EvoExplorer
Textual Content

[Homepage]

What is evolution?

Darwin defined evolution as "descent with modification", referring to the idea that different species share common ancestors and these descendant species are different – modified – from the ancestral species. In narrower terms, evolution can be defined as the change in genetic composition of a population from generation to generation. Evolution can be broken down into **microevolution** (changes in gene frequency in a population from one generation to the next) and **macroevolution** (the descent of different species from a common ancestor over many generations). Evolution is responsible for the incredible biodiversity we see on earth.

This learning web app focuses on helping you build your knowledge, comprehensively understand and distinguish the nuances in the concepts of evolution. Now, let's explore!

[Natural Selection Unit]

[Introduction]

Natural selection: adaptive evolution

In biology, **adaptation** has two meanings: it can refer to a state that has evolved because it enhances a population's relative **reproductive success**, and it can also refer the process that produces that state. Natural selection is the only mechanism that consistently results in adaptations. Natural selection describes a process in which some individuals with certain inherited traits survive and reproduce at higher rates compared to other individuals *due to* those inherited traits. In response to **selection**, genetic traits that improve reproductive success increase in frequency (in the population) over many generations. In other words, natural selection works on **heritable phenotypic variation** to produce adaptive change.

With a growing human population and increasing global urbanization, human activities have significant impacts on many organisms. In this web learning application, we will consider how human activities may provide selection for or against organismal traits.

Learning outcomes:

- Understand the concept of natural selection
- Understand the necessary conditions for natural selection to occur: 1) genetic variation 2) heritability and 3) differential survival
- Understand how generation time may affect adaptation by natural selection

[Pre-test on misconceptions]

How well do you know natural selection?

Identify each statement as true or false and justify your choice.

(A) Natural selection occurs because the organism *needs* to adapt
(B) Natural selection will result in an organism being a perfect match to the environment
(C) Individuals cannot adapt
(D) Evolution by natural selection can only occur slowly
(E) Natural selection is not random

[Module 1]

Heritability as a requirement for adaptation

Natural selection is a process that occurs to a *population* over many generations and can only lead to **adaptation** in a population if the traits that are selected for or against are **heritable**.

[BUTTON: BEGIN CASE STUDY 1 →]

Scenario

[ILLUSTRATION 1: Depiction of industrial revolution and smoke pollution]

The Industrial Revolution was a transition from hand production methods to machines, new chemical manufacturing, and steam-powered factories. It began in Great Britain and occurred in the period from the 18^{th} to 19^{th} century. While it increased the standard of living for the general population, it also led to a significant and sudden increase in levels of smoke pollution due to coal consumption in factories.

[ILLUSTRATION 2: Depiction of black and white peppered moths on pre-industrial revolution light-coloured tree bark]

Before the Industrial Revolution, the black peppered moth was rare amongst the population since light-coloured moths were better able camouflage with the light-coloured lichens and English tree bark.

[ILLUSTRATION 3: Depiction of black and white peppered moths on sooty bark]

However, within the first few decades of the Industrial Revolution in England, the trees darkened due to the soot emitted from coal-burning factories and light-coloured lichens died from toxic emissions. Light-coloured moths no longer blended in with the darkened environment and were easily preyed upon by birds, whereas, dark-coloured moths were able to camouflage. This led to an increase of the dark-coloured moth in the population, peaking at 98% within approximately 50 years.

[BUTTON: NEXT →]

Predict

Specific **alleles** are responsible for either colour (dark or light) we see in the peppered moths, meaning that both dark and light colour traits are heritable.

Now as a scientist, you are fascinated by how heritability of colour will affect the population as time passes after the Industrial Revolution. You decide to consider two possible scenarios:

[BUTTON: PREDICT →]

Scenario A: At the end of the Industrial Revolution, the moth population consisted of 90% dark coloured moths. Due to efforts to reduce atmospheric pollution, the barks of trees have become light again and light-coloured lichens are flourishing. If colour is heritable, what colour do you expect to see most of in the moth population after a few decades of reduced pollution?

a) No significant change
b) Decrease in the percentage of population with dark colours
   Increase in the percentage of population with light colours
c) Increase in the percentage of population with dark colours
   Decrease in the percentage of population with light colours

[BUTTON: PREDICT →]

Scenario B: If the population at the end of Industrial Revolution consisted of 50% dark coloured moths, and dark and light colour traits were non-heritable, what colour do you expect to see most of in the moth population after a few decades following the Industrial Revolution in which the pollution is reduced (light-coloured tree bark and light-coloured lichens)?

a) No significant change
b) Decrease in the percentage of population with dark colours
   Increase in the percentage of population with light colours
c) Increase in the percentage of population with dark colours
   Decrease in the percentage of population with light colours

[BUTTON: LET'S EXPLORE →]

Experiment

Experiment A:

First, let's look at scenario A in which colour is heritable.

