Environmental Science Institute
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Bottle-Necking and the Survival of the Alpine Chipmunk

Lesson plan for grades 6-8
Length of lesson: 1 class period
Authored by: Jesús Aguilar-Landaverde, Environmental Science Institute, October 2013

SOURCES AND RESOURCES:

- UC Berkeley: Yosemite's alpine chipmunks take genetic hit from climate change
  - http://newscenter.berkeley.edu/2012/02/19/climate-change-erodes-alpine-chipmunk-genetic-diversity/
- Genetics Society of America: J.F. Crow, "Hardy, Weinberg and Language Impediments"
  - http://www.genetics.org/content/152/3/821.long
- Nature Climate Change: Emily M. Rubidge, James L. Patton, Marisa Lim, A. Cole Burton, Justin S. Brashares & Craig Moritz, "Climate-induced range contraction drives genetic erosion in an alpine mammal"
  - http://www.nature.com/nclimate/journal/v2/n4/abs/nclimate1415.html
- University of Tennessee - Knoxville, Institute for Environmental Modeling: Population Bottlenecks: Heterozygosity vs. Allelic Diversity
  - http://www.tiem.utk.edu/~gross/bioed/bealsmodules/bottlenecks.html

POTENTIAL CONCEPTS TEKS ADDRESSED THROUGH THIS LESSON:

§112.18. Science, Grade 6, Beginning with School Year 2010-2011.b.

(10) Organisms and environments. The student knows that there is a relationship between organisms and the environment. The student is expected to:

(B) describe how biodiversity contributes to the sustainability of an ecosystem; and

(11) Organisms and environments. The student knows that populations and species demonstrate variation and inherit many of their unique traits through gradual processes over many generations. The student is expected to:

(B) explain variation within a population or species by comparing external features, behaviors, or physiology of organisms that enhance their survival such as migration, hibernation, or storage of food in a bulb; and

(13) Organisms and environments. The student knows that a living organism must be able to maintain balance in stable internal conditions in response to external and internal stimuli. The student is expected to:

(A) investigate how organisms respond to external stimuli found in the environment such as phototropism and fight or flight; and

(14) Organisms and environments. The student knows that reproduction is a characteristic of living organisms and that the instructions for traits are governed in the genetic material. The student is expected to:

(A) define heredity as the passage of genetic instructions from one generation to the next generation;

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(B) compare the results of uniform or diverse offspring from sexual reproduction or asexual reproduction; and

(C) recognize that inherited traits of individuals are governed in the genetic material found in the genes within chromosomes in the nucleus.

(11) Organisms and environments. The student knows that interdependence occurs among living systems and the environment and that human activities can affect these systems. The student is expected to:

(B) investigate how organisms and populations in an ecosystem depend on and may compete for biotic and abiotic factors such as quantity of light, water, range of temperatures, or soil composition;

(C) explore how short- and long-term environmental changes affect organisms and traits in subsequent populations; and

(D) recognize human dependence on ocean systems and explain how human activities such as runoff, artificial reefs, or use of resources have modified these systems.

§111.22. Mathematics, Grade 6.b.

(1) Number, operation, and quantitative reasoning. The student represents and uses rational numbers in a variety of equivalent forms. The student is expected to:

(A) compare and order non-negative rational numbers;

(B) generate equivalent forms of rational numbers including whole numbers, fractions, and decimals;

(9) Probability and statistics. The student uses experimental and theoretical probability to make predictions. The student is expected to:

(B) find the probabilities of a simple event and its complement and describe the relationship between the two.

(10) Probability and statistics. The student uses statistical representations to analyze data. The student is expected to:

(A) select and use an appropriate representation for presenting and displaying different graphical representations of the same data including line plot, line graph, bar graph, and stem and leaf plot;

(D) solve problems by collecting, organizing, displaying, and interpreting data.

(11) Underlying processes and mathematical tools. The student applies Grade 6 mathematics to solve problems connected to everyday experiences, investigations in other disciplines, and activities in and outside of school. The student is expected to:

(A) identify and apply mathematics to everyday experiences, to activities in and outside of school, with other disciplines, and with other mathematical topics;

§112.19. Science, Grade 7, Beginning with School Year 2010-2011.b.

(10) Organisms and environments. The student knows that there is a relationship between organisms and the environment. The student is expected to:

(A) observe and describe how different environments, including microhabitats in schoolyards and biomes, support different varieties of organisms;

(B) describe how biodiversity contributes to the sustainability of an ecosystem; and

(11) Organisms and environments. The student knows that populations and species demonstrate variation and inherit many of their unique traits through gradual processes over many generations. The student is expected to:

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(B) explain variation within a population or species by comparing external features, behaviors, or physiology of organisms that enhance their survival such as migration, hibernation, or storage of food in a bulb; and

(C) identify some changes in genetic traits that have occurred over several generations through natural selection and selective breeding such as the Galapagos Medium Ground Finch (*Geospiza fortis*) or domestic animals.

