



Exploring the Effects of Mutation Rate on Populations

Lesson Overview

This lesson allows students to explore relationships between mutation rate and fitness and how each influences the evolution of a population over time.

Big Ideas

Fitness is, simply stated, a relative measure of an organism's ability to survive and, ultimately, reproduce in the environment in which it lives. Some organisms are more fit than others in the same population due to variation in traits that contribute to survival and reproduction. Traits that confer a reproductive advantage are more likely to spread throughout the population and result in higher relative individual fitness. Thus, fitness is tied closely to genetic variation, the origin of which is **random mutation**.

The **rate of mutation** in a population can have significant effects on average population fitness. For example, as mutation rate increases the average population fitness will tend to decrease due to a higher incidence of harmful mutations. However, because mutations are random, it is possible for average fitness in a population to increase despite a high mutation rate. Therefore, we should expect to see a distribution of average fitness values for populations evolving at various mutation rates.

The effect of mutation rate on population size is even more pronounced. Being subjected to a lot of mutations can lead to decreased growth rates and heightened mortality; therefore, population size also tends to decrease as mutation rate increases, though here too we should expect to see a distribution in population numbers.

Objectives for Student Learning

Through engagement in this lesson, students will:

- Explain what fitness is and how it is connected to variation (mutations).
- Predict and explain the effects of mutation rate on population size and average population fitness.
- Practice the procedure for testing hypotheses (Hypothesize, Predict, Test, Evaluate).
- Explain why there is variation in experimental data and why this is significant for experimental design.

Students' Prior Knowledge

- Students should be familiar with the idea of genetic variation and its origin (mutations).
- Students are likely to have several misconceptions regarding mutations and the role they play in evolution. Some of these include:
 - "Evolution is a purely random process." Although mutations are random, the selection that acts on them is not.
 - "Mutations are always harmful, never beneficial." While most mutations are neutral or deleterious, some are indeed beneficial (e.g., those contributing to antibiotic resistance in bacteria).





- “All mutations have strong phenotypic effects.” Some mutations can cause large phenotypic changes, others small, and some not at all (e.g., “silent” mutations). Regardless, all mutations result in genetic variability.
- Students may have misconceptions about the concept of “fitness”, such as:
 - Fitness refers to the health or strength of an organism.
 - Students have likely heard the phrase “survival of the fittest” with regard to natural selection and may not realize that it is reproduction (i.e., number of viable offspring), rather than survival *per se*, that determines an organism’s relative fitness.
 - Students may not be aware that individual fitness is relative to other organisms within the population and dependent on the environment. An organism with a very high fitness in one environment may have a lower than average fitness in a different environment.
- Students should have a basic understanding of probability. However, they may struggle with what is meant by a particular mutation rate. Rather than indicating that there will always be a 10% difference between the ancestor and offspring, a 10% mutation rate means that each site in the genome independently has a 10% chance of changing during replication. The actual number of variations in a given replication event will vary.

Conceptual Connections

Biological Connections	Nature of Science Connections
Effects of radiation on DNA replication (increased mutation rate, higher incidence of cancers and birth defects); Probabilistic nature of beneficial mutations	Hypothesis development and testing; Significance of experimental replication

Activity

Materials

- Lecture PowerPoint (available for download from www.aida-ed.msu.edu)
- Handout: Exploring the Effects of Mutation Rate on Populations

Introduction

Interactive introductory lecture: What are mutations (review from previous lessons)? What are the consequences of mutations (what happens to an individual that carries a mutation)? What is fitness, both in biological organisms and in Avida?

Main Teaching Activities (95 minutes)

- Small group exercise (15 minutes): Students will work in groups of 3 or 4 during class to develop and justify hypotheses and predictions about the effects of mutation rate on average population fitness and population size using their knowledge of mutations and the effects of mutation rate on individuals.
- Data collection (30 minutes): In the same groups, students will run experiments at four mutation rates (1%, 5%, 10%, and 15%) for 2000 updates each, recording the





average fitness and size of their population after each run. These data will be sent to the instructor and combined with the data collected from other groups.

- Exploring class data (20 minutes): Provide students with a graphical representation of the combined class data (see sample data as an example). Students will work in groups to compare their group's data with the combined class data. They will decide whether the data they collected in their group supports their hypothesis, and whether the combined class data supports their hypothesis.
- Whole class discussion (30 minutes): The instructor will facilitate a discussion about the patterns that emerge from the combined class data. Guiding questions might include: What are the general trends? How can they be explained? Are the results reproducible/predictable? Why is there a distribution (e.g., why is there variation in results between groups? Why might their data differ from the class data)? How can it be explained, given the nature of mutations? What implications does this variation have for experimental design (e.g., why is replication important)?

Conclusion

Extension (in class or as a homework assignment): Students will work in groups to revise their original hypotheses based on the combined class data and design an experiment to test their new hypothesis in Avida-ED.

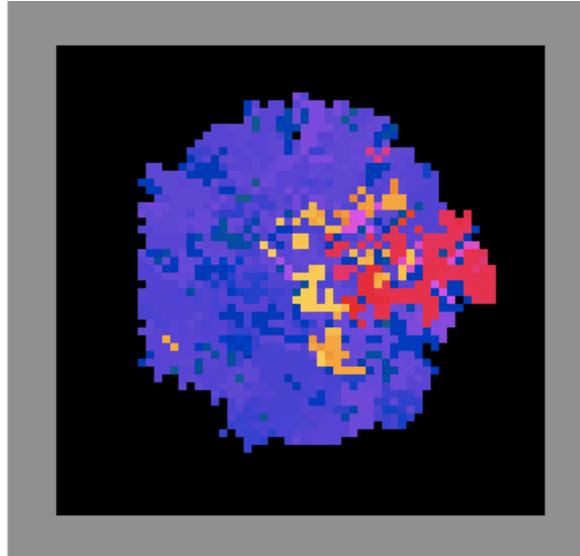
Variations and Supplemental Activities

- Variation: Instead of asking students to send their data, the instructor may choose to use the sample data provided.
- Variation: The instructor can give the collected class data (or sample data) to students/groups and ask them to decide how to analyze it, or provide them with directions on how to analyze it.
- Supplemental activity: This exercise can be preceded by the exercise "Exploring the Effects of Mutation Rate on Individuals", with students drawing from patterns observed at the level of the individual to explain the patterns observed at the population level.