At the end of the Industrial Revolution, the moth population consisted of 90% dark coloured moths. Due to efforts to reduce atmospheric pollution, the barks of trees have become light again and light-coloured lichens are flourishing.

First, adjust the toggle to "trait is heritable".

[BUTTON: NEXT →]

You predicted that if the trait is heritable, then < student prediction >.

Peppered moths have a generation time of one year. To observe the overall trend, you decide to collect data on the moth population for the next 20 years following the end of the Industrial Revolution as the tree barks have become lighter.

Record how many individuals in the population are light coloured and dark coloured in the starting population (generation 0). Click "play" and pause every 2 years to continue collecting data.

Notebook inputs:

- Generation number: input number
- Number of individuals with trait: input number
- Number of individuals without trait: input number

Generation 0: Industrial revolution, population consists of 90% dark, 10% light

Generation 1-20: Population eventually consists of 90% light, 10% dark

[BUTTON: EXPERIMENT B →]

Experiment B:

Let's look at scenario B in which colour is non-heritable.

Consider a hypothetical scenario in which the population at the end of the Industrial Revolution consisted of 50% dark coloured moths.

Adjust the toggle to "trait is non-heritable".

[BUTTON: NEXT →]

You predicted that if the trait is non-heritable, then < student prediction >.

Peppered moths have a generation time of one year. To observe the overall trend, you decide to collect data on the moth population for the next 20 years following the end of the Industrial Revolution as the tree barks have become lighter.

Record how many individuals in the population are light coloured and dark coloured in the starting population (generation 0). Click “play” and pause every 2 years to continue collecting data.

Notebook inputs:

- Generation number: input number
- Number of individuals with trait: input number
- Number of individuals without trait: input number

Generation 0: Industrial revolution, population consists of 50% dark, 50% light

Generation 1-20: Moth population remains approximately 50% dark despite selection pressure because the trait can’t be selected for (you could still potentially get light-coloured moths).

[BUTTON: RESULTS →]

[POPULATION GRAPHS DEPICTING THE RESULTS FROM THE TWO EXPERIMENTS]

You’ve hired a statistician to help you plot the data. Take a look at your plotted data to observe the trends. Note the changes between the two populations.

Note: As you progress to higher-level evolution courses, you will discover that heritability is not binary and is rather complex. However, for the purposes of introducing heritability in the context of natural selection for this app, we’ve presented heritability as binary (present or not present).

Now that you have your data, it’s time to analyze them!

[BUTTON: ANALYZE →]

Analysis Questions

To be written. Questions should direct students to the following:

- Misconception that (A) natural selection occurs because the organism *needs* to adapt
- Heritability as a requirement for adaptation by natural selection; in this case study, if colour is not heritable than no adaptation occurs as shown by scenario B in which no trait is selected. Individuals *can* be selected for (more black-coloured moths die in a light environment) but because the trait is not heritable, light-coloured moths still persist in subsequent generations.

[BUTTON: FINISH]

[Module 2]

Genetic variance as a requirement for adaptation

Natural selection is a process in which individuals with certain heritable traits have greater relative survival rates and reproductive success in a specific environment due to those traits. The evolutionary result of natural selection is that alleles encoding for those traits increase in frequency in the population over many generations. In other words, while natural selection does act on individuals, the evolutionary change caused by natural selection is only apparent when considering a population of organisms over time.

The phenotypic variation we can perceive may reflect **genetic variation** which is the difference between individuals in the composition of their genes and other DNA sequences. However, not all phenotypic variation results from genetic differences and therefore is not heritable. Thus, only **phenotypic variation with a genetic basis** provides the raw material for evolutionary change and is an essential prerequisite for evolution by natural selection.

[BUTTON: BEGIN CASE STUDY 2→]

Scenario

[ILLUSTRATION 1: Depiction of heavy metals in soil]

Heavy metals, such as copper, zinc and nickel, at low amounts, are micronutrients for plants. However, toxic levels of heavy metals can occur either naturally or due to human activities such as mining.

