SUGGESTED TEXTBOOK ANSWERS

Chapter 14 Evolutionary mechanisms

The following are suggested answers only. Other answers to the same questions may also be correct.

Science inquiry

Activity 14.1 A model of genetic drift

What to do

4 If mating occurs and one offspring is produced, calculate the probability that it will have the mutant *A* allele.

Answer: 0.5 or 1/2 or 50%

5 Calculate the probability that if two offspring are produced, that they will both have the mutant *A* allele.

Answer: $0.5 \times 0.5 = 0.25$ or 1/4 or 25%

6 Now consider the situation where a large number of offspring are produced. What proportion would you expect to be albino (*aa*) and what proportion normal pigmentation (*Aa*)?

Answer: Albino (*aa*) = 0.5 or 1/2 or 50%. Normal pigmentation (*Aa*) = 0.5 or 1/2 or 50%

7 To continue with our model, we will assume only two offspring were produced, one of each sex, and they both had normal pigmentation. Put two pairs of beads in front of you to represent these individuals – each pair should have one white bead and one black bead.

8 Simulate meiosis again by separating the beads, duplicating them and separating them again to form the gametes.

9 Calculate the probability of getting an individual homozygous for normal pigmentation (*AA*) if offspring of the parental generation were to mate.

Answer: 0.25 or 1/4 or 25%

10 Determine the probability that an offspring could be heterozygous for normal pigmentation (*Aa*).

Answer: 0.5 or 1/2 or 50%

11 Work out the probability that an individual in this generation from the offspring of the original survivors will have at least one *A* allele.

Answer: 0.75 or 3/4 or 75%

Studying your data

1 If we assume that the original parents and their children died soon after producing their offspring, what is the frequency of the *A* allele in the third generation?

Answer: 0.5 or 1/2 or 50%

2 How does this compare with its frequency in the original generation?

Answer: The frequency has doubled.

3 Explain how, in this model of genetic drift, a further generation could be produced in which the *a* allele could be entirely eliminated.

Answer: The *a* allele could be eliminated if:

- individuals with the *A* allele produce many more offspring than those possessing an *a* allele
- individuals with the *a* allele have a lesser chance of survival compared with those with an *A* allele.

In summary

1 Explain why genetic drift can only occur in a very small population.

Answer: The effect of chance is greater in a small population. The effect of a particular individual's alleles has a significant impact on the total allele frequency in small populations.

2 What barriers exist in the world today that might isolate small groups of humans and hence promote conditions in which drift can occur?

Answer: Barriers that exist are political, economic, religious and cultural isolation. Some of the small Micronesian and Polynesian islands may still be subject to geographical isolation. Some religious groups, such as the Mennonites in the United States, are isolated by their religion and culture. (Note that other answers are possible.)

Activity 14.2 Sickle-cell haemoglobin

Interpreting the results

1 What was Allison's dependent variable? What was his independent or experimental variable?

Answer: Allison's dependent variable was whether the participant did or did not develop malaria, while the independent variable was the presence or absence of the sickle-cell allele.

2 What factors did Allison appear to control in his experiment?

Answer: Age; African (where from); no previous malarial infection; sex (male); 40-day observation time; none of the volunteers had been in an area where malaria occurred for at least 18 months; all inoculated with malaria; all inoculated at around the same time

3 Which group of subjects was the control group, and which the experimental?

Answer: Control group: lacking a sickle-cell allele

Experimental group: with a sickle-cell allele

4 Did Allison's results support his hypothesis? Explain why you think so.

Answer: Yes. The majority of those with the sickle-cell allele did not develop malaria, whereas a majority of those without the sickle-cell allele did develop malaria.

5 Do the results Allison obtained suggest a reason why the sickle-cell allele has survived in Africa?

Answer: Yes, because this is a region where malaria is prevalent, and the presence of the sickle-cell allele, although a disadvantage in most parts of the world, appears to have a selective advantage where malaria is prevalent.

6 Refer to Figures 14.12 and 14.13. Does the information provided in these figures support your answer to Question 5? Give reasons for your answer.

Answer: Yes. These figures indicate that in areas where malaria is still common, sickle-cell anaemia is still prevalent, or, there is a close correlation between the parts of the world where malaria is endemic and the areas where sickle cell anaemia occurs.

