# BLUEPRINT OF LIFE

# Evolution

## *Evidence of evolution suggests that the mechanisms of inheritance, accompanied by selection, allow change over many generations*

### Evidence, scientific theories and evolution

How have living organisms come to be the way they are? Were they all created independently of each other in their current form, or have living things changed over time to arrive at their present state? This kind of thinking, over many centuries, has led to diverse explanations: some include an indigenous perspective such as the Dreaming; some are based on religious views such as *creationism* and *intelligent design*; and others, such as evolution, take a scientific approach.

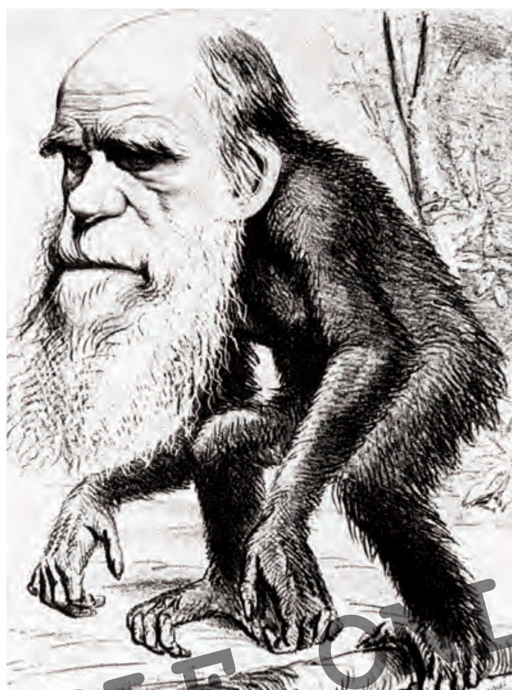
Biology is a natural science and so its explanations of natural phenomena are based on *evidence* and *confirmable* data. Scientists look for evidence that shows 'cause and effect' and they base their inferences on factual information that can be observed and/or measured. Scientists do not state that views such as creationism or intelligent design are 'untrue', but that they are not based on empirical data and therefore do not constitute science.

**Figure 1.1**
(a) the Dreaming
(b) Creationism and
(c) evolution

(a)

(b)

(c)



## The theory of evolution

Two hundred and fifty years ago, natural scientists proposed the theory of evolution to try to explain how living organisms have come to be the way they are: that living things change over time. The concept that we call evolution had been alluded to over many thousands of years, but in the early 1800s, biologists took one step further, proposing possible *mechanisms* to try to explain how this change may come about. This has led to the currently accepted *theory of evolution by natural selection*. In this chapter, we as biologists will consider the evidence from which inferences have been drawn, to see why the current theory of evolution has come to be accepted as an underlying concept of biology.

TR

Teaching resource—theories, laws and hypotheses

## Validating scientific theories

A **theory** is a scientist's explanation of a principle. Since scientific explanations are provisional and these scientific views at any time depend on the evidence available to support these views, theories may change—therefore we say that science is 'tentative'.

### How scientists validate a theory

To answer questions such as: 'How have living organisms come to be the way they are?', scientists propose what they think is a plausible explanation and then look for *testable evidence* to support or refute (disprove) these ideas.

A number of predictions are made and then tested, either by experiment or by looking for irrefutable evidence to support or oppose them. If scientists gather a significant amount of evidence that supports the *hypotheses* being tested (and no evidence arises to the contrary), they put forward a *theory* that is acceptable to the scientific community at the time.

As technology advances and understanding increases, new evidence that becomes available may further support a view or it may invalidate that view, leading to the development of a new theory.

PFA H2

# 1.1 Evolution: selection, inheritance and change

## Evolution

**Evolution** means a *change* in living organisms over a long period of *time*. As far back as the 4th century BC (during the time of Aristotle), the concept that organisms may change over time had been considered, but no testable theory or *mechanism* explaining how it could occur was proposed.

Evolutionary thinking as we know it today had its beginnings in the mid to late 1700s, but it was not until the early 19th century that a *mechanism* for evolution that was worth serious consideration was proposed by Jean Baptiste Lamarck. Although his theory was later rejected, his ideas opened the way for the proposal of new ideas, resulting in the currently accepted theory of evolution by *natural selection*, proposed by Charles Darwin and Alfred Wallace in the late 19th century.

All theories of evolution share some common basic criteria:

- Living organisms arose from common ancestors or a common life form and have changed over time.
- *Differences* that occur amongst groups of living organisms imply that living things *change over time*.

- *Similarities* occur in living things and suggest a *common ancestry*—the basic chemistry, inherited from a common life form, has remained relatively unchanged and has been passed down through generations.

## Selection

Darwin and Wallace suggested **natural selection** as the mechanism that could account for the survival of organisms. Many individuals within populations naturally possess differences or variation in their structure, behaviour and/or functioning. If these variations confer some kind of an advantage, they enable organisms to better survive a change in the environment. Those organisms that are well suited to a habitat survive to reproduce (described as '*survival of the fittest*' by a later biologist) and these surviving individuals would pass on their favourable characteristics to future generations.

When this theory was first proposed, difficulties arose in trying to fully explain it because at that point in time there was no knowledge of *how* characteristics could be *inherited* or the cause of these differences (variation) in living organisms. The theory of evolution by natural selection was proposed before there was any knowledge of genes or an explanation of how inheritance could come about.

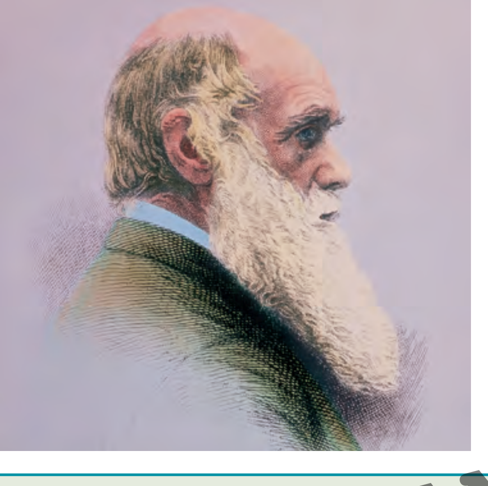
## Inheritance

**Inheritance** or **heredity** in living organisms depends on the transmission of genetic characteristics from parents to their offspring. If a variation for a particular characteristic in a population has a genetic basis, the variation will be passed on to the next generation during reproduction. Inheritance of favourable variations (e.g. long necks in giraffes) will better equip the offspring to survive the environmental conditions.

While Darwin and Wallace were presenting their research in England, Gregor Mendel, a monk living in Austria, was conducting experiments on inheritance in garden pea plants. Darwin and Wallace were unaware of Mendel's work at the time, work that would later be of enormous significance in the acceptance of their evolutionary mechanism. Eventually, when their ideas and observations were considered together, Mendel's results provided the much-needed evidence of a hereditary mechanism, lending credibility to Darwin and Wallace's theory of evolution by natural selection.

