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Learning Evolution in the "Lecture" Room: Using Post-It® Notes Size Variation to Learn About Population Frequency Distributions

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One of the key underpinning concepts for learning how evolution occurs is the mathematical and graphical description of populations as frequency distributions of individual phenotypes. Phenotypic variation, regardless of its cause (environmental or genetic) is best described in terms of a frequency histogram that is generally abbreviated by simply drawing the shape of the histogram across the range of the variation to be described. A frequency histogram of the existing phenotypic variation is necessarily the starting point for describing how a population may change as a consequence of natural selection, or any other cause for evolutionary change (mutation, genetic drift, or migration). Consequently, when students do not conceptualize the smooth curve of a frequency distribution as the actual representation of the numbers of individuals exhibiting each form (or categories) of a trait, subsequent discussions on how natural selection causes populations to change are undermined. An in-lecture activity using Post-It® Notes of different sizes permits students in small groups to quickly and easily create population frequency histograms, calculate population trait means, and evaluate the effects of selection. This activity takes very little time away from lecture and is very inexpensive. However, this activity makes population frequency histograms more concrete, and permits students to make the link between the shape of their Post-It® Note histograms and the more abstract smooth line frequency distributions that are used to describe the responses of populations to natural selection.

Keywords: evolution game, frequency distributions, natural selection

Introduction

This simulation was developed as a consequence of my frustration when I asked students to draw a sequence of frequency histograms to show how a population might change over time when subject to directional selection. Despite having already spent several lectures on the evolutionary process and discussing how natural selection works, too many students had difficulty drawing simple phenotypic distribution frequency histograms let alone describing the dynamics of change over time. I decided on this completely artificial system because it would readily lead to students creating frequency histograms on their desk and provide both numerical and graphical information about population change as a consequence of natural selection. Adding mutation to the simulation is a simple matter that provides the opportunity to discuss the independence of mutation and natural selection. This simulation is simple, quick, and very cheap. I have done this in both introductory and advanced classes with equal success. When I do this in a lecture class, I do not provide students with any handouts, but here I have provided a student handout for instructors who would be more comfortable using a handout. When I do this, I use PowerPoint slides that describe the simulation circumstances and the tasks that each group of students must address and we move seamlessly from lecture to simulation and back to lecture again. The entire simulation, 3-4 rounds of "reproduction" and "selection", may be accomplished in 15 to 20 minutes.

Student Outline

Simulating Natural Selection and Evolution

Objective

Simulate three or more generations of directional selection on Post-It® Notes size; create population frequency distributions and mean "phenotypes" for each generation.

Introduction

Among the most fundamental processes in biology, on par with the Central Dogma of molecular genetics, is the process of evolution by natural selection. Yet for all its importance as the principal cause for evolutionary change, it is essentially a statistical process that is best described by changes in the mean phenotype and the shape of the phenotypic frequency histogram for a population over time. Charles Darwin (1859) and Alfred Russell Wallace developed their theory of evolution by natural selection without knowledge of genetics (Mendelian or molecular), so it is perfectly reasonable to simulate this evolutionary process using a non-biological system. You will work in groups of 3-4, to create and display populations of Post-It® Notes that reproduce, mutate and are subject to "natural selection" by a predator. Does the phenotypic frequency distribution histogram of your population change as a consequence of natural selection? What is the mean phenotype of your population in each generation of the simulation?

Simulation Process

Each group of 3-4 students will be given a zip-lock bag containing Post-It® Notes that are all 3 inches (7.5cm) wide but vary in their height from 1 inch (2.5cm) to 5 inches (12.5cm). In this simulation, Post-It® Notes reproduce by binary fission and the offspring of a given Post-It® Note will have the same height as their parent (heritability of 1.0). Mutations occur randomly and may result in either a 1 inch (2.5cm) increase or decrease in the height of one Post-It® Note in the tallest or shortest phenotypic category respectively. A Post-It® Note predator (Post-It® Note Raptor) preferentially remove the tallest Post-It® Notes from a population.

Your instructor will direct you to create a starting population of Post-It® Notes with one - 2 inch (5.0cm) tall note, two - 3 inch (7.5cm) tall notes, and one - 4 inch (10cm) tall note. Using masking tape, create the axes for a frequency histogram of Post-It® Note height and label the tape with the axes names.