[ILLUSTRATION 2: Depiction of plants near mines]

Surprisingly, heavy metal polluted soils are never completely bare, and it is possible to find plants capable of growing and reproducing in places like mine dumps (tailings) despite the environmental stress. Although some species of grasses have shown potential to rapidly evolve tolerance to the toxic levels of heavy metals, other species have not.

[BUTTON: NEXT →]

Predict

Now as a scientist, you are curious about how genetic variation will affect the population as time passes after environmental change. You have found an *uncontaminated* area with two populations of plants.

Management at a nearby mining site has plans to start dumping mine tailings in this area, so you decide to investigate these two populations of plants and observe what happens after the soil becomes contaminated with toxic amounts of copper.

Grass population A has greater genetic variation, varying genetic traits for heavy metal tolerance including copper tolerance is present in a very small percentage of the population

Grass population B has lower genetic variation, currently no genetic trait for copper-tolerance is present.

[BUTTON: PREDICT →]

What will happen to grass population A once the workers start dumping mine tailings in the area, for a) the first following generation and b) after a couple of generations?

[BUTTON: PREDICT →]

What will happen to grass population B once the workers start dumping mine tailings in the area, for a) the first following generation and b) after a couple of generations?

[BUTTON: LET'S EXPLORE →]

Experiment

Experiment A:

First, let's look at grass population A which has greater genetic variation.

Adjust the toggle for greater genetic variation in order to observe grass population A.

Select traits in the population to see what traits are present in the starting population and how many individuals have them. Record them in your notebook.

[BUTTON: NEXT →]

You predicted that in population A, < student prediction >.

This grass population has a generation time of 26 weeks. To observe the overall trend, you decide to collect data on the grass population for the next 10 years both before and after soil contamination with copper wastes.

Click "play" and pause every 2 generations to record how many individuals in the population have or don't have copper tolerance.

Notebook inputs:

- Generation number: input number
- Number of individuals with trait: input number
- Number of individuals without trait: input number

Generation 1-4: Individuals with copper tolerance at a small percentage

Generation 4: Soil contamination

Generation 5-20: Individuals with copper tolerance is selected

[BUTTON: EXPERIMENT B →]

Population B:

Grass population B has lower genetic variation.

Adjust the toggle for lower genetic variation in order to observe grass population B. Record down what traits are present in the starting population and how many individuals have them.

Select traits in the population to see what traits are present in the starting population and how many individuals have them. Record them in your notebook.

[BUTTON: NEXT →]

You predicted that that in population B, < student prediction >.

This grass population has a generation time of 26 weeks. To observe the overall trend, you decide to collect data on the grass population for the next 10 years both before and after soil contamination with copper wastes.

Click "play" and pause every 2 generations to record how many individuals in the population have or don't have copper tolerance.

Notebook inputs:

- Generation number: input number

- Number of individuals with trait: input number
- Number of individuals without trait: input number

Generation 1-4: All individuals with no copper tolerance

Generation 4: Soil contamination

Generation 5-20: Individuals die-off indiscriminately, population diminishes drastically

[BUTTON: RESULTS→]

[POPULATION GRAPHS DEPICTING THE RESULTS FROM THE TWO EXPERIMENTS]

You've hired a statistician to help you plot the data. Take a look at your plotted data to observe the trends. Note the changes between the two populations.

Now that you have your data, it's time to analyze them!

[BUTTON: ANALYZE →]

Analysis Questions

To be written. Questions should direct students to the following:

- Misconception (A) natural selection occurs because the organism *needs* to adapt
  - Heritable phenotypic trait must be present in the population prior to change in environment for natural selection to occur, i.e., natural selection cannot create adaptations from scratch, it only modifies
- Misconception (C) individuals can adapt
  - Adaptation is a product of evolution by natural selection. Natural selection is a process that involves changes in the genetic makeup of populations over time, therefore, populations can evolve and species can adapt, but individuals cannot evolve or adapt in their lifespan.
- Natural selection requires BOTH heritability and phenotypic variation and will lead to adaptation when there is a positive (or negative) correlation between a heritable trait and reproductive success. Note: When there is no correlation between a trait and reproductive success, it is called genetic drift. Genetic drift is a process in which the frequency of an allele in the population changes due to random sampling of organisms. Genetic drift has a large effect on small population size. For the purposes of this unit, we have disregarded the effect of genetic drift on our experiment sample size.
- The amount of genetic variation can affect differences in survival and reproductive success in the population.
  - Genetic variation may lead to differential survival of individuals with various heritable phenotypes under various environmental conditions. Greater genetic variation means more potential for the presence of beneficial mutations/genetic traits to select from (greater range of differential survival of individuals with various heritable phenotypes under various environmental conditions).