Together, the theory of *evolution by natural selection* and the mechanism of *inheritance* of genes form the basis of our understanding of how living things change over time.

(a)



(b)

**Figure 1.2** Proponents of evolution and genetics: (a) Charles Darwin (evolution); (b) Gregor Mendel (genetics)

**Note to teachers:** The first-hand investigation to model natural selection (page xxx) may be done at this point (before section 1.2) to introduce students to the concept of the impact of environmental change on natural selection. Alternatively, it may be done after section 1.2, when students will already have some concept of the relationship between natural selection and changing environments.

# 1.2 Environmental changes

- ***outline the impact on the evolution of plants and animals of:***
  ***—changes in physical conditions in the environment***
  ***—changes in the chemical conditions in the environment***
  ***—competition for resources***

Since evolution involves change over time, a key question that arises is: 'What factors are thought to bring about evolutionary change?'

## Environmental change and competition

Evidence suggests that change in the *environment* is a driving force behind change in living organisms. The **environment** can be described as the living (biotic) and non-living (abiotic) surroundings of organisms. The abiotic environment includes:

- *physical conditions*—factors such as temperature, availability of water, light, wind, slope and tides
- *chemical conditions*—factors such as the presence (or absence) of gases such as oxygen and carbon dioxide in the environment of living organisms, as well as pH and differing concentrations of chemicals such as salts and heavy metals in the surroundings.

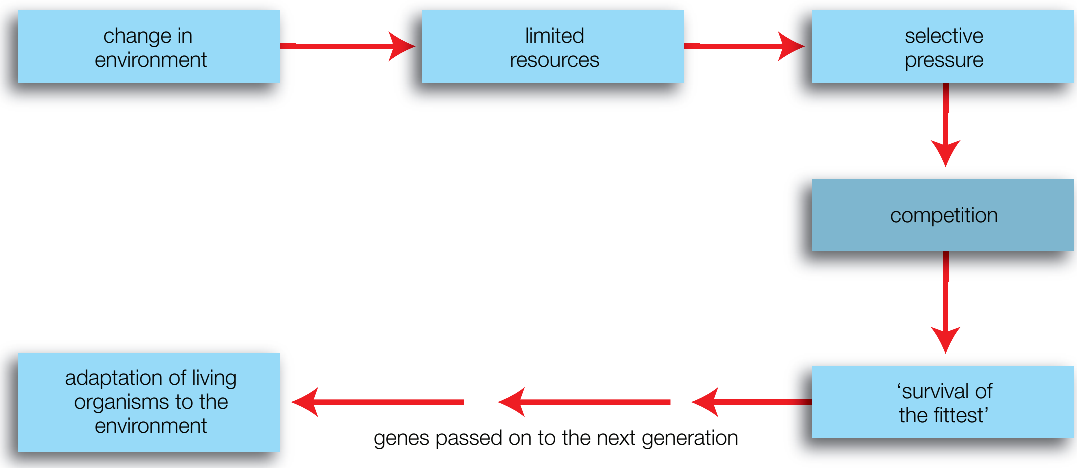
As a result of environmental change, *resources* may become *limited* and so living organisms will begin to compete for the available resources in order to survive. **Competition** will arise between organisms for resources such as light, soil nutrients and water in plants, or food, water, shelter, mates and breeding territory in animals. *Change in the environment* of a population influences evolution because it results in **selective pressure** acting on organisms. Selective pressures include:

- environmental change
- competition
- predation
- disease.

Those organisms that compete most successfully for available resources survive to breed and therefore to pass on their genes to the next generation. That is, those individuals that *compete successfully* in the new environment outlive those that do not have such variations. Such organisms are said to have an **adaptation** to the environment.

**Note:** It is important to remember that an individual does *not* develop an adaptation *in response* to the environmental change—the organisms *already* possess the random variation that confers an advantage under the new conditions. This variation is now called an *adaptation* because it enables the organisms that possess it to cope better with the selective pressure conferred by the changed environment and out-compete those organisms that do not possess it.

**Figure 1.3** How a change in the environment leads to competition, resulting in adaptation

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Terminology—evolution, selection and inheritance

## Chemical and physical changes in the environment

It is commonly accepted that physical and chemical changes in the environment may have been responsible for the evolution of organisms from ancient forms to forms that we know today, but they may also have been responsible for the very origins of life itself.

Evolution can be considered over very long periods of time and over shorter periods of time:

- **Macro-evolution** takes place over millions of years, measured as geological time, and results in the arising of new *species* (and even larger groups such as new *families* and *orders*). In the Preliminary Course module 'Life on Earth', we looked at how life evolved on Earth and discovered a correlation between **chemical changes** in the environment and the *types of organisms* that were prevalent at the time. We also learnt how **physical changes** in the environment could have resulted not only in the evolution of existing life forms, but also in the evolution of the first organic molecules from inorganic substances—the beginnings of macro-evolution.

  Another example of macro-evolution is the evolution of the red wolf, jackal and dog from a common ancestor. Each is a separate *species* belonging to the genus *Canis*: *Canis rufus* is the *red wolf*, *Canis aureus* the *jackal* and *Canis familiaris* the *dog*.
- **Micro-evolution** takes place over shorter periods of time and results in changes within populations, but it does not produce new species. New forms that arise within populations are sometimes referred to as *varieties* or *races*. An example is the different *breeds* of dogs, which all belong to the same species. (This form of evolution is most commonly seen in current short-term studies of living organisms.)

### Physical changes in the environment

#### Macro-evolution

Physical changes in the environment may have been instrumental in the evolution of organic molecules from inorganic substances on early Earth.

Urey and Miller's experiments supported Haldane and Oparin's theory that organic compounds may have formed on Earth in the presence of strong ultraviolet radiation, electrical energy from lightning and high temperatures from volcanic eruptions—all of which are physical environmental factors.

The reduced incidence of ultraviolet radiation on early Earth, as a result of the formation of the ozone layer, is thought to have played a key role in the movement of living organisms from water to land habitats.

Other *physical changes* in the environment are thought to have affected evolution:

- a change in the Australian climate from cool and wet to hot and dry, affecting the change in vegetation from rainforest to woodland, dry sclerophyll and grassland vegetation—this in turn led to changes in animal life
- the drying up of lakes in the Australian interior, leading to the evolution of plants and animals that could conserve water (e.g. the water-holding frog)
- the influence of fire, resulting in the survival of fire-resistant species in Australia (e.g. the bottlebrush)
- dust clouds that formed as a result of a meteorite striking the Earth—this may have reduced the light to such an extent that much of the plant life was greatly reduced, leading to a lack of food for the dinosaurs and thus their extinction.