7 Explain how the high incidence of the sickle-cell allele in parts of Africa could be considered an example of natural selection.

Answer: In parts of Africa where there is still a high frequency of the sickle-cell allele, those people who survive malaria are usually those in possession of a sickle-cell allele. Therefore, when they reproduce they pass on this advantageous allele. Those who do not have this allele may contract malaria and die, thus removing alleles for normal red cells from the population. This is a good example of natural selection in human populations. Because individuals with two alleles for sickle-cell anaemia may die from the condition, and individuals without a sickle cell allele may die of malaria, it is the heterozygotes that have the best chance of survival.

8 Would a university ethics committee today be likely to approve an experiment such as the one that Allison performed? Give reasons for your answer.

Answer: It is highly unlikely that a university ethics committee today would approve Allison's experiment, because there was little supporting evidence at the time for his hypothesis. To do such an experiment today, Allison would have to explain the risks and benefits of the experiment to all the participants, any possible long-term effects and then obtain their informed consent.

Activity 14.3 Modelling natural selection

Studying your results

1 Which colour frog became the most frequent in the population? Why do you think this was the case?

Answer: Responses may vary, however one would expect the green frogs to be the most frequent, because they suffered less predation

2 Which colour frog was eliminated first? Explain why this occurred.

Answer: The yellow frogs would be expected to be eliminated first, because they were exposed to the greatest amount of predation

3 Compare your results with other groups in the class. Have all groups obtained similar results? How much variation was there in the results between the different groups?

Answer: One would expect the green frogs to be the most frequent in all groups. There would be variation between the groups because the colour of offspring, and the colours taken by predators, depend on the number displayed when the die is thrown – that number is a matter of chance.

Interpreting your results

1 How has this activity modelled the process of natural selection? In your answer describe what was creating the selection pressure on the population of frogs.

Answer: This activity has modelled natural selection as there was variability in the colour of the frogs and there was different selection pressure dependent on their colour. That is, the chance of survival (and reproduction) depended on the colour of the frog. The selection pressure for the frogs was the predation by birds.

2 Explain why there was variability, if any, between the groups in your class.

Answer: There was variability due to chance (that is, rolling of the die determined the colour of offspring and the colour taken by predators).

3 What changes would you have to make to predation by the water birds to achieve a completely orange population of frogs? Repeat the activity with your changed parameters. Was your prediction correct?

Answer: You would need to change the rate of predation. In this case, make the orange frogs the least preyed on, and increase the predation on the green frogs.

4 Over several generations, what would happen to the composition of the frog population if water birds preyed equally on the three frog colours?

Answer: If predation were equal across the three different colours of frog, then the proportions of different colours in the frog population would be expected to remain the same. In this situation there would be no natural selection – all colours of frog would be selected equally.

5 Write a summarising paragraph, using the principles of natural selection, to link the breeding patterns of the frogs and predation by water birds.

Answer: The paragraph would need to include such things as:

- the variation in frog colour
- the differing rates of predation by birds
- the selective advantage of a particular colour
- the difference in survival rate
- that only frogs that survive long enough to reproduce are able to pass on their favourable alleles to the next generation.

Review questions

1 How do new variations arise in a population? Give a brief description of the ways in which this may occur and the genetic structures involved.

Answer: New variations may arise in a population through mutations. A mutation is a change to the DNA in a single gene or a change in part, or all, of a chromosome. When mutations affect the reproductive cells (a germline mutation), they can be passed on to the next generation as the gametes will contain the changed genetic information.

Students could also mention the random combination of gametes at fertilisation and the recombination of alleles through crossing over as sources of variations in a population.

2 a Explain what 'random genetic drift' is.

Answer: Random genetic drift is when characteristics of members of a population occur as a result of chance, rather than by natural selection. It only occurs in small populations that are genetically isolated.

b Select a modern population in which genetic drift is thought to have had an effect and describe why this might be the case.

Answer: One example of random genetic drift in a modern population is the Dunker population in North America. Individuals are not allowed to marry (or reproduce) outside their own population, with its particular beliefs. This has led to a small genetically isolated population.