[BUTTON: FINISH]

[Module 3]

How generation time affects the rate of adaptation

Climate change has led to temperature increases, earlier springtime, and rising sea levels in certain areas. This has huge impacts on many animals and plants. The **generation time** (the average time between two consecutive generations in the lineages of a population) of these species play a role in how fast they can adapt to the rapidly changing climate.

During meiosis, **recombination** results in new combinations of alleles on chromosomes and **independent assortment** results in gametes with different combinations of maternal and paternal alleles. This produces great potential genetic variation. Therefore, sexual species with shorter generation times generally have faster rates of molecular evolution compared to species with longer generation times, because they undergo these events of recombination and assortment more often per year, resulting in greater genetic variation being present in the population and greater potential for adaptive traits to be selected for.

[BUTTON: BEGIN CASE STUDY 3 →]

Scenario

[ILLUSTRATION 1: Depiction of salmon life cycle]

Species A – Pink Salmon

The timing of events in the salmon life cycle is often adapted to local thermal conditions in freshwater rivers, streams and lakes, and the ocean. In particular, the growth of juvenile salmon requires cold, oxygenated water.

In the spring, the eggs hatch, and tiny pink salmon (called alevins at this stage) rely on the yolk sac of the egg attached to their bellies. After a few months, they will have consumed all the yolk sac and grown in size. The fish at this stage are called fry and pink fry will immediately travel to the ocean and stay there for 18 months. Once a female pink salmon reaches about two years old, they migrate back to their home stream to spawn, usually sometime between July to October. This means that pink salmon have a generation time (the time between consecutive generations of a lineage) of 2 years.

[BUTTON: NEXT →]

With climate change, spring occurs earlier and waters become warmer each year, which means that populations of pink salmon that migrate later to spawn may be laying eggs in less-than-optimal thermal conditions.

[BUTTON: NEXT →]

[ILLUSTRATION 1: Depiction of polar bear life cycle]

Species B – Polar Bears:

The native range of the polar bear lies largely within the Arctic Circle. While polar bears can sometimes be found on the tundra, they usually live near water and travel on floating sheets of sea ice to hunt their favourite food, harp seals.

While polar bears begin mating in April and May, fertile eggs remain in a suspended state (i.e., do not implant) until August or September, and only if the mother has enough fat to sustain herself and her cubs during the denning season. Polar bears have an average generation length of 11.5 years.

[BUTTON: NEXT →]

With rising temperatures, sea ice melts earlier each year, which makes it difficult for polar bears to hunt and limits them to the shore before they have built enough fat reserves to survive the period of scarce food in late summer and early fall. Insufficient nourishment leads to lower reproductive rates in adult females and lower survival rates in cubs and young bears.

[BUTTON: NEXT →]

Predict

Now as a scientist, you are curious about how generation time can potentially affect how quickly adaptations arise. First, calculate how many generations the pink salmon and polar bears would have gone through in the past 34 years of increasing temperatures, earlier springtime and rising sea levels.

[BUTTON: NEXT →]

You've discovered a small percentage of the population migrate earlier while most migrate later. You suspect that earlier migration may allow the pink salmon to avoid the warmer temperatures of earlier spring and contribute to overall reproductive success. In addition, you are pleased to find that migration timing has a genetic basis.

However, you have yet to discover an advantageous genetic trait that would lead to greater chances of survival and reproductive success for the polar bear in a warmer climate.

[BUTTON: PREDICT →]

Predict the changes you would expect between the two populations in terms of population size and percentage of advantageous traits in 34 years with warmer climate.

[BUTTON: LET'S EXPLORE →]

Experiment / Visual representation

In 34 years, pink salmon population will have gone through 17 generations whereas the polar bears will have gone through approximately 3 generations.

Knowing that a small percentage of the pink salmon population possess traits that leads to earlier migration which may help them avoid the warm temperatures of earlier spring, you predicted that < student prediction >.

Toggle towards "short generation time" to observe changes in the salmon population over time.

[BUTTON: NEXT →]

To observe the overall trend, you decide to collect data on the salmon population for 34 years.