Other physical factors, such as severe changes in temperature and sea levels during the ice age, are believed to have been a driving force behind the evolution of many life forms.

Besides physical and chemical factors in the environment, **biological** (living) **factors** may also influence evolution. For example, the arrival of humans and their hunting may have contributed to the extinction of megafauna. Often, introduced species (such as humans in Australia) *compete* with local species and, if successful, can out-compete them and cause their elimination.

**Figure 1.4** Fire—a physical change in the environment

## Chemical changes in the environment

### Macro-evolution

The first life forms are believed to have lived in an *anoxic* (oxygen-free) environment some of these primitive life forms began to produce **carbon dioxide** as a result of their metabolism. The appearance of carbon dioxide in the environment led to the emergence of *photosynthetic organisms*—the precursors to plants. They used this carbon dioxide in their metabolism and produced **oxygen** as a by-product.

The increasing oxygen levels in the environment led to the evolution of organisms that were aerobic—organisms that could use oxygen in their respiratory pathway. Since aerobic respiration generates far more energy than anaerobic respiration, these

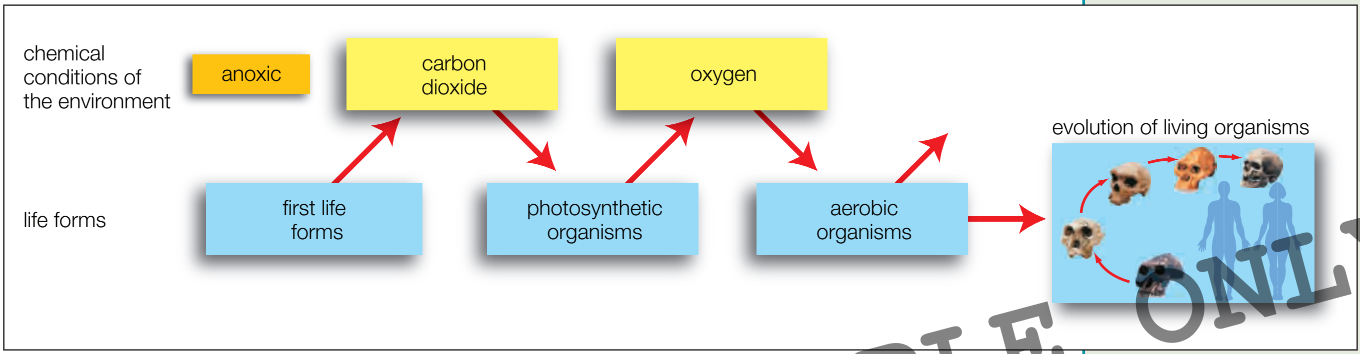


**Figure 1.5** Flow chart showing chemical change and the evolution of life on Earth

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Student activity—macro-evolution

organisms could grow larger and more complex, leading to the great diversity of aerobic life forms that we know today, including all animals.

**Micro-evolution**

The influence of physical and chemical change in the environment on micro-evolution is also significant. It is evident in examples of living organisms that we study today (e.g. the peppered moth, DDT resistance in insects and antibiotic resistance in bacteria) and helps us to understand the concepts of convergent and divergent evolution, and to explain 'modern' examples of natural selection. Examples of micro-evolution as a result of change in the physical and chemical environment are dealt with in subsequent pages (pages xxx–xx).

## Modelling natural selection

**FIRST-HAND INVESTIGATION**

**BIOLOGY SKILLS**

H11.1; H11.2; H11.3

H12.1; H12.2; H12.4

H13.1

H14.1; H14.2; H14.3

■ ***plan, choose equipment or resources and perform a first-hand investigation to model natural selection***

The HSC syllabus requires students to plan this investigation themselves, so it is recommended that students should not simply follow a procedure that has already been planned for them. This practical provides the ideal opportunity for students to learn to design their own investigations, following the structured sequence of steps outlined on this Student Resource CD.

### Aim

To model natural selection.

### Background information

Predator–prey relationships are often the easiest to use when modelling natural selection. In planning the investigation, think of everyday situations where individuals within a species compete for resources (e.g. food, shelter, mates). Those individuals which have variations that are an advantage in their environment will out-compete the others. This is what should be modelled.

Some ideas to generate discussion and provide ideas for models are listed below:

- The colour of some animals provides them with camouflage, so that they are not easily seen by predators. Base the model on a variation in colouration.
- The shape of some organisms makes them more difficult to grasp, so they slip out of the clutches of their predators. Base the model on a variation in either the shape of the prey or the 'grasping structures' of the predators. (Remember to test only *one* variable at a time for an experiment to be valid).
- Some organisms are tastier than others—students could use lollies to model natural selection based on a variation in flavour of lollies of different colours.

(See Teacher's Resource CD for more detailed ideas and websites for teachers; on the Student Resource CD there is more guidance for students.)

### Task

Using the outline given below, plan a valid investigation to model natural selection and investigate its effect, based on a variation within a population that leads to 'survival of the fittest'. Follow the step-by-step guide provided on the Student Resource CD to assist you to plan this investigation so that it meets the criteria of a valid, reliable and accurate scientific investigation.

### Investigation outline

Text surrounded by a border in the notes below outlines all information that should be recorded in your preliminary investigation plan and in the final practical report that you will submit to your teacher.

#### Planning your investigation

1. Identify what is being used to represent the:
   a) prey population
   b) predator population.
2. Predict a characteristic of the population that you think will most ensure or hinder its survival.
3. On a separate sheet of paper, begin writing your investigation plan.

- Write an **aim**, a short statement that makes clear the problem that you have to solve.

- List the materials you will need (include quantities).
- Write a research question or HYPOTHESIS and then make a PREDICTION.
- Give reasons for your prediction.

4. Write a rough plan that says what you intend doing. Say what you will do to make this a **valid investigation** (that is, a 'fair test'). Remember to identify:
   —the independent variable
   —the dependent variable
   —what variables you will need to control to make it a fair test.
   (*Hint*: Think about such things as the length of time allowed for the 'predator' to hunt, and the use of the left or right hand.)
5. Carry out some preliminary trials. Identify any problems and **modify your method** to fix these problems.

### Method

*Now*, on your investigation plan:

6. Write out your METHOD in point form, starting each point with an action verb (e.g. '*place* the cards …' and '*measure* …').

Include a description of:

- the variables
- how you will ensure reliability—consider the sample size you will use (this may require modification after a test run), and averaging and/or comparison of results
- precisely how you intend measuring your results
- a suitable format in which to represent your data.

### Results

7. Prepare a results sheet in a suitable format, with headings, that will allow you to record all your observations and measurements concisely and in a manner that is easy to interpret.
8. Interpreting the results: Re-read your AIM and HYPOTHESIS and then analyse your data—you may consider using a computer to assist e.g. with graphing.

