Life Sciences/HHMI OutReach PROGRAM

Variation, Selection and Time: A Recipe for Biodiversity

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INTRODUCTION AND BACKGROUND: A popular television series called *How It's Made* features a series of short documentary videos showing how common everyday objects are manufactured. The program breaks down the production of complex items into step-by-step processes for us to follow. Follow this link to see how pianos are made: http://www.vidly.net/video-how-its-made-pianos.html. **[Answer question 1]** In 1859, Charles Darwin published the Origin of Species, his monumental work that has become the foundation for evolutionary biology. Darwin's theory was based upon three key components: variation, selection and time. In this activity you will examine each component in a *How It's Made* style to see for yourself how populations evolve over the course of generations. Along the way you will be asked to answer a few questions. Please answer these questions on the separate STUDENT WORKSHEET

The first two key components, variation and selection, involve some element of chance, so we will begin by looking at probability.

PROBABILITY

When the weatherman predicts that there is a 50% chance of rain in the morning he is stating that there is a 50% probability or an even chance that it will rain. In other words, based on what he sees with the given weather conditions, it has rained in the past on days with similar conditions 50% of the time. Probability may be calculated using the following formula:

Probability = number of events of choice / number of possible events

For example, what is the probability of selecting a heart form a shuffled deck of cards? There are 52 cards (52 possible choices or events) in the deck 13 of which are hearts (number of events of choice). So 13/52 = 1/4 or .25 or 25% chance of selecting a card that is a heart. Use the formula to calculate the probability of selecting the six of hearts from the same complete, shuffled deck of cards. **[Answer question 2]** We hear about predictions and probabilities all of the time. Every time the Powerball jackpot builds to millions of dollars people purchase additional tickets to increase their probability of winning, even though statisticians have calculated that, on average, a person who purchases 50 tickets a week will win the jackpot about once every 30,000 years!


http://www.clker.com/clipart-9763.html

Understanding evolution or change over time requires an understating of the everyday mathematics used to calculate probabilities and compound interest. When you put money into a savings account at a bank, the bank pools your money with that of other customers in order to make loans. In return you earn interest on your savings and increase your net wealth. If you earn 7 percent interest compounded you see your wealth double about every 10 years. If, however, you only earn 1 percent compounded you will see your wealth double about every 70 years. This interest rate difference means that seven doublings will occur in the first example (2 x 2 x 2 x 2 x 2 x 2 x 2 or 128 fold) versus only 1 doubling (or 2-fold) in the second. That 6 percent difference in interest adds up to a 64 fold difference in wealth! Look up the savings account interest rates at your local bank. **[Answer question 3]**

The source of all biological variety is mutation. Every time DNA gets copied, as when cells are dividing by mitosis, mistakes are made. In humans approximately 175 new mutations occur among the 7 billion DNA letters in every individual. These mutations lead to variation in each of us, anything from color, size, shape or chemical property. In essence these mutations are the raw material of evolution.

SELECTION
Darwin called his theory of evolution Natural Selection. Unlike the growth of wealth under compounding interest, living creatures cannot grow exponentially as resources are not unlimited and organisms die. Because resources are limited, all organisms must compete for them in order to survive. Those organisms that have a variation or variations that allow them to outcompete their rivals are said to be selected by nature (*naturally selected*) to survive in that environment. List three examples of variations that allow plants or animals to outcompete other organisms for resources. **[Answer question 4]**

The power of selection is calculated by biologists in terms of selection coefficients (abbreviated as *s*) which are very similar to bank interest rates. Selection coefficients indicate those creatures that have a mutation that allows them to survive and reproduce better than others. For example, say a trait gives an individual a small advantage in survival and reproductive success such that it produces 101 offspring versus those individuals without the trait that only produce 100 offspring. This amounts to a 1 percent advantage (or in terms of banking a 1 percent rate of compounding) and s = positive *0.01.* Alternatively, if there is a disadvantage to having a trait and it negatively affects your survival and reproduction (only 99 offspring are produced while your competitors have 100 offspring produced, then the value of s is negative *0.01.* With a 1% selection advantage biologists have shown that a dominant trait would increase in frequency from just 8 individuals in 1000 to greater than 90% of individuals in only 3000 generations. If the selection advantage was 10% then the increase in frequency to 90% of the population would only take 300 generations.

