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Proportions, not numbers - a computer simulation that facilitates students' understanding of natural selection

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Students hold several misconceptions related to natural selection and evolution. They therefore often find it difficult to explain mechanisms and predict when evolution will occur. For example, if a population of white rabbits is preyed upon by wolves, students may state that evolution has occurred because the number of rabbits decreased (even though the proportion of white rabbits stayed the same). Alternatively, students may state that evolution will occur because rabbits are forced to change fur color. This activity gives students an opportunity to confront their misconceptions. Students first predict the outcome of different scenarios, e.g. in the presence or absence of variation within a population and in the presence or absence of selection pressures. Thereafter, they run a simulation and graph changes in the number as well as the proportion of individuals with different traits over time to test their hypotheses. The activity can be expanded upon in several ways and is suitable for introductory biology for both majors and non-majors. The exercise can be used in lab, in lecture, or be assigned as an assignment.

Keywords: natural selection, evolution, population growth, exponential growth, selection pressure, simulation, misconceptions

Link To Supplemental Materials: https://doi.org/10.37590/able.v42.sup30

Introduction

Students hold several misconceptions related to natural selection and evolution. They therefore often find it difficult to explain mechanisms and predict when evolution will occur. This computer simulation activity gives students an opportunity to confront their misconceptions in natural selection and evolution. It facilitates students' understanding of the difference between the number of individuals with a certain trait and the proportion of individuals with a certain trait. Furthermore, it gives students practice forming hypotheses and comparing them with their results, as well as drawing graphs and drawing conclusions from them. After the activity students should be able to: 1) Explain how natural selection works to someone with little background in biology, 2) Predict whether or not natural selection is likely to occur given a certain situation or circumstance, 3) Set up a hypothesis and compare it to results, 4) Determine if natural selection and/or evolution has taken place based on population data, 5)

Explain why variation, inheritance and selection pressure are necessary for natural selection to occur, 6) Calculate proportions, and 7) Present data using suitable graphs. The exercise can be completed as a 2-3 hour lab, or be assigned as an assignment and then followed up upon in class.

The activity uses an online free simulation program called PhET Interactive Simulations. The natural selection simulation (https://phet.colorado.edu/en/simulation/natural-selection) simulates population growth of rabbits under different scenarios. The simulation provides the option of applying several different selection pressures, e.g. predation, food limitation, and competition. However, this specific activity is using predation as the only selection pressure.

Students first predict the outcome when there is no variation (i.e. no new mutations) or selection pressures in a population. In this scenario all rabbits are white and there is no predation. Students are asked to set up a hypothesis, to which they can compare the results after completing the simulation. Thereafter, they run the simulation, collect data, and graph changes in the number as well as the proportion of individuals over five generations to test their hypothesis (see Notes for the Instructor below for more information about how to collect data from the simulation). After completing the graphs students are asked to compare their graphs with their hypothesis and to explain whether or not the data supports their hypothesis. They are also asked whether or not there is evidence of natural selection and evolution in the population. While students typically have no problems predicting that the number of white individuals will increase with time, some students may also predict that the proportion of white rabbits will increase.

After completing the first simulation (as described above), students predict the outcome of the second scenario, i.e. when the population is exposed to a predator, but when there is still no variation (i.e. no new mutations) in the population. The same procedure is used as in the first simulation (see Notes for the Instructor below for more information about how and when to add predators during the simulation). Many students may predict that evolution will occur in this scenario because it is common for students to think that evolution happens because organisms have to change in order to survive. In this case students may think that the rabbits will be forced to change fur color in order to survive. In addition, some students are likely to conclude that evolution has occurred in this scenario as the number of individuals decreased with time, even though the proportion of white rabbits stayed the same.

In the third simulation students predict the outcome if a mutation (in this case brown fur) is introduced into the population while the population is exposed to a predator (see Notes for the Instructor below for more information about how to add a mutation during the simulation).