Record how many individuals in the population have or don't have an advantageous trait for warmer climate in the starting population (generation 0). Click "play" and pause every 2 years to continue collecting data.

Notebook inputs:

- Generation number: input number
- Number of individuals with trait: input number
- Number of individuals without trait: input number

Generation 0-1: Small percentage of population with early migration

Generation 1: Temperature increase / early springtime starts occurring

Generation 3-17: Selection for early-migrators, population size remains stable

[BUTTON: EXPERIMENT B →]

Next, you plan to observe the polar bears. You have yet to discover advantageous genetic traits that would lead to greater chances of survival and reproductive success for the polar bear in a warmer climate. Therefore, you predicted that < student prediction >.

Toggle towards "long generation time" to observe the changes in the polar bear population over time.

[BUTTON: NEXT →]

To observe the overall trend, you decide to collect data on the polar bear population for 34 years.

Record how many individuals in the population have or don't have an advantageous trait for warmer climate in the starting population (generation 0). Click "play" and pause every 2 years to continue collecting data.

Notebook inputs:

- Generation number: input number
- Number of individuals with trait: input number
- Number of individuals without trait: input number

Generation 0-1: Population all don't have any advantageous trait

Generation 1: Temperature increase / early springtime starts occurring

Generation 2-3: Population still don't have any advantageous trait; population size starts diminishing

[BUTTON: RESULTS →]

[POPULATION GRAPHS DEPICTING THE RESULTS FROM THE TWO EXPERIMENTS]

You've hired a statistician to help you plot the data. Take a look at your plotted data to observe the trends. Note the changes between the two populations.

Now that you have your data, it's time to analyze them!

[BUTTON: ANALYZE →]

Analysis Questions

To be written. Questions should direct students to the following:

- Misconception (A) natural selection occurs because the organism *needs* to adapt
- Misconception (D) natural selection only occurs slowly
- Misconception (B) natural selection will result in an organism being a perfect match to the environment
- From 1970-1980, the progeny of early-migrating adult pink salmon had lower early marine survival than progeny of later-migrating fish. Has early migration adaptation allowed the pink salmon population to be a perfect match to the environment? Have their adaptations made them "better" than the previous generations? Are there any situations in which their adaptations may not be ideal?

[BUTTON: FINISH]

[Module 4]

Bringing it all together

Let's explore how a combination of factors can potentially affect how quickly adaptation by natural selection can occur.

[BUTTON: BEGIN CASE STUDY 4 →]

Scenario

Insects spread disease and destroy millions of tonnes of crops each year. Farmers often deal with this problem by applying insecticide to their crops. However, the continual use of insecticide has resulted in increased resistance in the insect population to insecticides that were previously effective at controlling the pest. Let's explore how the three factors we've previously investigated (heritability, genetic variation, and generation time) interact to affect how slowly or quickly insecticide resistance may arise.

[BUTTON: PREDICT →]

Predict

With continuous application of insecticide to a crop that is frequented by a certain population of insects, what combination of factors should the insects possess that would potentially allow the population to rapidly evolve by natural selection?

- The insect population should have the following:
  - Trait for the upregulation of a gene that codes for a protective enzyme that breaks the pesticide into less toxic chemicals: heritable or non-heritable?
  - Genetic variation: high or low?
  - Generation time: short (10 days) or long (40 days)?

[BUTTON: NEXT →]

Experiment

With continuous application of insecticide to the insect population's preferred crop, you predicted that if the population had < student prediction >, they would potentially be able to rapidly evolve insecticide resistance by natural selection.

Adjust the three toggles according to your prediction and observe what happens in 2 years. Record in your Notebook differences you observe in the percentage of population with the trait for the protective enzyme and whether insecticide resistance occurs and when the population is 90% resistant.

Notebook inputs:

- Trial number: input number
- Combination of factors: heritable or non-heritable trait / high or low genetic variation / short or long generation time
- Population evolves insecticide resistance: yes or no
- Percentage of population with trait for protective enzyme: input number
- Percentage of population with trait for protective enzyme: input number
- Generation of when the population becomes 90% resistant: input number
- Time of when the population becomes 90% resistant (automatically calculated based on number input previously)

If you observed slow or no evolution, try other combinations of factors to see if rapid evolution can occur. Remember to save your trials for you to consult later in your analysis.