Natural Selection and Animal Coloration, Example 1 -- Peppered Moths
You may have read about the case of industrial melanism and the peppered moths of England. Prior to the industrial revolution in England, peppered moths came in two varieties, light and dark. When factories burned coal for fuel coal soot polluted the local areas altering the color of lichens growing on trees where peppered moths rest. As a result there was a rapid rise in the frequency of darker moths and an equal drop in the frequency of lighter moths in industrial areas.


The melanic *carbonaria* (left) and the more common light-colored *typica* (right). Source: http://en.wikipedia.org/wiki/Peppered_moth

Table 1 below represents data on the number of moths captured yearly during a 10-year study on a peppered moth population in an industrial area. Complete a graph of this data on your answer sheet. **[Answer question 5]**

Table 1

Year	Number of Light Moths Captured	Number of Dark Moths Captured
1	537	112
2	484	198
3	392	210
4	246	281
5	232	311
6	225	357
7	193	412
8	147	503
9	84	594
10	56	638

The peppered moths represent one example of evolution where the selection pressure is very strong and therefore evolution occurs rapidly. The selection coefficient during the early industrial revolution against light moths on dark trees was estimated to be negative 0.2 (a 20% disadvantage). With the advent of anti-pollution laws however, the environment again changed as less pollution (soot) covered the trees.
A second study of a peppered moth population was conducted from 1959 until 1995. In this study data was collected on the percentage of dark moths in the population over this period.

Create a second graph of table two on your answer sheet. **[Answer question 6]**

Table 2

Year	Percentage of Dark Moths
1959	94
1963	92
1967	93
1971	90
1975	90
1979	80
1983	73
1987	41
1991	26
1995	19


Light and dark pocket mice on a light rock
http://www.hhmi.org/biointeractive/evolution/pocket_mouse_predation.html

Natural Selection and Animal Coloration, Example 2 – Pocket Mice

In the Pinacate desert of Arizona there is a population of Rock Pocket mice found in two variants, light and dark (see image above). They live among the sandy soil and dark volcanic rock outcrops that are found in the desert. In order to evade owls, their main predator, the mice make burrows in soil near or under rocky outcrops. As you might expect, the light colored mice are at a disadvantage when they browse for food among the dark volcanic outcrops while the dark colored mice are similarly disadvantaged when on the sandy soils. Click on this link to see a video animation of Pocket Mice and Predation:
www.hhmi.org/biointeractive/evolution/pocket_mouse_predation.html

In this activity you will use the information you learned in the introduction to see how pocket mice have evolved over time. For this activity we will answer the following two questions:

1. How long will it take for a black-causing mutation to arise in a population of light-colored mice?
2. How quickly will that mutation spread?

To answer the first question we have to look at chance and time similar to calculating the chance of winning the lottery jackpot. To answer the second question we have to look at selection and time.

1. **How long will it take for a black-causing mutation to arise in a population of light-colored mice?**

Many varieties of mice are used as model organisms in laboratory experiments all over the world. As a result mice have been extensively studied, including their mutation rates. Mice have 5 billion DNA bases in their genome and mutation at any one base occurs in about 2 out of every billion bases. There are about 1000 bases in an average gene that can be mutated. Multiply 1000 bases per gene times 2 mutations per billion bases and we get that mutation occurs in a specific gene in about 500,000 individuals. Mice breeding labs have found several mice mutants involving fur color traced a gene called MC1R. There are 10 sites within this gene that if mutated cause the mice's coat color to be black even if they carry only one copy of the gene (all mice have 2 copies of every gene just as human have 2 copies of every gene – 1 from your mother and 1 from your father).

Table 3. Mice Mutation Rates

Mutation Rate	2 per 1,000,000,000 bases
Number of sites in MC1R that can be mutated to make a mouse black	10
Number of copies of MC1R gene	2

On your answer sheet, calculate the number of mutant mice having a black causing mutation in the MC1R gene that you would expect in 1 billion mice. What are the odds of just one mouse having a black causing mutation in the MC1R gene? **[Answer question 7]**

Now let's look at mice population size and birth rates – factors that play a role in the determining how long it takes for one mutation to arise. Pocket mice live in population sizes that range from 10,000 to 100,000 individuals. These mice also have a high reproductive rate – on average 5 babies are born to every female per year.