This particular activity includes the three scenarios described above. However, as mentioned, this activity can be built upon by adding additional scenarios. For example, students can predict what would happen if a new mutation is introduced into a population that is not exposed to a selection pressure or whether or not it matters if the new mutation is dominant or recessive.

I typically require students to write up a report based on this activity, including the hypotheses, graphs and conclusions. As such, this activity could also serve as a great introduction to basic report writing.

Student Outline

Learning outcomes

After this lab you should be able to:

1. Explain how natural selection works to someone with little background in biology.

2. Predict whether or not natural selection is likely to occur given a certain situation or circumstance

3. Set up a hypothesis and compare it to results.

4. Determine if natural selection and/or evolution has taken place based on population data.

5. Explain why variation, inheritance and selection pressure are necessary for natural selection to occur.

6. Calculate proportions.

7. Present data using suitable graphs.

Introduction to natural selection and evolution

Natural selection and evolution

Natural selection is a mechanism that leads to **evolution** in a population. Individuals in a population that possess traits that are beneficial are more likely to survive and therefore have more offspring. Therefore, over time, the number as well as the proportion of individuals with beneficial traits (the number of individuals with a specific trait/the number of total individuals) will become higher than the proportion of individuals with other (potentially disadvantageous) traits. This mechanism is referred to as **natural selection**. **Evolution** is defined as a **change in the proportion** of individuals with a specific trait from one generation to the next. Therefore evolution occurs in populations, but **never** in individuals.

Variation in traits

For natural selection to occur there has to be a variation in traits among the individuals in a population. Variation in a trait within a population arises if there are more than one gene variety (allele) present for a specific trait. For example, if the color of fur in rabbits is determined by one gene with two gene varieties (alleles), one that produce a protein that makes the fur white (we call that allele F) and one that makes the fur brown (we call that allele f). If the white allele is dominant, rabbits with genotypes FF and Ff will have white fur and rabbits with genotypes ff will have brown fur. Because this population will have some rabbits with white fur and some with brown fur, there is a variation of fur color in this population. The ultimate source of different alleles is mutations (changes in DNA). A mutation of an allele may create a new gene variety (allele) for a specific gene.

Inheritance

For natural selection to occur offspring have to inherit traits from their parents. Traits that are not inherited (i.e. traits that are not determined by genes, e.g. traits that are acquired during an individual's lifetime such as muscle mass), will not be affected by natural selection. If traits are not inherited by offspring, the number or proportion of individuals with those traits will not change from one generation to the next.

Selection pressure

Selection pressure is also essential for natural selection to occur. However, evolution (changes in the proportion of individuals with certain traits) can take place without selection pressure due to genetic drift, mutations, or migration. A selection pressure or a selection factor is a factor that causes the survival and reproductive rates to vary among individuals in a population due to their traits. An example of a selection pressure is predation. Individuals in a population with a trait that allows them to camouflage and thus hide from predators will likely have higher survival rate and thus higher reproductive rate. The proportion of individuals that can camouflage is thus likely to increase from one generation to the next. Another example of selection pressure would be competition for food. Individuals in a population with a trait that allows them to better compete for food will likely have higher survival and reproductive rates. The proportion of individuals that can better compete for food is thus likely to increase from one generation to the next.

The computer simulation

For this activity you will use the following computer simulation: https://phet.colorado.edu/en/simulation/natural-selection to explore natural selection in a population of rabbits. You will be able to explore what happens to a population if a population is exposed to a selection pressure such as predation and what happens when a mutation is introduced into a population. You will first set up a hypothesis that predicts how the number and proportion of individuals with different traits will change from one generation to the next due to the nature of their traits and whether or not they are exposed to the selection pressure. Thereafter you will collect data and draw graphs in order to conclude whether or not your hypothesis is supported. Your data should be collected using the posted spreadsheet.

