**Supplementary Materials (Section I)**

**Introductory Information for Students**

*(The following material was given in printed form to the students and also briefly presented verbally.)*

Evolution can be defined as change in an inherited trait within a population over the course of generations. This is often measured by allele frequencies. An allele is a variant of a gene. A gene is composed of a sequential arrangement of nucleotides, and any change in these nucleotides will result in the creation of a new allele. For example, a gene that specifies body color may have multiple alleles, each differing by a single nucleotide. Different combinations of these alleles may result in different coloration (e.g., red, yellow, blue, green). There are four ways that evolution can occur. These are referred to as the mechanisms of evolution.

1. **Migration** occurs when alleles move from one population to another. This can occur by movement of individuals or dispersal of gametes (e.g., pollen).

2. **Mutation** occurs when there is a change in DNA sequence. This can result in change from one allele to another.

3. **Natural selection** occurs when individuals with one phenotype survive and reproduce at a greater rate than individuals with a different phenotype.

4. **Random genetic drift** is the effect of chance on the allele frequencies found in a population. For example, this can occur during a random sampling error (e.g.: when gametes are formed, each has only one of two possible alleles for each gene; when a drastic reduction in population size occurs, some alleles will be lost from the population due to chance alone) or chance variation in individual survival or reproductive success.

**Supplementary Materials (Section II)**

**Exercise Answer Sheet (with key in boldface)**

NAME [ **ANSWER KEY ]**

LEGO EVOLUTION LABORATORY ACTIVITY—ANSWER SHEET

**Table 1.** Group Colors

|  |  |
| --- | --- |
| LEGO Block Colors | Paper Colors |
| Color #1 = |  |
| Color #2 =  |  |
| Color #3 =  | N/A |
| Color #4 =  | N/A |

**Q1.** What evolutionary mechanism is the cause of reduction in genetic variation that is associated with population bottlenecks *in general*?

**Random Genetic Drift. Students will often write “migration” here, most likely because they are considering the that the population has “recently been separated from the rest of the population” rather than the reduction in genetic variation. It will be important to emphasize that chance determines which alleles are represented in the new population, and therefore also the reduction in genetic variation.**

**Table 2.** Initial Population Frequencies.

|  |
| --- |
| Color Frequency |
| Color #1 = **1/6** |
| Color #2 = **1/6** |
| Color #3 = **1/3** |
| Color #4 = **1/3** |

**PART A: SIMULATION OF EVOLUTION IN A NEW POPULATION**

**Q2.** What evolutionary mechanism does this process represent?

**Natural Selection**

**Q3.** What do you hypothesize will happen to the frequency of each color over time? Explain the reasoning behind your hypotheses.

**The LEGO colors that match the background will increase in frequency because of their selective and reproductive advantage.**

**Table 3.** Color Frequency Over Time

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Color | Initial  | Generation 1  | Generation 2 | Generation 3  | Generation 4 |
| #1 | 2/12 = 0.17 |  |  |  |  |
| #2 | 2/12 = 0.17 |  |  |  |  |
| #3 | 4/12 = 0.33 |  |  |  |  |
| #4 | 4/12 = 0.33 |  |  |  |  |

**Table 4.** Death per Generation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Generation | Generation 1 | Generation 2 | Generation 3 | Generation 4 |
| Deaths (tally) |  |  |  |  |

**Q4.** Did the results match your initial hypothesis? If not, does this mean your hypothesis is flawed? What are some other explanations?

