Who gets to survive and reproduce? Are there factors that have nothing to do with phenotype and genotype? In 1929, Sewall Wright used the term drift to describe the random change in frequency of alleles from one extreme to the other (Wright 1929), explaining how traits are randomly passed to offspring within small populations (e.g., endangered species), thus reducing biodiversity.

Genetic drift is a change in the frequency of alleles in a population due to chance. Both fixation (100% of the population carries the allele) and loss (the allele is removed from the population) of alleles can be harmful if the allele is associated with diseases and abnormalities, or if it is associated with characteristics necessary for survival. Natural selection can be overshadowed by genetic drift in small populations because it’s difficult to overcome non-random mating and inbreeding (Grueber, Wallis, and Jamieson 2013). Biodiversity is an important indicator of the health of our planet. Genetic variation is essential for evolutionary change, and human activities intensify decreasing biodiversity because of climate change, habitat loss, and pollution.

Mechanisms of evolution in classrooms
Models of biological evolution have been documented over the past five decades. Kuhn (1969) described constructing a model of natural selection using art materials to construct different environments to explore protective coloration of insects. Based on Sewall Wright’s work, Thornton, and Ashley (1977) developed a game to illustrate how gene frequencies can change as a result of varying topography of a mountain to represent “peak of adaptiveness.” Tieman and Haxer (2007) created an activity where students are competitive predators and jellybeans are prey to explore cryptic coloration, mimicry, and population shift. Blattner, Hug, Watson, and Korol (2012) describe a game about how fish adapt to environments and hypothesized about which habitats favor which traits.

This article provides two activities (Appendix A; see Online Connections), exploring genetic drift of small breeding populations, highlighting the black-footed ferret (Mustela nigripes). According to the U.S. Fish and Wildlife service, all black-footed ferrets are descended from 18 individuals, making them extremely vulnerable to genetic drift. They were thought to be extinct until the 1970s and 80s, due to population expansion in the western United States. Activity 1 uses a conceptual computer model to explore fixation and loss in black-footed ferrets. Activity 2 uses a mathematical model in an Excel spreadsheet to examine genetic drift of allele frequencies by varying the initial population number of black-footed ferrets and other nearly-extinct species.

Theoretical framework: Scientific models and construction of knowledge through social interaction

Scientific Models
A scientific model is a simplified imitation of scientific phenomena. Rutherford and Ahlgren (1990) describe a conceptual model as a metaphor or analogy to give an unfamiliar idea meaning. For example, the Bohr model treats an atom like a miniature solar system with electrons orbiting the nucleus.
Mathematical models use mathematical relationships to explore scientific phenomena. Mathematical models may include rules and instructions that specify a series of steps to be taken that are mathematical or logical (Rutherford and Ahlgren 1990). For example, Kac (1947) described how taking a random walk can be used to represent Brownian motion. Coin flips determine walking direction randomly, like pollen randomly moving in water.

Social Interaction
Constructivist and sociocultural views of learning frame the activities described below. These views of learning posit that knowledge construction occurs through reflective thought (Fosnot 1996) and that social interaction is an essential part of the learning process (Vygotsky 1978). Furthermore, a range of knowledge that might be out of reach for an individual student may be accessible with support from peers and “more knowledgeable others” (Vygotsky 1978).

These activities are particularly well-suited to the construction of knowledge with diverse student populations because they are experiential, guided by “a more knowledgeable other,” and encourage reflective thought. Students engage both physically and socially—they have direct experiences with scientific phenomena and engage in scientific discourse informed by the experiences. Visual and physical experiences along with scientific discourse lead to opportunities for formulating explanations and hypotheses, developing and using models, and engaging in argumentation.

Activity 1: Observing genetic drift
Activity 1 initiates knowledge construction about mechanisms of allelic change by tracing the reproduction of black-footed ferrets using the conceptual model found at [http://php2.umkc.edu/education/alodom/Science_Teacher/ferret/ferret_model.html](http://php2.umkc.edu/education/alodom/Science_Teacher/ferret/ferret_model.html) (please watch the instructional video for using the conceptual and mathematical models [https://www.youtube.com/watch?v=ny9lAnl93U&feature=youtu.be](https://www.youtube.com/watch?v=ny9lAnl93U&feature=youtu.be)). The activity provides an opportunity for students to experience and think about factors other than natural selection and migration that cause allelic frequency change. Groups of two to three students were given the following questions and prompts to guide observations:

- Describe physical conditions (diversity) of ferrets at the beginning of the simulation (see Figure 1).
- Possible observation: The ferrets appear to have different fur colors.
- How was it determined which ferrets could reproduce?
- Possible observation: The roll of the dice determined who reproduced (see Figure 2a, b, c).
- Describe how the diversity changed after several generations. Compare your findings with other groups.
- Possible observation: All the ferrets became the same physical type. (The physical type will vary by student group).
Use the terms fixation and loss to describe the change in diversity of black-footed ferrets at the end of the simulation (see Figure 3).

Possible description: Normal, cystadenocarcinoma, smaller limbs, and mammary neoplasm ferrets were lost. Fixation was toward smaller limb size.

How could hidden traits influence the health of the population?

Possible description: The black-footed ferret became fixated on smaller limb size possibly hurting its ability to find food or become more susceptible to being preyed upon.