Simulation 1: No variation in traits without selection pressure

In the first simulation you will explore what happens to a rabbit population if all rabbits are white, i.e. there is no variation in traits and no new mutations are introduced within a population and if there is no selection pressure (i.e. the population is not exposed to predation). Please complete the activity according to the following order:

1. Set up a hypothesis for your first simulation, i.e. predict how the number and proportion of white rabbits will change with time if there is no variation, i.e. no new mutations and no selection pressure. Use the following structure for your hypothesis and fill in the blanks according to your prediction: If there is no variation or selection pressure, then the number of white rabbits is likely to _____ with time and the proportion of white rabbits is likely to _____with time.

2. Start the simulation. Click "**Add a mate"** right away so that there are two rabbits in the population. This will allow for reproduction. Use the spreadsheet to collect data before and after reproduction for five generations (stop after the 5th reproduction event). The number of individuals in the population before and after reproduction can be found in the graph. Zoom in to be able to get more precise data. Make sure that you collect data both right before and right after reproduction, i.e. before and after each new generation. Calculate the proportion of white individuals (i.e. the number of white individuals/the number of total individuals) using an Excel formula.

3. Graph the number of white individuals and the proportion of white individuals in the population over time. Because the y-axis of these two graphs will be different you need to make two separate graphs. On your x-axis you will have "Before 1st reproduction", "After the 1st reproduction" etc.

4. **After you have completed your graphs answer the following questions:** Compare the two graphs with your hypothesis. Does the data support your hypothesis? Is there evidence of natural selection and evolution in this population? Explain why or why not.

Simulation 2: No variation in traits with added selection pressure

In the second simulation you will explore what happens to a rabbit population if all rabbits are white, i.e. there is no variation in fur color, but we add a predator (i.e. selection pressure).

1. Set up a hypothesis for your second simulation, i.e. predict how the number and proportion of white rabbits will change with time if there is no variation, i.e. all rabbits are white and we add a predator (selection factor). Use the following structure for your hypothesis and fill in the blanks according to your prediction: If all rabbits are white and we add a predator, then the number of white rabbits is likely to _____ with time and the proportion of white rabbits is likely to _____with time.

2. Start the simulation. Click **"Add a mate"** right away so that there are two rabbits in the population. This will allow for reproduction. **Add wolves <u>after</u> the first reproduction event.** Do not add them earlier than that. Use the spreadsheet to collect data before and after reproduction for five generations (stop after the 5th reproduction event). Calculate the proportion of white individuals (i.e. the number of white individuals/the number of total individuals) using an Excel formula.

3. Graph the number of individuals and the proportion of individuals with white fur in the population over time. Because the y-axis of these two graphs will be different you need to make two separate graphs. On your x-axis you will have "Before 1st reproduction", "After the 1st reproduction" etc.

4. **After you have completed your graphs, answer the following questions:** Compare the two graphs with your hypothesis. Does the data support your hypothesis? Is there evidence of natural selection and evolution in this population? Explain why or why not.

Simulation 3: Variation in traits (Brown fur is added as a dominant trait) with added selection pressure

In the third simulation you will explore what happens to a rabbit population if a mutation is introduced into the population that causes some rabbits to be born with brown fur and if we add a predator (i.e. selection pressure).

1. Set up a hypothesis for your third simulation, i.e. predict how the number and proportion of white and brown rabbits will change with time if there is a predator present. Use the following structure for your hypothesis: If there is a predator present and brown fur is the dominant trait, the number of white rabbits will _____ with time and the number of brown rabbits will _____ with time. The proportion of white rabbits will therefore _____ with time and the proportion of brown rabbits will _____ with time.

2. Start the simulation. Click **"Add a mate"** right away so that there are two rabbits in the population. This will allow for reproduction. Click **Add brown fur as a mutation** right away. Ensure that brown fur is set as the dominant trait and white fur as the recessive trait. **Add wolves after the first reproduction event.** Do not add them earlier than that. Use the to collect data before and after reproduction for five generations (stop after the 5th reproduction event). Calculate

the proportion of white individuals (i.e. the number of white individuals/the number of total individuals) using an Excel formula.