**Frequently students will find that their hypothesis was not supported by the simulation. This can result from a number of factors. In our simulation we have a high mutation rate, so this partially randomizes the population of each generation and reduces the impact of selection. It is also at least partially due to the small population sizes, which increases the role of chance (random genetic drift). Finally, it is possible that too few generations were observed for a substantial effect to be noticed.**

**PART B: PHYSICAL SEPARATION OF POPULATION**

**Q5.** Keeping this in mind, what other barriers might separate populations from one another?

**Sexually reproducing organisms may be effectively isolated from one another if they do not regularly mate in nature (prezygotic isolation) or if they do not produce viable offspring (postzygotic isolation).**

**Q6.** Would selection be considered to be stronger or weaker when compared to Part A?

**Selection is stronger in Part B, because instead of needing to match one of two colors, all organisms must match a single color. More organisms will die without reproducing as a result, which indicates stronger selection.**

**Q7.** What do you hypothesize will happen to the frequency of each color over time? How does this differ from your initial hypothesis in Part A?

**The LEGO colors that match the background will still increase in frequency because of selective advantage. However, it should occur more quickly than in Part A because the selective pressure is stronger.**

**Table 5.** Death Tally

|  |  |  |  |
| --- | --- | --- | --- |
| Generation | After Physical Separation | Generation 2 | Generation 3  |
| Deaths (tally) |  |  |  |

**Table 6.** Color Frequency in Isolated Environment One

Color of Paper: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

|  |  |  |  |
| --- | --- | --- | --- |
| Color (fill in the colors represented in your kit) | Initial Frequency (after physical separation) | 2nd Generation Frequency | 3rd GenerationFrequency |
| #1 |  |  |  |
| #2 |  |  |  |
| #3 |  |  |  |
| #4 |  |  |  |

**Table 7.** Color Frequency in Environment Two

Color of Paper: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

|  |  |  |  |
| --- | --- | --- | --- |
| Color (fill in the colors represented in your kit) | Initial Frequency (after physical separation) | 2nd Generation Frequency | 3rd GenerationFrequency |
| #1 |  |  |  |
| #2 |  |  |  |
| #3 |  |  |  |
| #4 |  |  |  |

**Q8.** Did the results match your initial hypothesis? If not, does this mean your hypothesis is flawed? What are some other explanations?

**The same possible reasons as in question 4 above, but in this case extinction of all organisms is also a real possibility because of the decreased population size and increased selective pressure. The separation event may have caused a severe population bottleneck, perhaps with only one or two organisms left in a particular environment. This, along with increased selective pressure, could result in none of the organisms surviving long enough to reproduce.**

**SUMMARY QUESTIONS FOR PARTS A & B**

**Q9.** What would you expect if we continued the activity for ten more generations? Explain your reasoning.

**Either extinction or an increase in frequency of the color that matches the background are reasonable predictions. In fact, given sufficient time, we would expect that either all populations would go extinct or that most bricks would match their background. Extinction is most likely in simulations with small population sizes.**

**Q10.** How could the strength of selection be increased in this simulation? If you did this, how would the rate of evolution change?

**We could specify that all three blocks must match the background in order to survive. In small populations, this would most likely result in extinction, but for those that did not go extinct, the rate of evolution would increase. (In this simulation, rate of evolution is measured by change in color frequency). Very strong selection would mean that only organisms of one color would survive long enough to reproduce, and that their offspring would tend to look similar (though mutation would introduce variation). This would result in a faster frequency of change of the background color than under the conditions in the original simulation.**

**Q11.** How could the mutation rate be increased in this simulation? If you increased the mutation rate, how would the rate of evolution change?

**Currently mutations occur such that, if you roll a 1, 2, or 3, there may be a mutation for that offspring. If you roll a 4, 5, or 6, there is no mutation. Mutation rate could be increased if mutation were also possible with a roll of 4, 5, or 6. Specifically, a roll of 1 or 4 could indicate a possible mutation at the top position, a roll of 2 or 5 for the middle position, and a roll of 3 or 6 for the bottom position. This may decrease the rate of evolution because it increases genetic drift (the effect of chance), which makes it harder for selection to act. With an increased mutation rate, the population is essentially randomized in every generation, and there can be no long term consequence of selection.**