Calculate the number of babies born in a population of 10,000 individuals each year. **[Answer question 8]**

Multiply answer 8 by answer 7 **[Answer question 9]**

Your calculations should reveal that in 1,000,000 years, a black-causing mutation will occur independently 1000 times. Every 1000 years you could say that our population of 10,000 pocket mice hit the black mutation jackpot! How often would a larger population, say 100,000 individuals hit the jackpot? Show your calculations on your answer sheet. **[Answer question 10]**

2. **How quickly will that mutation spread?**

The spreading of a new mutation (black fur trait) is a matter of selective advantage and time. Does the black trait confer a favorable selective advantage to the mouse with the mutation? In other words does the black mutant mouse have a greater chance of survival and reproduction than the white colored mice? Based on a population of 10,000 individuals the values for the spread of the trait to the whole population may be seen in Table 4.

Table 4

Selection coefficient	Time (in number of mice generations)
$s = 0.001$	Time = 19,807 generations
$s = 0.01$	Time = 1,981 generations
$s = 0.05$	Time = 396 generations
$s = 0.1$	Time = 198 generations
$s = 0.2$	Time = 99 generations

What is the relationship between the selection coefficient value and the amount of time for the favorable mutation to spread? **[Answer question 11]**

In pocket mice the estimated selection coefficient for dark mice living on dark lava rocks is greater than 0.01. Approximately how many generations would it take for the dark fur mutation to spread to the entire population? **[Answer question 12]**

Biologists have shown that the chance of a mutation successfully spreading through a large population is approximately 2 times the selection coefficient. What is the chance that the black mutation will spread through the pocket mice? What would be the chance if the selection coefficient were 0.05? If the black mutation arises by chance alone 1000 times in a million years (see your calculation above) then how many times could the black mutation arise and spread? **[Answer question 13]**

List at least two reasons why the black mutation might not spread throughout a population? **[Answer question 14]**

Click here to see an animation of the spread of the black mutation among pocket mice. http://www.hhmi.org/biointeractive/media/pocket_mouse_evolution-lg.mov

TIME

Human lifetimes rarely last beyond 100 years. We think that 100 years is a long time but when you consider the length of a human life against the age of the earth, our thinking gets bogged down. The age of the earth, 4.5 billion years, *is a long time!* Time spans of even a million years are difficult to comprehend. When we consider the time it takes for gene mutations to arise it is helpful to note that life on earth evolved billions of years ago. To help you gain an understanding of the vastness of time of earth history please go to the following link and explore the history of life on earth. http://www.ucmp.berkeley.edu/education/explorations/tours/geotime/ **[Answer questions 15-18]**

CONCLUSION

In order to understand evolutionary processes it is crucial that you appreciate that the forces of mutation and selection operate in nature all the time. Evolution is always on-going. As long as organisms reproduce, mutations are inevitable (DNA copying mechanisms are not perfect). Since environments change, competition among organisms for resources will inevitably lead to natural selection where the fittest individuals survive.

Name: ____ Date: ____________ Per.____

STUDENT WORKSHEET: Variation, Selection and Time: A Recipe for Biodiversity

ANSWERS TO ACTIVITY QUESTIONS

1. Describe one key component to the construction of a piano?

2. Use the probability formula to calculate the probability of selecting the six of hearts from a shuffled deck of cards. (Show your work)

3. What is the current savings account interest rate at your local bank?

4. List three examples of variations that allow plants or animals to outcompete other organisms for resources.
    a.

    b.

    c.

5. Complete a graph of the data found in table 1. Be sure to label your axes and give the graph a title.

6. Complete a graph of the data found in table 2. Be sure to label your axes and give the graph a title.

7. Calculate the number of mutant mice having a black-causing mutation in the MC1R gene that you would expect in 1 billion mice. (show your work)

   What are the odds of just one mouse having a black causing mutation in the MC1R gene?

8. Calculate the number of babies born in a population of 10,000 individuals each year. (show your work)

9. Multiply answer 8 by answer 7

10. How often would a larger population, say 100,000 individuals hit the jackpot? (Show your calculations)

11. What is the relationship between the selection coefficient value and the amount of time for the favorable mutation to spread?

12. In pocket mice the estimated selection coefficient for dark mice living on dark lava rocks is greater than 0.01. Approximately how many generations would it take for the dark fur mutation to spread to the entire population?

13. Biologists have shown that the chance of a mutation successfully spreading through a large population is approximately 2 times the selection coefficient.
    What is the chance that the black mutation will spread through the pocket mice?

    What would be the chance if the selection coefficient was 0.05?

    If the black mutation arises by chance alone 1000 times in a million years (see your calculation above) then how many times could the black mutation arise and spread?