3. Graph the number of white and brown individuals in one graph and the proportion of white and brown individuals in a separate graph. On your x-axis you will have “Before 1st reproduction”, “After the 1st reproduction” etc.

4. **After you have completed your graphs answer the following questions:** Compare the two graphs with your hypothesis. Does the data support your hypothesis? Is there evidence of natural selection and evolution in this population? Explain why or why not.

Materials

Each student needs to have access to a computer as well as an internet connection.

Notes for the Instructor

It is a good idea for instructors to run through the three scenarios before using this activity. The simulation program is very user friendly, but it is important to get familiar with the different options ahead of time. Also, the collection of data from the graph may be confusing for some students so it is important that instructors can help out.

How to run the simulations

Some of the information below is included in the "Student Outline" above, but included here as well for instructors.

Opening the simulation: The simulation can be found on the following website: https://phet.colorado.edu/en/simulation/natural-selection The simulation program does not need to be downloaded, you can just play it in your browser. For this activity you will use the "intro" option.

Getting started: All simulations are started by adding a second individual so that reproduction can occur. This is done by clicking on "**Add a mate"**. Before you add a mate, nothing will happen. Once you add a second individual, the rabbits will reproduce every 10 seconds. As expected, if no selection pressure is introduced, the rabbit population will grow exponentially.

Adding selection pressure: The selection pressures are referred to as environmental factors. The only type of selection pressure used in this activity is predation by wolves. Start the simulation by adding a second individual as usual. Add wolves by clicking on the wolf **after the first reproduction event.** Do not add them earlier as the wolves will eat the rabbits before they have a chance to reproduce. After adding wolves the rabbit population typically dies out after the fourth generation. If you find that the rabbit population dies out earlier than that, you can experiment with adding wolves after the second reproduction.

Adding a mutation: In order to add variation in traits to the population, you need to add a mutation. Click on **"Dominant brown fur"** in the Add Mutation menu **before you add a mate**.

Collecting data: Students should enter the collected data into the student spreadsheet (Appendix A). Each simulation should be stopped after five generations (right after the 5th reproduction) as this time provides students with enough data to draw conclusions from their graphs. In order to compare the outcomes for the different scenarios, the number of individuals in the population should always be collected right before and right after each reproduction event, i.e. before and after each new generation. The number of individuals at any specific time can be read from the graph. The numbers collected can be approximate as it can be difficult to read the exact number of individuals in the graph. However, students can zoom in and get more precise data. The proportion of individuals with a certain trait can also be found by selecting "Proportions" in the menu on the right. However, I encourage students to calculate the proportions in their spreadsheet instead. This allows them to practice setting up a simple formula in their spreadsheet and students are more likely to understand what "proportions" actually means if they calculate it themselves. In addition, graphing the number of individuals and the proportion of individuals becomes easier if the collected data (i.e. the number of individuals) and the calculated data (i.e. the proportion of individuals) are entered as demonstrated in the instructor spreadsheet (see Appendix B).

Graphing the data: The specifics on how to make graphs are not explained here. If students need an explanation on how to make graphs, consider adding that to this activity. The spreadsheet is designed to make it easy for students to graph the data collected in this activity. Please note that an empty spreadsheet has been included for students to use (Appendix A). There is also a demonstration spreadsheet with data for instructors (Appendix B). When graphing the number of individuals and the proportion of individuals with white fur in the population over time students should be reminded that two separate graphs are required as the y-axis of these two graphs will be different.

About the Author

Malin Hansen is an instructor in introductory biology. She has an interest in science education research and is specifically interested in learning how students' mindset affects the way they learn science. She uses active learning to help her students improve their understanding of challenging concepts in biology as well as of how learning works in general.

Appendices

Appendix A: Student spreadsheet.

Appendix B: Demonstration spreadsheet for instructors.

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