### Discussion

9. EXPLAIN (give reasons for the *cause of*) the patterns/trends in your data (both expected and unexpected).
10. Evaluate investigation

- Were your findings what you expected?
- Identify any sources of experimental error.
- How did you/could you reduce the errors associated with measurement, controlling variables and sampling?
- Identify the limitations of your model. Could the design have been further improved?

### Conclusion

11. Identify any patterns/trends that are made evident by your results.
12. Outline, in the form of a general statement, what your results show in terms of the question or hypothesis you were investigating. (That is, state the relationship between the variables you have investigated.)

### Further discussion questions

1. Write a general statement to compare the prey population after each round of selection, in terms of number of individuals with each type of variation that survive.
2. In a natural population, reproduction maintains and increases population numbers under favourable conditions. Did each of the remaining prey organisms in your population 'reproduce' itself at the end of a round of selection? If not, predict the general trend in the population after several rounds of selection and reproduction.

TR

Teaching strategy for Investigation

TR

Modelling natural selection—guide to preparing the investigation

# A modern example of 'natural' selection

SECONDARY SOURCE INVESTIGATION

BIOLOGY SKILLS

H12.4

H13.1

H14.1; H14.3

## ■ *process and analyse information from secondary sources to explain a modern example of 'natural' selection*

**Note:** This dot point appears in the syllabus under Syllabus Statement 4. It has been addressed in this textbook under Syllabus Statement 1 because it fits in well with the concept of natural selection being dealt with here.

(a)

(b)

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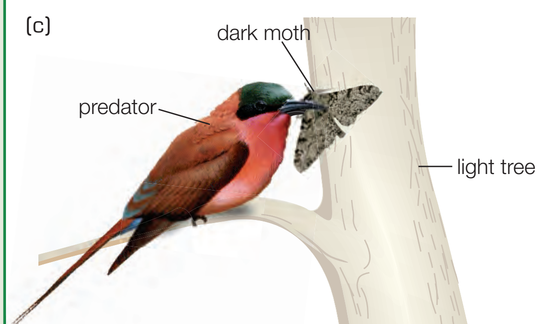


**Figure 1.6** Peppered moths *Biston betularia*:
(a) light and dark moths on naturally light trees;
(b) light and dark moths on dark trees affected by industrial soot; and (c) bird predator eating a peppered moth

### Introduction

The experiment with the peppered moth described below is a classic example used in biology to demonstrate the process of 'natural' selection—the term 'natural' here is in inverted commas, because the change in the environment is not a 'natural' occurrence, but due to the intervention of human beings. Other modern day forms of changes in populations, due to physical or chemical changes in the environment, are common, such as changes in the mosquito population as a result of the use of the insecticide DDT and changes in bacterial populations as a result of the use of antibiotics. Researching the detail of one of these examples would provide the ideal material for a case study to show how an environmental change can lead to changes in a species (see page xxx).

### The peppered moth and industrial melanism

#### Change within a species

The peppered moth (*Biston betularia*) is a European moth that rests on tree trunks during the day.

In England until the mid-19th century, most moths of this species that were captured were very light in colouration—their wings were described as having a 'peppered' appearance. Darker forms existed, but were rare. During the 19th century, this changed and the number of dark forms within the population increased.

#### Physical change in the environment

In the 19th century, a physical change in the environment occurred as a result of the Industrial Revolution: woodlands near to industrial cities became blackened by soot deposits, leading to a darker overall appearance in the bark of tree trunks.

H. Bernard Kettlewell put forward a hypothesis (which he successfully tested) that the darkening trend in the moth population was as a result of the environmental change—an example of evolution by natural selection. Kettlewell used a controlled study—he studied an unpolluted woodland near Dorset and compared this with a polluted woodland near Birmingham, using the capture–mark–recapture method.

**Explanation in terms of natural selection**

Prior to the Industrial Revolution, the *original populations* of peppered moths were mostly of the light/peppered form, and the black form was less common. The light-coloured individuals were at a *selective advantage* because they were camouflaged against the white lichen on tree trunks on which they rested during the day. The black variety could be more clearly seen by bird predators and so they were eaten in greater numbers, keeping their overall numbers low.

As a result of the *physical change in the environment* during the Industrial Revolution, the tree trunks became darkened by soot and, as the soot spread, much of the light-coloured lichen that grew on the tree trunks died off, leaving tree trunks dark. The black moth now had better camouflage. As a result of the selective advantage over the light form, the darker form of the moth became more abundant within the population. The light-coloured moths were captured and killed by predators more frequently because they could be more easily seen during the day while resting against the dark tree trunks.

The *resulting population* in the polluted wood changed due to natural selection. The *selective pressure* in the environment changed to suit the darker form and differential reproduction or 'survival of the fittest' occurred—the dark variety survived to produce offspring. This led to the dark variety of moths becoming more abundant than the white moths.

**Industrial melanism** is the term used to describe a population that changes during industrialisation so that the darker form becomes predominant as a result of natural selection in the evolutionary process. It was seen in many species of moths in areas throughout Europe, Asia and North America, as industrialisation spread. What is interesting is the reversal that was noticed in the late 20th century, coinciding with the implementation of pollution controls.

## Case study: environmental change leads to changes in a species

- ***analyse information from secondary sources to prepare a case study to show how an environmental change can lead to changes in a species***

To identify and describe physical or chemical changes in the environment that are the driving force behind evolution, students are required to perform a **case study** to show how an environmental change can lead to changes in a species.

A **case study** in biology involves a detailed investigation or study of an individual organism or group of organisms, analysing information that emphasises its relationships with the environment.

### Task

1. Identify the plant or animal species.
2. Describe the *change* that occurred within the species.
3. Include an illustration or photograph of the plant or animal (remember to acknowledge your source).
4. Describe the change in environment that occurred.
5. Identify whether the environmental change was a physical or chemical change.
6. Identify and describe the selective pressures acting on the organism as a result of the environmental change.
7. Explain how (4) led to (2) (show cause and effect).
8. Discuss whether you consider the example to be a form of *macro-evolution* or *micro-evolution*.

(See the example of the peppered moth on page xxx, which has been done in a similar format.)

**SECONDARY-SOURCE INVESTIGATION**

**BIOLOGY SKILLS**

H12.3

H12.4

H13.1

H14.1; H14.2; H14.3

SR

For a guide to preparing the case study; an extension activity on biological change; and recommended websites

### Chemical change: modern day 'natural selection'

Some examples of chemical change in the environment leading to chemical resistance in species are:

- DDT and mosquitoes
- insecticide resistance in the sheep blowfly (*Lucilia cuprina*)
- antibiotic resistance
- ticks and arsenic-based cattle dips
- possums and sodium fluoroacetate resistance.