1. Arrange the Post-It® Notes of your starting population in your frequency histogram. Record this histogram and calculate the mean height of this starting population (POP 1).
2. Now let your Post-It® Notes reproduce once by binary fission. Again, arrange the Post-It® Notes the entire population in your frequency histogram. Record this histogram and calculate the mean height of this population (POP 2). Did the mean height changed (evolved) from POP 1 to POP 2?
3. The Post-It® Note Raptor attacks your population and removes three of the tallest individuals. Then the population reproduces once by binary fission. Arrange the Post-It® Notes the entire population in your frequency histogram. Record this histogram and calculate the mean height of this population (POP 3). Did the mean height changed from POP 2 to POP 3?
4. The Post-It® Note Raptor attacks again and removes five of the tallest individuals. Then the population reproduces once by binary fission. Arrange the Post-It® Notes the entire population in your frequency histogram. Record this histogram and calculate the mean height of this population (POP 4). Did the mean height changed from POP 3 to POP 4? If selection were the only process occurring, how short could the population of Post-It® Notes evolve?
5. If time permits, your instructor will announce the occurrence of a mutation that causes one of the shortest Post-It® Notes to produce offspring 1 inch (2.5cm) shorter than themselves when reproduction occurs. The Post-It® Note Raptor attacks once again and removes five of the tallest individuals. Then the population reproduces once by binary fission. Arrange the Post-It® Notes the entire population in your frequency histogram. Record this histogram and calculate the mean height of this population (POP 5). Did the mean height changed from POP 4 to POP 5?

Simulation Analysis

Arrange your drawings of the frequency histograms of the four or five populations of The Post-It® Notes so you may compare them to each other on the same X-axes.

In the absence of selection (POP 1 to POP 2), did evolution occur in your Post-It® Note population?

How did the Post-It® Note population change when subjected to predation by the Post-It® Note Raptor (POP 2 to POP 4)? How did the shape of the histograms change? How did the mean phenotypes (height) change?

Is there a limit to the evolution of Post-It® Note height in the absence of mutation?

What happens once mutation occurs and some smaller phenotypes enter the population?

What caused mutation to occur?

Did the Post-It® Note Raptor cause mutation to occur?

Notes for the Instructor

Assemble a plastic bag or small box of Post-It® Notes for each group of 3-5 students. Each group of 3-5 students will be given a zip-lock bag containing Post-It® Notes that are all 3 inches (7.5cm) wide but vary in their height from 1 inch (2.5cm) to 5 inches (12.5cm). In this simulation, Post-It® Notes reproduce by binary fission and the offspring of a given Post-It® Note will have the same height as their parent (heritability of 1.0). Mutations occur randomly and may result in either a 1 inch (2.5cm) increase or decrease in the height of one Post-It® Note in the tallest or shortest phenotypic category respectively. A Post-It® Note predator (Post-It® Note Raptor) preferentially remove the tallest Post-It® Notes from a population.

Supplies for Class of 25-40

- Prepare eight packets of Post-It® Notes of one color, 3” (7.5 cm) wide:
  - Five differ heights: 5” (12.5cm), 4” (10cm) 3” (7.5cm), 2” (5cm), 1” (2.5cm)
  - Ten pieces of each size is more than sufficient for each group.

I cut larger Post-It® Notes to create the phenotypes needed. The 5” (12.5cm) and 3” (7.5cm) sizes are common. One pad of each of these sizes would provide sufficient supplies for one group. Take one-half of the 5” (12.5cm) and cut (and save) a 1” (2.5cm) strip to create 4” (10cm) tall and 1” (2.5cm) tall Post-It® Notes. Do the same with the 3” (7.5cm) size to create 2” (5cm) tall and more 1” (2.5cm) tall Post-It® Notes.

Eight sets would require 8 pads of 5” (12.5cm) and 8 pads of 3” (7.5cm) Post-It® Notes.

Starting the Game

Each starting population consists of:

1 – 4” (10cm)
2 – 3” (7.5cm)
1 – 2” (5cm) tall Post-It® Notes

Ask students in groups of 3 – 5 to arrange the Post-It® Notes to form a frequency histogram of Post-It® Note heights. The trait is Post-It® Note height. Identify the axes of the frequency histograms.

Calculate the mean height of the starting population.