(13) Organisms and environments. The student knows that a living organism must be able to maintain balance in stable internal conditions in response to external and internal stimuli. The student is expected to:

(A) investigate how organisms respond to external stimuli found in the environment such as phototropism and fight or flight; and

(14) Organisms and environments. The student knows that reproduction is a characteristic of living organisms and that the instructions for traits are governed in the genetic material. The student is expected to:

(A) define heredity as the passage of genetic instructions from one generation to the next generation;

(B) compare the results of uniform or diverse offspring from sexual reproduction or asexual reproduction; and

(C) recognize that inherited traits of individuals are governed in the genetic material found in the genes within chromosomes in the nucleus.

§111.23. Mathematics, Grade 7.b.

(1) Number, operation, and quantitative reasoning. The student represents and uses numbers in a variety of equivalent forms. The student is expected to:

(A) compare and order integers and positive rational numbers;

(B) convert between fractions, decimals, whole numbers, and percents mentally, on paper, or with a calculator; and

(3) Patterns, relationships, and algebraic thinking. The student solves problems involving direct proportional relationships. The student is expected to:

(A) estimate and find solutions to application problems involving percent; and

§112.20. Science, Grade 8, Beginning with School Year 2010-2011.b.

(11) Organisms and environments. The student knows that interdependence occurs among living systems and the environment and that human activities can affect these systems. The student is expected to:

(B) investigate how organisms and populations in an ecosystem depend on and may compete for biotic and abiotic factors such as quantity of light, water, range of temperatures, or soil composition;

(C) explore how short- and long-term environmental changes affect organisms and traits in subsequent populations; and

(D) recognize human dependence on ocean systems and explain how human activities such as runoff, artificial reefs, or use of resources have modified these systems.

§111.24. Mathematics, Grade 8.b.

(1) Number, operation, and quantitative reasoning. The student understands that different forms of numbers are appropriate for different situations. The student is expected to:

(A) compare and order rational numbers in various forms including integers, percents, and positive and negative fractions and decimals;

(B) select and use appropriate forms of rational numbers to solve real-life problems including those involving proportional relationships;

(11) Probability and statistics. The student applies concepts of theoretical and experimental probability to make predictions. The student is expected to:

- (A) find the probabilities of dependent and independent events;
- (B) use theoretical probabilities and experimental results to make predictions and decisions; and
- (C) select and use different models to simulate an event.

PERFORMANCE OBJECTIVES (in order of increasing difficulty to permit tailoring to various age groups):

Students will be able to:

- In writing, generate and compare nonnegative rational numbers, percentages, and decimals.
- In writing and in words, explain the processes of genetic drift and population bottleneck.
- In words, relate a simulated population model to modern studies of genetic variance among mammals due to environmental factors.

MATERIALS (per group of four):

1 cup of beads (<= 15)

CONCEPTS: (non-exhaustive list)

Natural selection, global warming, fixation, effective population, population bottle-necking, climate change, basic probability, elementary manipulations of real and rational numbers, calculating percentages, genetic drift

BACKGROUND:

The field of population genetics is a way to model the change in allele frequencies within a natural population. Ideal models of equilibrium populations such as Hardy-Weinberg yield inertial predictions of allele and genotype frequencies in the absence of external forces. However, these models do not say anything about real factors affecting the distribution and changes of these states in light of random fluctuations stemming from genetic drift (non-directed, guided by probability) or non-random processes like natural selection (directed) and non-random mating.

In particular, mathematical models show that the effects of random fluctuations in gene frequency are more prominent and more significant with lower populations, where they may be comparable to or even overshadow effects due to selection. This lesson is designed to introduce intermediate-level students to the genetic and mathematical fundamentals of population genetics through hands-on modeling, calculation, and comparison of recorded data from random processes. Later, students are asked to consider the effects of non-random external forces like climate change on species through modeling.

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PREPARATION:
Cups for the activity should be prepared before the lesson begins. Also, copies of the Yang (2012) article cited above should be made, if they are to be passed out individually.

ENGAGE & EXPLORE:
The fundamental mathematics behind population genetics is isomorphic to those of statistical and thermal physics and other quantitative fields where counting is involved. In other words, the name of the game and the language of this activity is rightfully that of *probability*. Using different colored beads, students in this activity will model the response of a small population to genetic drift effects. Using dice to represent the probabilistic, stochastic nature of these variations students will quantitatively record, graph, and plot their results to observe the behavior of gene frequencies over time in small population.

Giving each group of students (preferably no more than 2 to a group if possible) a small plastic cup containing an initially equal number of a binary set of bead colors (e.g. red and blue), students will work together in modeling variations in 'allele' (bead) frequencies. In order for this activity to demonstrate the expected behavior, the number of beads in each cup (N), should be a small number (no more than 10). To add to the modeling, the instructor may choose to use laminated paper cutouts of real animals with labeled genotypes. Anything to add to the creativity and the sense of real-world modeling is encouraged.