14. List at least two reasons why the black mutation might not spread throughout a population?

15. If you were to write a history of the Earth's past, allowing just one page per year, your book would be ______________________________ pages long.

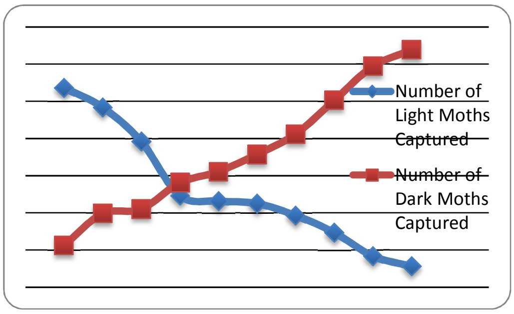
16. The earliest life occurred on earth approximately how many years ago? What type of life existed then?

17. Take the quiz at the end of the lesson. How many questions did you get correct?

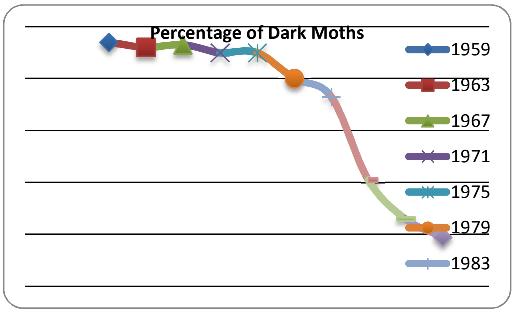
KEY

1. Student answers will vary. Students should describe one key component of constructing a piano as seen in the video.
2. There are 52 possible events (cards in a deck from which to choose). There is only 1 event of choice however – selecting the six of hearts. The probability is 1/52.
3. Student answers will vary. At the time of this writing my local bank advertised an interest rate of 0.10% on a personal savings account.
4. Student answers will vary. Students should list three variations that allow plants or animals to outcompete other organisms for food, sunlight, etc.
5. The graph should look similar to this one:

Figure 1. Peppered Moth Survey pre- anti-pollution laws



6. The graph should look similar to this one:



7. The number of mutant mice having a black causing mutation in the MC1R gene that you would expect in 1 billion mice is calculated as: 10 sites per gene x 2 genes per mouse x 2 mutations per 1 billion bases = 0.00000004 * 1,000,000,000 = 40 mutants in 1 billion mice

   What are the odds of just one mouse having a black causing mutation in the MC1R gene?
   1 billion divided by 40 = 25 million. So there is a 1 in 25 million chance of a mouse having a black-causing mutation in the MC1R gene.
8. The number of babies born in a population of 10,000 individuals each year is calculated as: half of the 10,000 are females (5,000 females) x 5 offspring per female = 25,000 babies per year

Comment [BS1]:

Comment [BS2R1]:

9. Multiplying answer 8 by answer 7 returns: 25,000 X 1/25 million = .001 mice per year or extrapolated up = 1 black mouse per 1000 years.
10. Out of a population of 100,000 individuals 50,000 would be female. Following the calculations laid out above then, 50,000 x 5 = 250, 000 x 1/25 million = 0.01 mice per year or 1 black mouse per 100 years.
11. As the selection coefficient increases, the amount of time for the favorable mutation to spread decreases
12. By consulting Table 4 students should see that the dark fur mutation would spread completely in fewer than 2,000 generations (less than 2,000 years)
13. The chance that the black mutation will spread through the pocket mice is equal to 2 times the selection coefficient *(s)*. For a mutation with a small advantage selection coefficient *(s)* of 0.01 the chance would be 0.01 X 2 = 0.02 or 2%

    What would be the chance if the selection coefficient were 0.05? The chance would be 0.05 x 2 = 0.1 or 10%

    If the black mutation arises by chance alone 1000 times in a million years (see your calculation above) then how many times could the black mutation arise and spread? The mutation could arise and spread 20 to 100 separate times (for a value of $s = 0.02$, 1000 chance mutation events x 0.02 = 20 and for a value of $s = 0.1$, 1000 chance mutation events x 0.1 = 100)

14. Student answers will vary but they should be thinking along the lines that there is the possibility that the black mutation might be lost (the black mouse preyed upon before it had the chance to reproduce). Mutation will be lost from the population as a function of chance and selection.
15. Your book would be 4,600,000,000 pages long.
16. 3, 900, 000, 000 billion years. What type of life existed then? Bacteria
17. Students should be able to get 5 questions correct out of 5