Students may also quote isolated populations of Australian Aborigines, Pitcairn islanders, the Finns and the inhabitants of Tristan da Cunha.

3 Briefly describe the significance of the founder effect in human evolution.

Answer: The founder effect is significant in studies of human evolution because, where a new isolated population is begun by a small number of people, the frequency of alleles in that small population may be quite different from the original population. The characteristics of the newly-founded population will then be different from the original population.

Teachers may wish to point out that as humans spread around the world there would have been many small founding populations, which would have contributed to differences between peoples in different areas.

4 Explain why geneticists think of migration as gene flow from one population to another.

Answer: Geneticists consider migration as gene flow, because when a person leaves one population and migrates to a new one, their genes go from the old to the new population.

5 List the common barriers that may lead to the isolation of one gene pool from another, and give examples of each type.

Answer:

- Geographical barriers: oceans, mountains, lakes, deserts

  Students may quote many examples such as the Sahara Desert separating populations in northern and southern Africa, or the Pacific Ocean separating peoples in the Americas from Australia and Asia.

- Sociocultural barriers: education, language, religion, social position

  Students may quote many examples such as Jewish people in Israel marrying within their own faith or the Basque people of the Pyrenees being united and separated by their language and other aspects of culture.

6 a List five different kinds of sociocultural barriers to gene flow, and describe how each is thought to act.

Answer:

- Education: People tend to marry and/or reproduce with someone from similar educational backgrounds.
- Religion: People tend to marry and/or reproduce with someone with the same religious beliefs.
- Language: It is more likely that people will meet and marry and/or reproduce with someone who speaks the same language.
- Economic status: People tend to marry and/or reproduce with someone of the same economic status.

- Social status: People tend to meet and marry and/or reproduce with someone with the same social status.
- Ethnic group: People are more likely to meet and marry and/or reproduce with someone within the same ethnic group.

In all of these cases people are more likely to meet a potential partner who has similar education, religion, language and so on, rather than individuals who are quite different. It is human nature to socialise with people who are similar to us.

b Outline the importance of gene flow for human evolution.

Answer: Gene flow increases variation within a population. This is important as variation allows natural selection to occur so that the population becomes better adapted to the environment.

7 Using the example of Tay-Sachs disease, explain how genetic diseases can lead to changes in allele frequencies in a population.

Answer: Genetic diseases may result in changes to allele frequencies in a gene pool. An allele causing an inherited, fatal disease would be expected to be gradually eliminated from a population because people with the allele would die and would not pass it on to the next generation. In the case of Tay-Sachs disease, the heterozygous form is thought to have a selective advantage in areas where TB is present. People with one copy of the allele are more likely to survive and reproduce and to pass the allele on to future generations. People who do not have the allele are more likely to die from TB.

8 Outline the main points of Darwin's theory of natural selection. Include an explanation of the terms 'struggle for existence' and 'survival of the fittest'.

Answer: The principles of evolution through natural selection include the following:

- All members of a species vary.
- Variations are passed on from one generation to the next.
- Organisms reproduce at a rate far greater than that which their available food supply and other resources allow, leading to competition for survival. This may be referred to as a 'struggle for existence'.
- More organisms with favourable characteristics survive and reproduce, passing on their favourable alleles. Many of those with unfavourable characteristics die before they have an opportunity to reproduce and do not pass on their unfavourable alleles. This may be known as 'the survival of the fittest'.
- The proportion of favourable alleles in the gene pool gradually increases.

9 Explain how the following people contributed to Darwin's theory of natural selection.

a Linnaeus

Answer: Linnaeus introduced the hierarchical system of classification that we still use today. This enabled Darwin to see relationships between groups of organisms and to organise all of his work.

b Malthus

Answer: Malthus, in *An Essay on the Principle of Population*, pointed out that the human population was increasing at a rate far exceeding the rate of food production. Drawing on examples from natural populations of plants and animals, Malthus demonstrated that natural reproduction rates of animals and plants produced more offspring than could possibly survive.

c Lyell

Answer: Lyell hypothesised that the Earth's surface had been gradually moulded over a very long period of time. This idea provided Darwin with a concept of constant change over a very long period of time.