Student Handout

Exploring the Effects of Mutation Rate on Populations



A population of digital organisms growing in a virtual Petri dish

Background

Genetic variation is introduced into a population by random mutations that occur as individual organisms replicate. The rates at which these random mutations occur affect both the number of mutations and viability of the individual's offspring. But how do mutation rates affect populations?

Two important characteristics that we can use to describe a population are the average fitness¹ of the individuals that make up that population and the population size. In this exercise you will determine whether these characteristics are affected by mutation rate and, if so, in what ways.

The exercise has two parts. In the first part, each student research team will develop a hypothesis about the relationship of mutation rate to the overall fitness and size of an Avidian population. Every team in the class will then run a series of experiments in Avida-ED under the same set of specified conditions. This will allow us to explore as a class the results of several independent experiments, and see if changes in mutation rate lead to predictable and repeatable outcomes in an Avidian population.

¹ A note on fitness: In biological organisms, "fitness" usually refers to a measure of (potential or actual) reproductive success. Organisms possessing traits that afford some sort of reproductive advantage will tend to have more offspring, and are therefore more fit, than organisms lacking such traits. In Avida, fitness is a function of an organism's metabolic rate divided by its gestation time. As an individual's fitness increases, the rate at which it is able to replicate increases; therefore, it will produce more offspring than organisms with lower fitness in a given amount of time.



In the second part of the exercise, each student team will test its own ideas about the relationships between mutations, mutation rate, and fitness. Using the class results as a starting point, student teams will devise a new hypothesis, and then devise and carry out their own experiments to test their hypothesis.

Assignment Tasks

Part 1.1 Generating class data

Hypothesize: As a team, discuss and formulate hypotheses (and the corresponding null hypotheses) regarding the relationships between the average fitness of individuals in your population of Avidians and population size as a function of the mutation rate. Be sure to include in your hypotheses a statement about why you think this is so.

Test: Follow the instructions carefully. Use the sheet provided to record your data.

- 1.) In the Population viewer, flip to Settings and set the following parameters:
 - World size: 60x60
 - Per site mutation rate: 1%
 - Place offspring: Near parent
 - Resources: All (checked)
 - Repeatability mode: Experimental
 - Pause run: At update 2000
- 2.) Drag the @ancestor organism into the dish and click Run. The experiment should pause automatically at 2000 updates.
- 3.) In your data sheet, record:
 - a. Population size and average fitness for your population.
 - b. Sketch (or export and copy/paste) the graph showing fitness as a function of update.
 - c. Describe what your Petri dish looks like (i.e., are there a lot of different colors? Are the different colors grouped together, etc.?).
- 4.) Repeat steps 1 – 3 at 5%, 10%, and 15% mutation rates.

Results and discussion: As a team, discuss whether or not *your team's data* support your team's hypothesis.

Contribute the fitness and population size data from each of your four experiments to the class database. (Your instructor will inform you as to how the data should be submitted to make up the class data.) The instructor(s) will process the class data and prepare graphs that will be explored as a group in class during Part 1.2.

Part 1.2 Exploring class data

- 1.) Incorporate into your team's data sheet the graphs of the class data for both Avg. Fitness and Population Size (at Update 2000) at all four mutation rates.
- 2.) As a team comment on the relationship of your team's data to the data collected by the class as a whole.
- 3.) As a team, discuss whether or not the *class data as a whole* support your team's hypothesis.
- 4.) Given your team's results, and the results of the class as a whole, would your team modify its original hypothesis in any way, or keep it the same? Explain your answer.





Discussion questions:

- 1.) Did all of the student teams in the class get the same results for their three trials with respect to average fitness and population size? Why or why not? How can you explain these results?
- 2.) If mutations are random, why do the results of our investigation not appear random?
- 3.) How is it that in some instances average fitness increased at a mutation rate of 15%, while in other instances average fitness decreased?

Part 2. Further exploration

In the space below, work as a team to develop an idea to test using Avida-ED pertaining to mutations, mutation rate, and fitness.



Team Data Sheet

Team Name: _____

Team Members: _____

Hypothesis:

Individual Team Data

1. Mutation Rate = 1%

a. Avg. Fitness at Update 2000: _____

b. Pop. Size at Update 2000: _____

c. Graph of Avg. Fitness as a function of Update

d. Picture of your plate

e. Description of the plate (50 words)

2. Mutation Rate = 5%

a. Avg. Fitness at Update 2000: _____

b. Pop. Size at Update 2000: _____

c. Graph of Avg. Fitness as a function of Update

d. Picture of your plate

e. Description of the plate (50 words)

3. Mutation Rate = 10%

a. Avg. Fitness at Update 2000: _____

b. Pop. Size at Update 2000: _____

c. Graph of Avg. Fitness as a function of Update

d. Picture of your plate

e. Description of the plate (50 words)





4. Mutation Rate = 15%

- a. Avg. Fitness at Update 2000: _____
- b. Pop. Size at Update 2000: _____
- c. Graph of Avg. Fitness as a function of Update
- d. Picture of your plate
- e. Description of the plate (50 words)