**PART C: WHAT IF?**

**Q12.** Describe what condition is varied and how the simulation will be altered. Hypothesize the outcome.

**Two obvious possibilities would be an increase in selection pressure or mutation rate (as described in questions 10 and 11 above). Students may also choose to increase or reduce population size. An increase in population size would mean that selection would be more effective, and they should see the rate of evolution increase. A decrease in population size would result in strong genetic drift and possibly no change in color frequency. They may also choose to extend the simulation for multiple generations to test prediction of question 9 above. These seem like the most obvious ways to alter the simulation based on the predictions made at the end of Part B; however, we have found that students are often very creative, so the answers may vary.**

**Table 8.** Color Frequency Over Time

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Color | Initial frequency | Generation 1 frequency | Generation 2 frequency | Generation 3 frequency  | Generation 4 frequency |
| #1 |  |  |  |  |  |
| #2 |  |  |  |  |  |
| #3 |  |  |  |  |  |
| #4 |  |  |  |  |  |

**Table 9.** Death by Generation

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Generation | Generation 1 | Generation 2 | Generation 3 | Generation 4 |
| Deaths (tally) |  |  |  |  |

**Q13.** Did the results match your initial hypothesis? If not, does this mean your hypothesis is flawed? Why or why not?

**There are a variety of possible answers here. If the answers to questions 9–11 above are well thought out and the simulation is altered correctly, then their results should match the initial hypothesis. If this is not the case, students should reconsider their hypothesis and/or the modification of the simulation.**

**Supplementary Materials (Section III)**

**Questions Used for Assessment**

1. Which of the following phrases most accurately describes biological evolution?

A. change over time

B. change over time of inherited traits

**C. change over time of inherited traits within a population**

D. change over time of inherited phenotypic traits within a population1

2. Which of the following is not a way that evolution can occur?

A. migration

B. mutation

C. natural selection

**D. nonrandom mating**

E. random genetic drift

3. Ongoing migration between two populations will tend to result in

**A. more similar populations.**

B. increase in population size.

C. stronger natural selection.

D. no overall change in either population.

4. Which one of the following sentences best describes the relationship between mutation and natural selection?

**A. Mutation generates the variation on which natural selection acts.**

B. Natural selection is an effective mechanism of evolution regardless of whether mutation occurs.

C. There is a positive correlation between natural selection pressure and mutation rate.

D. Every mutation affects the probability of an organism’s survival.

5. A population bottleneck is likely to2

A. reduce strength of natural selection.

B. reduce mutation rate.

C. lead to speciation.

**D. reduce genetic variation in the population.**

6. Rolling dice most closely simulates which of the following processes?

A. migration

**B. mutation**

C. natural selection

D. nonrandom mating

7. Imagine a population of organisms, each consisting of three LEGO bricks. In the population below, what is the frequency of yellow bricks?

Answer: **0.43**

8. Imagine that in the previous population there are many predators of the LEGO organisms. The more closely they match the environment, the more likely they are to survive. Which of the following would you expect to be true?

**A. In a yellow background, organisms consisting of two yellow bricks would produce more offspring on average than organisms with only one yellow brick.**

B. In a yellow background, brown organisms would survive at greater rates than yellow organisms.

C. In a yellow background, organisms consisting of two brown bricks would produce more offspring on average than organisms with only one brown brick.

D. In a brown background, white organisms would survive at greater rates than yellow organisms.

9. Natural selection

A. works on populations, but its long-term effect is rendered on individuals.

**B. works on individuals, but its long-term effect is rendered on populations.**

C. can work only on populations of genetically identical individuals.

D. works regardless of the amount of genetic variability in populations.

1 In question 1, choices C and D could be interpreted as indistinguishable. To resolve this issue, choice D could be changed to “change over time of phenotypic traits within a population.”

2 In question 5, although choice D is inevitable, there are cases in which A and C could occur as well. These could potentially be replaced by “increase population size” and “increase mutation rate,” respectively.