10 Once the mechanisms of inheritance were understood, the theory of natural selection was modified to account for this new knowledge. Outline briefly the way natural selection is now thought to operate.

Answer: Natural selection can now be viewed as a gradual change in the frequencies of alleles in the gene pool of a population.

11 People of short stature tend to live in cold climates, and people with long limbs and short trunks tend to live in hot climates. Explain how these adaptations to cold and hot environments could have come about.

Answer: Originally, there would have been a range of variants for stature in all human populations. Through natural selection, those with characteristics that best suited them to the climate in which they lived would have survived and reproduced, passing on their favourable alleles to their offspring. People of short stature with a smaller surface area in relation to body volume lose heat at a slower rate giving them a survival advantage in cold climates. Those with long limbs and short trunks have a survival advantage in hot climates because they have a larger surface area for heat loss.

12 a What is sickle-cell anaemia? Explain why it is usually lethal.

Answer: Sickle-cell anaemia occurs when the red blood cells have an abnormal crescent or sickle shape. It is usually lethal because the sickled red blood cells clump together causing organ damage and decreasing life expectancy.

b List the advantages and disadvantages of having the sickle-cell trait in an area where malaria is prevalent.

Answer:

Advantages	Disadvantages
Malarial resistance	Red cells sickle when oxygen concentration is low Complications from sickled cells

13 Explain what 'a selectively advantageous mutation' means.

Answer: A selectively advantageous mutation is one that aids survival in a particular environment. It is more likely to be passed on to the next generation because an individual with that mutation is more likely to survive and reproduce.

14 How could isolation lead to selection and speciation?

Answer: Isolation over a considerable period of time may result in a population undergoing many changes in allele frequency through natural selection, as well as the possibility of genetic drift and mutation. This may result in that population becoming so different from the original that it is no longer able to reproduce with the original population. It has become a different species.

Apply your knowledge

1 Malthus claimed that species of organisms always produce more offspring than the existing resources can support. Is this true of the human species in the past or at present? Is it likely to be true of the human species in the future?

Answer: This claim by Malthus was probably true for the human species in the past, especially in traditional hunter-gatherer societies. The development of agriculture meant that populations were able to increase without starvation occurring. Technological advances such as the green revolution have enabled the human species to keep up with increasing demand for food. In some regions of the world where resources are very limited, or are limited at particular times through drought, famine and floods, the population does exceed existing local food resources.

In the future, ever increasing population growth could result in more offspring being produced than resources could support. However, technology may keep pace with population growth in ways that are yet to be imagined.

2 During the fourteenth century, plague epidemics caused drastic reductions in the human population of Europe. Use this as an example to describe the way natural selection operates so that only the fittest tend to survive.

Answer: There is variation in all human populations and those of fourteenth century Europe would have had some individuals who possessed alleles that gave them a survival advantage when exposed to the micro-organism causing the plague epidemics. These people would have survived the epidemics and passed on their favourable alleles to their offspring. Those that died did not possess alleles that gave them a survival advantage and could not pass on their alleles. Thus, in this case, the fittest individuals survived.

3 Using the concepts of natural selection and of gene pools, describe how a new variation could arise in a population and then become frequent within that population.

Answer: In a gene pool there are many different alleles resulting in much variation. A new combination of genes or alleles can arise from mutation, environmental influence or gene expression resulting in a new phenotype. This new variation could give any person possessing it a survival advantage. It would therefore be selected for and become frequent in that population.

4 According to a recent report, 13% of Scotland's population are redheads. Two out of every five Scots carry the allele for red hair. However, only 2% of the world's population are estimated to be natural redheads.

a Suggest a reason for the high frequency of the allele for red hair in the gene pool of the Scots.

Answer: The original reason for the high frequency of the allele for red hair in the Scottish population may have been the founder effect or random genetic drift. The high frequency of the allele has been retained because Scots would tend to reproduce with other Scots.

b In the population of Scotland, what do you think will happen to the frequency of the allele for red hair over time? Give reasons for your answer.

Answer: The frequency of the allele for red hair will probably stay about the same because there would be no selective advantage conferred by the red hair allele and people living in Scotland are more likely to meet and marry other people living in Scotland. If there were a significant migration into the Scottish population, then the allele frequency would change.