Activity Instructions (per group of students):

- **Random assignment of roles**: one student (student 1) handles the cup of beads and performs the random selection; the other student (student 2) records data at each interval. The alternation of roles is also encouraged.
- **Time limit set:** instructor notifies students in advance of time allotted for this activity (no more than ten minutes) and begins a visible countdown timer for students, if possible. For classroom management, it is encouraged to remind students that both partners should be prepared their pair's results at the end of the time limit after a random selection.
- **Activity:**
  1. Student 1 and 2: count and record the initial number of beads of each color as well as total number (N)
  2. Student 1 places a piece of paper (or other seal) on the opening of the bead cup and shakes it for a few seconds. Afterward, the student draws **one** bead from the cup without looking. The agitation of the cup and the blind pick are the random element in the activity.
  3. Student 2: records the color (one of two possible outcomes) and records it in a tally count.
  4. Student 1: after the initial draw of a color (e.g. red), then the student replaces the first bead and *adds* a bead of the *same color* drawn to a second cup from an external bead supply
  5. Repeat steps 2-4 N times
  6. Repeat steps 1-4 for cup number two.

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7. Finally, students 1 and 2 observe cup three. Students 1 and 2 play one game of rock-paper-scissors. The outcome of the game decides which color is more "fit" in cup three. If student 1 wins, then red is more fit. If student two wins, then blue is more fit. If the game is a draw, then both red and blue are equally fit.

The second cup and third cups are models for second and third "generations" of "offspring" in a very simplified model. Given a small enough bead population (a condition set at the outset by the instructor), recordings made by students should demonstrate the expected changes in allele ratios with increasing generations. The game at the end of the activity will be compared to the results a later activity.

EXPLAIN:

The heart of the bead exercise is in students to extracting meaning from the numbers they will record. Here flexibility is given to the instructor on area of focus. This activity could be a centered on becoming more familiar with conversion between decimals, percentages, and fractions. Or, it could serve to compare observed versus expected probabilities. Regardless, students should compare the fraction of each color in each cup (cup one through three) and report in writing, in a bar graph, or in words how these fractions (or percentages) change. In small populations, there is a higher probability of observing a decrease in the fraction of a given color. This is a stochastic effect and is the main idea behind genetic drift. The instructor should bring groups that observe this trend to the attention of the class.

Student results can and should be varied. This is a breaking point for rich and meaningful dialogue. With enough pairs or groups or with small enough 'populations', it is very likely to observe 'fixation' in this model, with all beads in a cup the same color. This is an opportunity to discuss things like the cause of such a phenomenon and what the physical meaning of it is. In other words, does that mean that an allele that is fixed will *never change?* (i.e. what are the assumptions of our model?)

Too, at this point it is appropriate to introduce standard biological/mathematical terms like allele frequency, genetic drift, *fitness,* and natural selection.

A mathematical discussion may stem from asking students to report their *percent differences* from their initial (ancestor) and final (nth generation) populations of beads. Why are all students' results the same/not the same? Why did [red] increase in [blue] decrease in some cases? Why is it flipped? (in other words, what does this say about the *mathematics we used?* Is it *always* true that two alleles are equally likely to be passed on? What kinds of things could affect that in the natural world?)

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ELABORATE:

Now, the students return to the bead activity. However, this time students will carry out a similar model but with new certain restrictions. Instead of replacing the bead from the first cup, each time a bead is drawn, it is not replaced (i.e. it does not survive to reproduce again), and an *additional bead of the same color* is drawn and *removed* from the population (i.e. it just dies and never reproduces). So, once a bead of a color (e.g. blue) is drawn from the usual random sampling, *two* blue beads are removed from the cup. The “fit” game of rock-paper-scissors should also be repeated. Given these conditions, this follow-up activity should be much shorter in duration with more drastic effects.

The new rules for the bead game serve to simulate a *population bottleneck.* That is, there is an external force impacting the gene pool and how the beads reproduce. This segues nicely into a discussion of natural processes (and some not so natural, like anthropogenic climate change) that can influence genetic diversity of a species. Further, it opens the doors to what effects lower diversity can have on the *fitness* of a species. Students can compare the fitness of an ending population in both activities; what is the most probable fate of a population that is not fit at all?

The models in this lesson are designed to provide the activity [in *Activity Before Content* (ABC)] leading to discussion of modern research in population genetic changes in light of environmental factors due to global warming. The published study linked under “resources” concerns the American alpine chipmunk (Tamias alpinus) in California, which is an example of a mammal decreasing in genetic diversity due to this external force of climate on its distribution in terms of altitude. The 2012 Yang article from UC Berkley is more accessible to younger audiences; a class activity may be to read the article together or for each student to read individual.

Evaluate:

Possible central questions to focus on for this lesson may include any of the following:

What does the term “genetic drift” mean in biology? How was it modeled in class?

What is a *population bottleneck?* How is it different from ordinary genetic drift?

What effect is global warming having on the genetic diversity of the alpine chipmunk? What could this mean in terms of the species’ fitness? Explain.