Additional background: The primary mode of transportation for U.S. settlers moving west was horses. As they moved across the great plains, horses would step into prairie dog burrows causing serious injuries. Farmers also viewed prairie dogs as pests because cattle were injured by their burrows. During the 1800s there was widespread extermination of prairie dogs. Extreme specialization of the black-footed ferret may have led to its near extinction. Campbell (1987) reported that 87 percent of all scats from the black-footed ferret were the remains of white-tailed prairie dogs. One wild black-footed ferret may eat over 100 prairie dogs per year (http://nationalzoo.si.edu/animals/black-footed-ferret), and a family needs to eat more than 250 prairie dogs per year.

The black-footed ferret is the only ferret species native to North America. It was extirpated in the wild. There are currently breeding programs that appear to be successful. According to the World Wildlife Federation (https://www.worldwildlife.org/species/black-footed-ferret) the population of black-footed ferrets has been restored to over 300 individuals across North America. As a result of the small population (18 captive individuals), genetic drift may have caused the ferret’s current population to suffer from genetic predispositions to neoplasia (Lair et al. 2002), and smaller limbs and smaller overall body size (Wisely et al. 2008).

Activity 2 initiates knowledge construction about mechanisms of allelic change by exploring the association of initial population number with genetic drift. This activity provides an opportunity to simulate ferret drift over and over with any starting population. The simulation uses the standard designation where $p$ and $q$ represent the frequency of two alleles at a locus ($p + q = 1$). The number of alleles in a population equals population number times two. The activity provides evidence of the association of small population size with genetic drift (see Figure 3). Groups of two to three students were given the following questions and prompts to guide observations:

- Open the Excel spreadsheet at the genetic drift tab. Examine the contents of the spreadsheet. Find the formulas ribbon and select the calculate now button several times. Notice the drift simulation graphs. With an initial population of 100 (cell B7), describe the number of generations to fixation and/or loss (cells B13 and 14).
- Possible observation: The number of generations to fixation or loss varies widely.
- The vaquita, black-footed ferret, amur leopard, and Florida panther are among the most endangered species on Earth. The most recent population estimates for each animal is listed at the top of the spreadsheet. Estimate possible fixation and/or loss and speculate about how genetic drift might influence the survivability of the animal.
Possible observation: The calculate button was clicked 10 times for the vaquita, fixation was as low as four generations. The highest number found was 92. For the amur leopard, fixation occurred in as few as 37 generations, the Florida panther reached fixation within 21 generations, and the black-footed ferret reached fixation by 11 generations. It’s possible that each of the organisms will be devastated by genetic drift.

Add several values of your choosing into cell B7. Note the generations to fixation. The model will estimate up to 10,000 generations. What would be a reasonable initial population to prevent genetic drift? Please provide reasoning.

Possible Observation: Fixation is frequent with an initial population of 1,000. Fixation was found within populations of 5,000. A reasonable initial population to reduce chances of genetic drift would be at least 1,000 to 5,000. The values will vary by group.

Additional Background: The vaquita, black-footed ferret, amur leopard, and Florida panther may have little time left to survive. At the writing of this article there were only 10 vaquita left on Earth. At what point does a species become endangered? Is there a population value in which we could conclude that a species is no longer endangered?

Wilcove, McMillan, and Winston (1993), examined U.S. plants and animals proposed for the endangered species list from 1985 through 1991. They found that median population size for vertebrate animals being listed as endangered was 1,075 individuals, and invertebrate animals it was 999. For plants the median population size was less than 120 individuals.

According to the U.S. Fish and Wildlife Service (2013), in order for the black-footed ferret to be delisted as an endangered species, there must be 3,000 free-ranging breeding adults, in 30 or more populations, with at least one population in each of at least nine of 12 states within its historical range.

The Florida panther began its recovery with as few as 20 individuals during the 1970s. Genetic drift may have caused them to have a predisposition for congenital heart defects, poor sperm quality, and high incidence of cryptorchidism (Maehr, Land, and Roelke 1991). Florida panthers face habitat loss, being hit crossing highways, mercury pollution, and diseases like feline leukemia. Reintroductions to new areas is a challenge because of fear and misunderstanding about the large cat.

Limitations
Models and simulations have both advantages and limitations. The advantages include time compression, reduction of the complexity of the concept, and active engagement with data with critical thinking opportunities. The first two advantages were also two drawbacks, time compression and reducing the complexity of the concept. Both can lead to misconceptions about evolution. For example, it took over 100 years for habi-

![Fixation on smaller limbs.](image-url)
tat destruction to extirpate black-footed ferrets, and extirpation was aggravated by plague and other diseases. This article highlights the endangered black-footed ferret within the context of a model emphasizing the advantages of simulations, while acknowledging drawbacks and potential misconceptions caused by time compression and reduction in complexity.

Conclusion
These activities offered students the opportunity to construct an explanation of evolution based on evidence and address the pressing need to use data to inform environmental policy for biodiversity protection (Evans, Malcom, and Li 2019). Genetic drift represents real-world problems where human activities can influence biodiversity. Understanding genetic drift is necessary to understand the consequences of loss of endangered species.

ONLINE CONNECTIONS
Instruction video for both models: https://www.youtube.com/watch?v=ny9lAnli93U&feature=youtu.be
Conceptual Model: http://php2.umkc.edu/education/alodom/Science_Teacher/ferret_model.html
Mathematical Model: http://php2.umkc.edu/education/alodom/Science_Teacher/drift4.xlsx

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