Each note reproduces by binary fission, so add the new additions to the population and again calculate the mean height.

When mutation occurs, it is most convenient to make it a mutation that makes a short individual yield offspring that are 1 inch shorter than the parent. When reproduction occurs, the parent is replaced by the two shorter offspring.

We are simulating directional selection causing directional evolution. The populations are changing as a consequence and the mean height is decreasing from the starting population.

Supplemental Activities

This simulation should occur prior to or following a discussion of real directional selection examples, such as the evolution of antibiotic resistance, the evolution of HIV resistance to AZT, or the evolution of antimalarial resistance in *Plasmodium*.

The simulation could be conducted in multiple versions by starting with selection by a predator and then adding complexity by incorporating mutation (or drift, or migration so long as you make those realistically random processes). Another alternative could be to make this an artificial selection experiment by making the cause for selection a farmer who wants to raise large (or small) Post-It® Notes for market.

Although I have not done so with my classes, you could certainly use a coin flip, or dice to determine the occurrence of random events such as mutation, and the direction of mutation.

A different set of phenotypes could be used in this simulation instead of body size. Using different color Post-It® Notes would permit you to do this simulation with a non-continuous trait, body color.

There are many uses of frequency histograms in biology and it may be useful to describe some of those uses to put this simulation in a broader context than just learning about the evolutionary process. I usually start this discussion by mentioning the frequency histogram that most students are fixated on, a course grade distribution. In biology, frequency distributions are used to illuminate the shape of a character distribution in a given population (indicating the mean and median) which permits us to make comparisons at different times in the same population, but also make comparisons to different population of the same species, or different species. Age structure frequency histograms are worth mentioning because we us them in demographic studies. These are age distributions, in which the typical axes are switched so age category is on the y-axis and the number or percentage of a population is on the x-axis. Males and females are shown on the same histogram but on opposite sides of the y-axis. In human populations, the shapes of these age structure frequency histograms correspond to the relative rates of per capita population growth, the lifetime average number of offspring per female, infant mortality rates, and the extent to which a given population has gone through demographic transition to equilibrium.

Sample Results

Given the conditions described in the Student Handout, the following results would be observed:

POP 1

Height	Frequency	Cumulative Height
2”	1	2
3”	2	6
4”	1	4
Totals	4	12” (mean = 3”)

POP 2

Height	Frequency	Cumulative Height
2”	2	4
3”	4	12
4”	2	8
Totals	8	24” (mean = 3”)

POP 3

Height	Frequency	Cumulative Height
2”	4	8
3”	6	18
Totals	10	26” (mean = 2.6”)

POP 4

Height	Frequency	Cumulative Height
2”	8	16
3”	2	6
Totals	10	22” (mean = 2.2”)

POP 5

Height	Frequency	Cumulative Height
1”	2	2
2”	8	16
Totals	10	18” (mean = 1.8”)

ABLE Evolution and Natural Selection Quiz

Erik Ekholm writing for the New York Times (15 September 2010, US Meat Farmers Brace for Limits on Antibiotics) reported that in the United States:

“Dispensing antibiotics to healthy animals is routine on the large, concentrated farms that now dominate American agriculture. But the practice is increasingly condemned by medical experts who say it contributes to a growing scourge of modern medicine: the emergence of antibiotic-resistant bacteria, including dangerous *E. coli* strains that account for millions of bladder infections each year, as well as resistant types of salmonella and other microbes.” “Hospitals now find that up to 30 percent of urinary infections do not respond to the front-line treatments, ciprofloxacin and the drug known as Bactrim or Septra, and that resistance to key newer antibiotics is also emerging. *E. coli* is also implicated in serious blood, brain and other infections.”

Draw a time series of frequency histograms (at least two fully labeled diagrams) to show how this kind of antibiotic resistance evolution likely occurred. Label all aspects of your diagrams.

Is this evolution a result of natural selection? If yes, what kind of selection and how do you know?

What was the cause for variation in antibiotic resistance in *E. coli* prior to the use of antibiotics on animals in agriculture?

Literature Cited

Darwin, C. 1859. *The Origin of Species by Means of Natural Selection 7th Edition and The Descent of Man and Selection in Relation to Sex*. Reprinted by The Modern Library, Random House, NY, 1000 pages.

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