Students are not compelled to use one of the above examples for their case study—these are only suggestions to give students some direction. They may study an example of physical or chemical change that has led to change in a species of their own choice.

### Physical change: other examples of natural selection

Some examples of species which have been affected by physical changes in the environment are:

- saltbush (*Atriplex*): Australian climate change—drying out led to an accumulation of salt and this increased salinity led to salt-tolerant species surviving
- snow gums and clines: the altitude at which the trees grow has affected their height
- the size of koalas is affected by environmental temperature.

# 1.3 The Darwin-Wallace theory accounts for divergent and convergent evolution

- ***explain how Darwin-Wallace's theory of evolution by natural selection and isolation accounts for divergent evolution and convergent evolution***

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Assumed knowledge—Darwin-Wallace theory of evolution

## Criteria on which the Darwin-Wallace theory of evolution is based

Like most theories of evolution, the Darwin-Wallace theory of evolution by *natural selection* assumes that living things arose from a common ancestor and that some populations moved into new habitats where they adapted over time to their environments.

To survive in a particular environment, organisms must possess traits that favour their survival in that environment—we say organisms possess variations that become **adaptations** to their environment. Charles Darwin and Alfred Wallace's theory of evolution proposes that **natural selection** and **isolation** could account for how living organisms become adapted to their surroundings. (See Student Resource CD—Assumed Knowledge)

**Natural selection** depends on the following criteria:

- variability: all populations have random differences or variation
- heritability: variation may be inherited
- over-reproduction: organisms produce more offspring than the environment can support (that is, not all offspring survive).

**Speciation in isolation**: Darwin and Wallace's idea that populations change by natural selection and become adapted to the environment gave rise to their ideas on *speciation*—the formation of new species. They proposed that the formation of a new species may occur when a population becomes *isolated* from the original group of organisms. Only those individuals that have variations that allow them to survive the changed conditions will reproduce and *pass on their characteristics* to the next generation. Eventually, the population becomes so different to the original population that individuals are *no longer able to interbreed* and produce fertile offspring—the defining condition for a population to be considered a different or *new species*.

It can be seen that natural selection may result in changes *within* a species (micro-evolution) or it may result in populations that become so different that *new* species are formed (macro-evolution). For *speciation* to occur, *isolation* is necessary.

## Accounting for similarities in species

Both Darwin and Wallace studied large numbers of living organisms and observed that similarities in structure were common. These similarities could be accounted for in one of two ways:

1. In closely related species, the basic similarities between the organisms could be as a result of their *relatively recent divergence from a common ancestor.* Natural selection could account for their differences—as they moved into different habitats, they would have been exposed to new selective pressures, which would result in their evolution by natural selection *to become different*. This is termed **divergent evolution**.
2. If more *distantly related species* (which diverged from a common ancestor further back in time) show similarities, this could be as a result of having moved into similar environments—they would have been exposed to similar selective pressures and so natural selection could account for them *evolving to become similar*. This is termed **convergent evolution** (see Fig. 1.7).

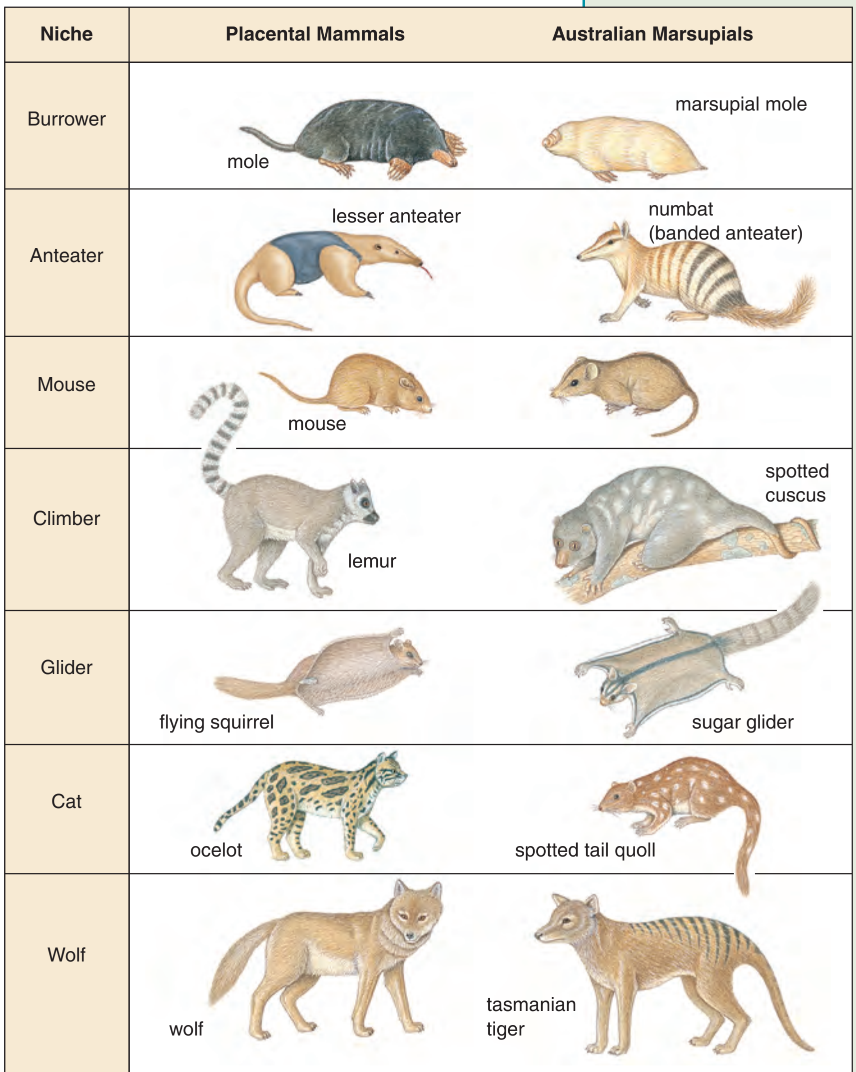



**Figure 1.7**
Convergent evolution: placental mammals in North America and Europe show similarities to marsupials in Australia

The Darwin-Wallace theory of evolution by natural selection and isolation therefore can account for both divergent and convergent evolution: the organisms in a changed or new environment are under *pressure* to survive. The environment *selects* certain variants within a population which have a trait that gives them a better chance of survival. When resources in the environment become limited, those individuals with favourable traits survive, reproduce and pass on their characteristics. The favourable traits that increase the organisms' chances of survival are termed **adaptations**. Natural selection can result in different organisms that are subjected to similar selective pressures becoming more similar (convergent evolution), or similar organisms becoming different (divergent evolution).