5 Today, humans adapt culturally to environmental change. Does natural selection affect cultural characteristics?

Answer: Today, natural selection has far less effect on populations than in the past. Modern culture has allowed humans to modify their environments to such an extent that they are now able to survive in even the most hostile of environments. In addition, modern medical technology enables people to survive and reproduce with what would have once been fatal conditions. Natural selection, therefore, has much less effect on present-day populations. However, a major human conflict, such as a war, could affect survival and selection in certain populations.

Natural selection does not affect cultural characteristics because culture is not inherited, it is passed from one generation to another through learning.

6 A team of American scientists has been trying to develop a vaccine to give permanent immunity against malaria. What do you think will happen to the frequency of the sickle-cell gene within a population if this vaccine is effective? In writing your answer, ensure that you explain the adaptive value of the various genotypes and the selection pressures on each.

Answer: If an effective vaccine were to be discovered to prevent malaria, one would expect the frequency of the sickle-cell allele to decrease as it would no longer have a selective advantage. Genotypes would reflect the decrease in selective pressure that previously favoured the retention of the sickle-cell allele. Those that possess two of the sickle-cell alleles would still die from sickle-cell disease, and those with two normal alleles would no longer succumb to malaria. Their survival would increase the frequency of the normal allele for haemoglobin in the population. The heterozygotes would no longer have a survival advantage and, over time, the frequency of the sickle-cell allele would decrease and possibly be eliminated from the population altogether.

7 Describe the barriers to gene flow that exist for the following populations.

a Groups in South Africa

Answer: Mountains; deserts; cultural barriers (for example, different tribal groups tend not to intermarry).

b Groups in the islands of Polynesia, such as New Zealand, Tahiti and Hawaii

Answer: Ocean barriers.

c The Jewish people.

Answer: Sociocultural barriers; in this case, religion.

8 Using analysis of mitochondrial DNA, researchers have determined that all humans are descended from a woman who lived in Africa 200 000 years ago – the so-called mitochondrial Eve. If we are all descended from a common ancestor, how is it that there are so many different types of humans today? Describe the processes that must have taken place to produce the differences between present-day groups of humans.

Answer: Even though present-day humans may have all descended from a common ancestor, dispersal into different environments exposed those migrating groups to different environmental selective pressures. Natural selection would have operated on these groups as they settled in differing environments, favouring different allele combinations and leading to different phenotypes. In small populations, especially in the case of small groups of hunter-gatherers, genetic drift may have resulted in different allele combinations. Similarly, the founder effect may have influenced the characteristics of many of the populations in the small islands in the Pacific Ocean. In the past, isolation and a lack of gene flow over considerable periods of time would have resulted in distinctive phenotypes.

9 Consider the population of the city in which you live, or the nearest large city to you. Do you think there are isolated breeding groups within that population? If there are, describe the mechanisms that tend to isolate them, and say whether you think they will continue to operate in the future.

Answer: Students will come up with many different answers to this question. Answers will cover some of the following: cultural groups, religious groups, farming communities, type of occupation and educational level. The continuation of these groups into the future will depend on the strength of the isolating mechanisms (for example, their religion, culture and so on).

10 Speculate on what might be the long-term effect on allele frequencies if a mutation suddenly produced a favourable allele that gave a natural resistance to all forms of heart disease.

Answer: Over time, the allele frequency for natural resistance to all forms of heart disease would be selected for and increase significantly within the population. This would see a gradual decrease in the incidence of the disease, as those dying from the disease would have their alleles removed from the gene pool. However, if death occurred after an individual had reproduced and had passed on their unfavourable alleles, the speed at which the allele frequencies changed would be very much reduced.

11 Describe the process involved in producing two separate species from a common gene pool.

Answer: For two separate species to be produced from a common gene pool, the gene pool would need to divide in some way. This would usually be in the form of an environmental barrier, such as an ocean, desert, or mountain range, which resulted in the two populations being isolated. If the environmental influences were different enough, changes to the allele frequencies within each population may result. If the isolation remained and there was no gene flow, over time the populations would become so different that, even if the barriers to reproduction were removed, interbreeding would no longer be possible. There would now be two separate species.