[Population graphs showing the following:]

1. **Heritable trait, short generation, high genetic variation**: rapid evolution
2. Heritable trait, short generation, low genetic variation: wipe-out
3. Heritable trait, long generation, high genetic variation: slow evolution

4. Heritable trait, long generation, low genetic variation: wipe-out
5. Non-heritable trait, short generation, high genetic variation: no selection
6. Non-heritable trait, short generation, low genetic variation: no selection
7. Non-heritable trait, long generation, high genetic variation: no selection
8. Non-heritable trait, long generation, low genetic variation: no selection

[BUTTON: ANALYZE DATA →]

Analysis Questions

To be written. Questions should direct students to the following:

- Misconception (D) evolution by natural selection can only occur slowly

Selection, not perfection: limitations to natural selection

In summary, natural selection is a process that requires heritability, phenotypic variation, and differential reproductive success in response to a selection pressure over generations. It might be tempting to think of adaptation as a drive towards perfection, but that's not true! The new population likely *is* better adapted to new environmental conditions but it may come at a cost or may be disadvantageous if the environment changes. Natural selection acts on all variable traits that contribute to the survival and reproduction of a species, and often, selected traits may not be ideal or "perfectly" designed for their lifestyle. What matters is *relative* and not ultimate fitness or reproductive success. Adaptations can be less-than-perfect because there are limitations to natural selection:

- The presence of heritable phenotypic variation limits the response to selection: Natural selection can only select phenotypic variants currently present in the population. If there is a lack of the necessary heritable phenotypic variation, selection pressure itself cannot create an advantageous phenotype – selection can only act on existing heritable phenotypic variations.
- Similarly, species may retain non-adaptive features or be unable to evolve adaptive traits due to their phylogenetic histories (phenotypic and genetic variation). Remember, evolution is "modification with descent", meaning that it operates on traits that are present in a population, primarily those that were passed down from ancestral forms.
    - For example: Birds with long necks, such as swans, have more neck vertebrae than birds with shorter necks. However, almost all mammals have seven neck vertebrae including giraffes and whales despite the extreme differences in the lengths of their necks. The number of vertebrae is a trait established in the first mammals and thus has become a phylogenetic (historical) constraint that has not been optimized by natural selection during the evolution of long necks in certain mammals such as giraffes.
- There are often trade-offs to adaptations; changes to one trait that increases reproductive success can be linked to changes in other traits that decrease reproductive success.
    - For example, cheetahs have longer and more slender leg bones, which allow them to run with great speed, but long and slender bones are weaker and is susceptible to break.

[BUTTON: FINISH]

[Post-test on misconceptions]

Test your knowledge!

Review your answer from the pre-quiz and see if you would like to make any changes. Then re-identify each statement as true or false and justify your choice.

(A) Natural selection occurs because the organism *needs* to adapt
Your previous answer was <student answer>. What is your answer now?
(B) Natural selection will result in an organism being a perfect match to the environment
Your previous answer was <student answer>. What is your answer now?
(C) Individuals cannot adapt
Your previous answer was <student answer>. What is your answer now?
(D) Evolution by natural selection can occur rapidly
Your previous answer was <student answer>. What is your answer now?
(E) Natural selection is not random
Your previous answer was <student answer>. What is your answer now?

[BUTTON: SUBMIT AND VIEW ANSWERS]

(A) Natural selection occurs because the organism *needs* to adapt
Answer: False, there is no goal or aim to adaptation by natural selection, i.e., organisms can't adapt because they desire or "need" to, they adapt if there is a heritable genetic trait that confers an advantage in which they are better able to survive and reproduce
(B) Natural selection will result in an organism being a perfect match to the environment
Answer: False, often, adaptations may result in trade-offs in which adaptive traits comes with disadvantages that make it harder for an organism to survive and/or reproduce in the same or a different environment.
(C) Individuals cannot adapt
Answer: True, adaptation is a product of evolution by natural selection. Natural selection is a process that involves changes in the genetic makeup of populations over time, therefore, populations can evolve, and species can adapt, but individuals cannot evolve or adapt in their lifespan.
(D) Evolution by natural selection can occur rapidly
Answer: True, in certain contexts, natural selection can occur very rapidly such as the evolution of antibiotic resistance or adaptations to use of pesticides, herbicides, and exposure to pollution.
(E) Natural selection is not random
Answer: True, the mutations that lead to novel genetic variation take place at random but the selection that acts on existing phenotypic variation is non-random