## Accounting for differences in closely related species

**Adaptive radiation** is a term used to describe the evolutionary variation in species that evolved from a common ancestor. As a result of the migration of organisms into new environments ('radiation' relates to spreading out), organisms would begin to occupy new niches (the term 'adaptive' suggests a change that favours their survival in a new niche in the environment).

## Examples from Darwin and Wallace's studies

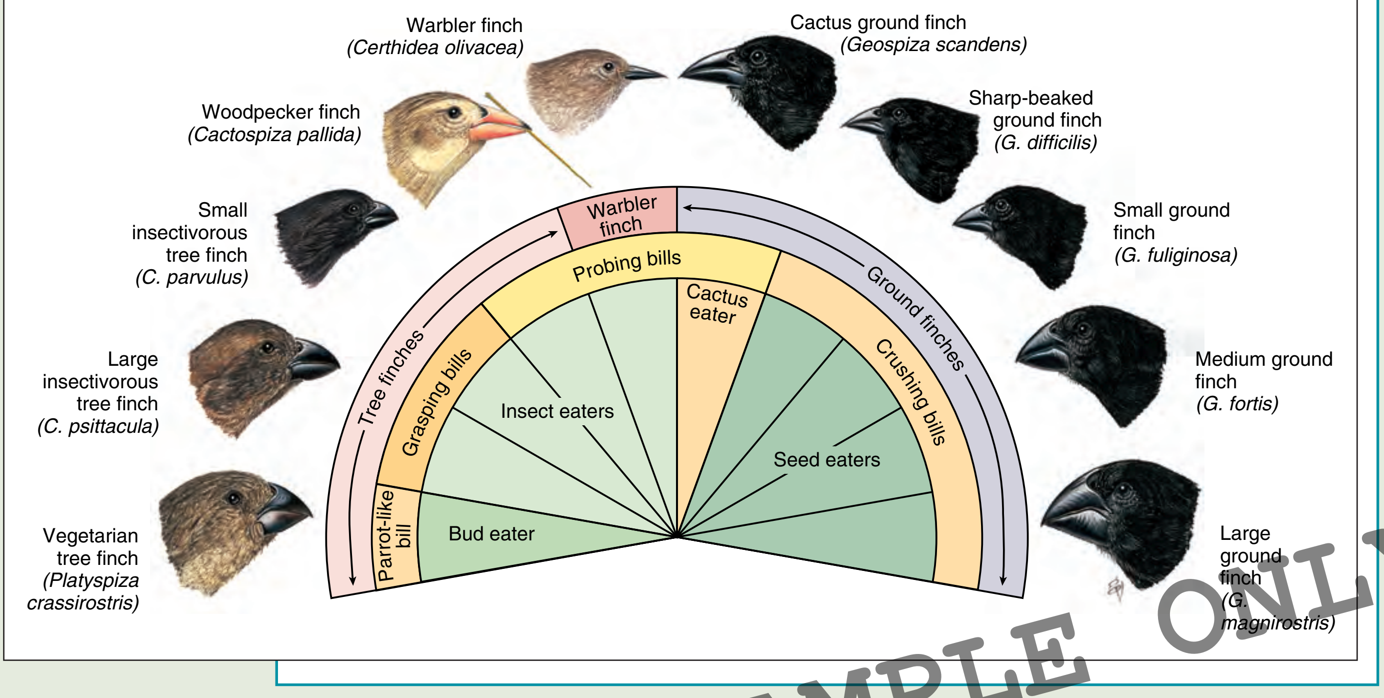
### Divergent evolution

Darwin recognised that several different lineages could arise from one common ancestor. Darwin's finches are a typical example of **divergent evolution** and **adaptive radiation** as a result of migration and isolation. Darwin observed 13 species of finches on the Galapagos islands which, he proposed, originated from one original population that first reached the islands by crossing the sea. Since all the different habitats on the island were unoccupied at the time of their arrival, the group of birds was subjected to a diversity of selective pressures, depending on which habitat they moved into. The ancestral group therefore rapidly split into diverse populations, which were acted upon by natural selection, and they became progressively different from the original population (see Fig. 1.8). (Examples of Wallace's studies are described on page xxx as biographical evidence for evolution.)

### Convergent evolution

Darwin studied particular marsupials in Australia and found similarities between them and certain placental counterparts in Europe (see Fig. 1.7). Although these pairs of animals were extremely distantly related (as is evident by the vast difference in their types of reproduction), they showed some remarkable similarities that could be accounted for only by the fact that any pair lived in similar environments. This led him to the idea of organisms

**Figure 1.8** Divergent evolution finches observed by Darwin on the Galapagos islands, showing divergent evolution of beaks



evolving to become similar (convergent evolution) because, if different organisms live in similar habitats, similar variations would be favoured by natural selection to enable them to survive and breed in those conditions.

Many other examples show similarities in distantly related organisms that occupy similar niches—e.g. the fin and flipper structures in sharks (fish), dolphins, whales and seals (mammals) and penguins (birds).

# Evidence to support the theory of evolution

1.4

- ***describe, using specific examples, how the theory of evolution is supported by the following areas of study:***
  ***—palaeontology, including fossils that have been considered as transitional forms***
  ***—biogeography***
  ***—comparative embryology***
  ***—comparative anatomy***
  ***—biochemistry***

## Validating the theory of evolution

Darwin's theory of evolution by natural selection is supported by a large amount of evidence, gathered over more than a century. Since macro-evolution takes place over millions of years, it is impossible to directly test it by experimentation or observation within a lifetime or even over many generations. Therefore evidence must be gathered to *support* the theory of evolution—the theory cannot be *proved*. To validate this theory, scientists have made predictions and then tested them—so far, many predictions have held true and so the theory is considered 'valid', but all strands of evidence have their limitations.

We will now look at *evidence that* have been found to support the five strands of theory, predictions that have held true and the limitations of each strand of evidence.

PFA H2

SR TR

Student activity and answers—evidence to support the theory of evolution

## Palaeontology and transitional forms

**Palaeontology** is the study of fossils. Fossils provide direct evidence of the existence of an organism in the past. Fossils may be mineralised remains in rock or the actual remains of the organism preserved in rock, ice, amber, tar, peat or volcanic ash.

Even before Darwin's proposal, scholars recognised that the idea of change in organisms over time was supported by evidence in undisturbed rock formations: the sequence in which fossils are laid down in rock reflects the order in which they were formed, with the oldest fossils in the bottom-most layers of the rock and the more modern fossils in the rock layers closer to the top. Based on this finding, predictions could be made and tested in attempting to validate the theory of evolution by natural selection.

### Predictions

One prediction based on the fossil record is that, the sequence of fossils found in rock formations should reflect the order of changes observed

TR

Additional information and extension activity

in organisms that originated from a common ancestor.

