasoning, logic, and nature of science by having the students investigate case studies, data, and make observations. Standards 4.4 and 4.5 focus on the life processes of plants and animals. The most related topics are behavioral and physical adaptations and survival and perpetuation of species. Standard 4.5 focuses on ecosystems and some of the most related areas are habitats, populations, niches, and the influence of human activity on ecosystems. Standard 4.9 is about conservation of natural resources and includes plants and animals and how public policy impacts the environment.

The language arts standards that are embedded in this curriculum unit are 4.1 which is oral communication, 4.6 which is reading of nonfiction texts, and 4.9 which is comprehension of materials for research. Standard 4.1 states that students will contribute to group discussions across content areas, seek ideas and opinions of others, communicate new ideas to others, and collaborate with diverse teams. There are many opportunities to work in small groups throughout this unit. Standard 4.6 refers to comprehension of nonfiction text which is the case studies. Standard 4.9 speaks to comprehension of information resources to research a topic. The students will research endangered species throughout the state and create brief descriptions for the electronic map.

Virginia Studies standard 2b relates to the five regions of Virginia. My students will pin the endangered species on a map of the five regions of Virginia.

Next Generation Science Standards

I am less familiar with these standards as they are not the adopted standards in Virginia. The Next Generation Science Standards 3-LS3-1, 3-LS3-2, 3-LS3, 3-LS4 are about heredity inheritance and variation of traits and biological evolution. The concepts covered in these standards are embedded throughout the curriculum unit.

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