Another prediction was made by Darwin himself: that the fossil record should yield intermediate forms—organisms that show transitions from one group to another ('missing links' between groups). For example, if amphibians have evolved from fish, one would expect to find fossils of organisms that show features of both their fish ancestors and the amphibian forms to which they would eventually give rise.

### Evidence

- Fossils in undisturbed rock formations throughout the world have shown a similar *sequence*, supporting the idea that living things arose in a particular sequence or order.
- Today, Darwin's prediction of intermediate forms is supported by evidence in the form of thousands of known fossils that appear to have features common to two known groups, suggesting that a *transition* occurred in the past from one group to another. These fossils, termed **transitional forms**, represent successive change in organisms over a long period of time.

### Examples of transitional forms

- *Fish to amphibians*: fossils of lobe-finned fish (***Crossopterygii***) (sometimes termed 'fleshy-finned' fish) show that these fish had bones in their paired fins that may have allowed them to drag themselves over land, from one mud pond to the next, when the environment changed and land was drying out. These fins are thought to represent the ancestral limbs of terrestrial vertebrates.

*Crossopterygii* were all thought to be extinct, but some *living* examples of these *lobe-finned* fish have been found fairly recently—the first, in 1938, was a coelacanth found off the South African east coast. This 'living fossil' caused great excitement in the research world.

Other *living* fish that may share a common ancestor with amphibians are the *lung fish*. Lobe-finned fish were originally thought to be direct ancestors of amphibians, but more recent research shows that amphibians and *lung fish* (which still have living forms in Australia today) seem to share a direct common ancestor.

- *Reptiles to birds*: The most ancient recognised fossil bird, found in rocks dated 150 million years old, is ***Archaeopteryx***, a reptile-like bird (see Fig. 1.9). *Archaeopteryx* has a mixture of *reptilian* and *bird*-like characteristics, having clear impressions in limestone of *feathers* on its forelimbs and on its tail, as well as a '*wishbone*' (fused clavicles called a furcula) extending into a *keel bone* for attachment of flight muscles, typical of birds. Yet it also displays features typical of a reptile, such as teeth (in its beak), bones in its tail and claws on three digits of its forelimbs.
- *Terrestrial mammals to marine mammals*: **whales** are aquatic (living in a marine habitat) mammals, not fish. They are thought to have evolved from a terrestrial mammal ancestor—a hypothetical four-footed, hoofed creature. By evolution, this creature is believed to have changed to a mammal with limbs similar to a modern sea lion. Fossilised remains of two transitional forms, *Ambulocetus* and *Rhodocetus* have been found showing hind limbs which became smaller, until they were eventually lost completely, resulting in whales which have no hind limbs, but do have remnants of a skeletal pelvis. (See the Teacher's Resource CD for whale 'missing links'.)
- *Early horses to modern-day horses*: fossils of early horses show small

TR

Transitional forms—worksheet and extension

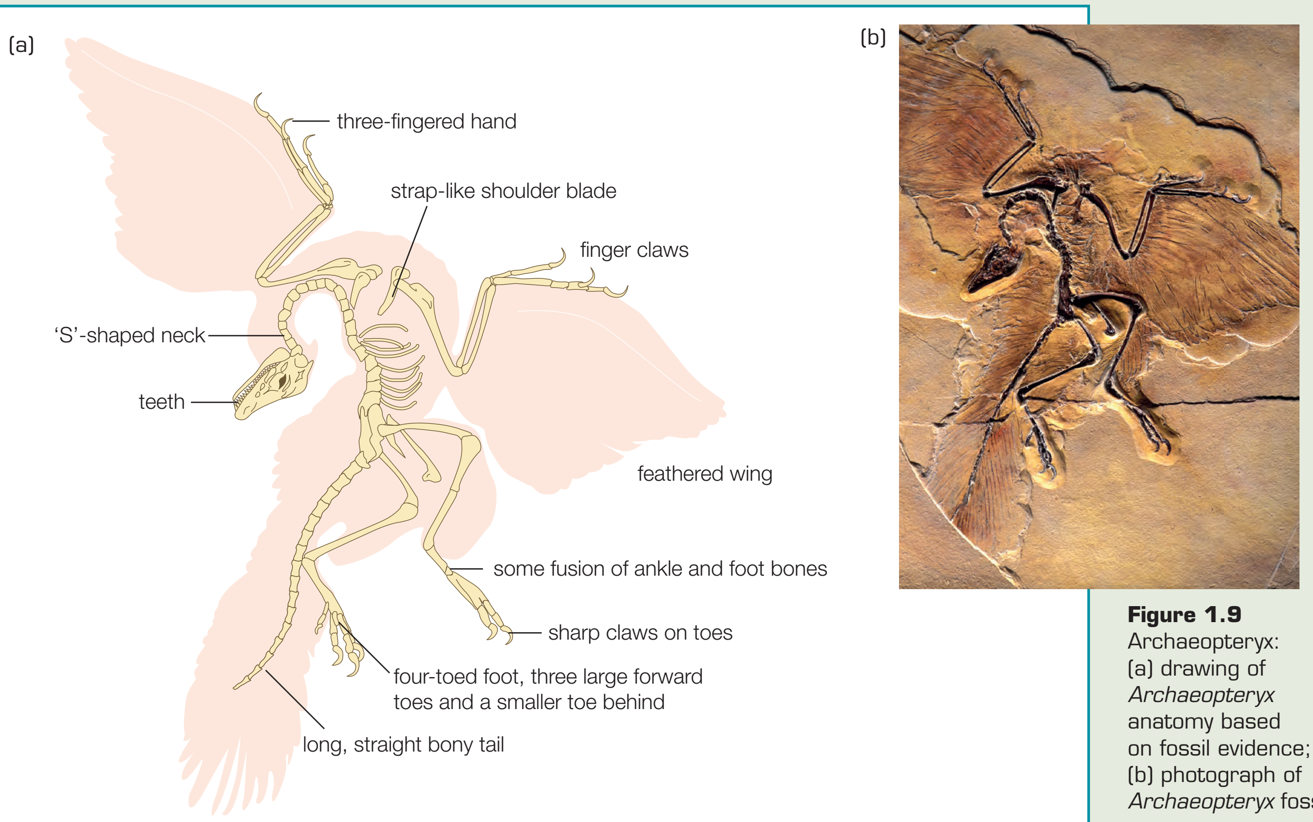



**Figure 1.9** Archaeopteryx: (a) drawing of *Archaeopteryx* anatomy based on fossil evidence; (b) photograph of *Archaeopteryx* fossil

animals with *four* toes and a *narrow* cheek span, compared with modern day horses which have only *one* toe and a *large* cheek span. Fossilised remains of *transitional forms* of horses show *three* toes with an *intermediate* cheek span.

Other commonly studied examples of fossilised transitional forms include ***Therapsida*** (mammal-like reptiles) and **seed ferns** in the plant kingdom (a seed fern is an intermediate between *ferns* which today reproduce by means of spores, and the more advanced *conifers* and *flowering plants* which are seed-bearing). (See Student Resource CD).

### Limitations of palaeontological as evidence

The main limitation of the fossil record is that it is incomplete and so it is not a random sample of past life:

- There is a bias towards organisms whose body parts or environment makes them better suited to becoming fossilised, e.g. those with hard body parts and those that live in aquatic environments. There is a lack of fossils representing the majority of early or soft-bodied organisms.
- There is an unequal representation of transitional organisms; e.g. certain organisms such as the horse have well-represented lines of descent, whereas evolutionary transitions of many other organisms are not represented in the fossil record at all.
- There is also some doubt about the correct age sequence of some fossils, since radiocarbon dating, the commonest method of determining the age of fossils, can be used to date fossils only as recent as up to 50 000 years old (not very old in evolutionary terms).

### Conclusion

Fossils give us consistent evidence of past life forms that reflect the evolutionary transitions to modern forms of living organisms. But since fossil evidence has its limitations, it is necessary to examine additional strands of evidence to further validate the theory of evolution.

## Biogeography

**Biogeography** is the study of the geographical distribution of organisms, both living and extinct. The Darwin/Wallace theory of evolution proposes that, for a **new species** to arise, a group of individuals must become *isolated* (geographically separated) from the rest. (A new species is one where the individuals cannot produce fertile offspring if they are mated with individuals of a pre-existing species.) Predictions based on biogeography provide evidence to support this feature of the theory of evolution.

SR

Assumed knowledge—ratitaes (flightless birds)

### Prediction

If isolation is a criterion necessary for new species to arise from an original species, the new species should resemble species with which they shared a habitat; e.g. they will be more similar to:

- species that lived close by, than to species found far away (even if that species is in an area with similar environmental conditions), or
- species that lived in a common area before it split up (e.g. Gondwana).

### Evidence

During his travels, Darwin studied and compared numerous animals (including his now-famous finches) on islands such as the Galapagos. He was the first to point out that, although animals and plants that live on islands are often somewhat different from those on the mainland, they still have a closer resemblance to their counterparts on the nearest mainland than to plants or animals on lands further away. Darwin queried how one could make sense of this if they were all '*equally* and *independently* created'.

Alfred Wallace noted that the north-western Indonesian islands, including Bali, had bird species most similar to those of the closer Asian mainland, whereas islands in the south-east, including Lombok, had birds that were most similar to those in nearby Australia. Noting how close Bali and Lombok are, it is easy to understand how this led to his conclusion that the island forms may have evolved from mainland forms which became isolated. (See map on page xxx for proximity of these two islands.)

A typical example where biogeographical evidence supports macro-evolution is that of the flightless birds (*ratitaes*) and continental drift: the present-day distribution of flightless birds suggests that these birds originated from a common ancestor on Gondwana (see Assumed Knowledge on the Student Resource CD) and that the different populations evolved on the isolated southern continents as they drifted apart. The result is the distribution of emus in Australia, ostriches in South Africa, kiwis in New Zealand and rheas in South America, all of which share similarities suggesting a common ancestor. Further evidence is that there are no similar flightless birds on the northern continents (which were part of Laurasia and became isolated from Gondwana before the flightless birds arose).

The flightless birds are not the only example—Australia's unique mammals and flowering plants are believed to have arisen as a result of the isolation of the continent. Australian organisms show similarities to fossils found on other southern continents, evidence that they may have had a common origin and later evolved.

This provides further support for the concept of adaptive radiation.

### Limitation

Comparisons based on biogeography are limited to studies of species which have became isolated at some point in time.

### Conclusion

Inhabitants of islands resemble individuals on the nearest mainland, supporting the idea that evolution occurred in these species once they became isolated. Organisms that originated in Gondwana and now live far apart show similarities in structure, suggesting a common ancestor before the continents split up.

## Comparative anatomy

**Comparative anatomy** is the study of similarities and differences in the *structure* (anatomy) of living organisms and can be used to determine evolutionary relatedness. This was one of the first forms of evidence that led to the idea that all living things arose from one common ancestor. Evidence from both living and fossilised plants and animals was gathered and compared.

### Predictions

The basic theory of evolution of organisms from a common ancestor led to a prediction being made that, if organisms are more *closely related* (that is, they separated from a common ancestor more recently), then they should be *more similar* in structure than organisms that separated further back in time.

This led to the corollary that: if organisms are more similar in structure, then they must have separated from a common ancestor more recently. For example, since humans and chimpanzees have more structural similarities than humans and cats, it could be inferred that humans and chimpanzees separated from a common ancestor more recently than humans and cats.

A *variety* of structures should be compared to draw conclusions about evolutionary relatedness from studies of comparative anatomy.

(See Student Resource CD for terminology related to studies of comparative anatomy).

SR

Comparative anatomy terminology

### Evidence

#### Homologous structures—evidence of divergent evolution

In organisms that are being compared, *similarities* in structure suggest descent from a *common ancestor*, whereas *differences* in structure represent modifications—how organisms have evolved to *become different*. This is typical of **divergent evolution** and the similarities are best explained by *common descent*—that is, sharing a common ancestor.

Organs that have the *same basic plan* to their structure, but show modifications because they are *used in different ways*, are termed **homologous** structures—they have the same evolutionary origins. For example the pentadactyl (five-digit) limbs of all vertebrates have the same basic bone plan. Therefore the wing of a bird, the forearm of a lizard and the flipper of a whale are homologous, because all share a common basic bone structure, suggesting that they shared a common evolutionary origin. Flowering plants show a number of homologies, including the arrangement of their leaves, the structure of vascular tissue in stems and their flower structure.

Comparative anatomists study such homologies and compare *many* body parts of organisms, to work out the degree of similarity, which helps them to determine the degree of evolutionary relatedness (or **phylogeny**) of the organisms.

#### Analogous structures—evidence of convergent evolution

An interesting pattern of evolution found in studies of comparative anatomy at first led to some confusion. Some body parts of organisms appear to be similar at first, but in-depth studies of their anatomy show that they are really vastly different in their basic structure—e.g. the wings of a bird (containing muscles and bones) and the wings of a grasshopper (made of a thin membrane of exoskeleton). Since these organs *differ* greatly in their basic plan, they are said to be **analogous**—they are thought to have started off being very different and then to have evolved independently to become similar, because they were selected to be used for a similar purpose: flight. This is typically **convergent evolution** where changes in structure are adaptations that favour the survival of these unrelated organisms, because they inhabit a similar environment. For example, vertebrates, insects and octopuses all have large, well-developed eyes and good vision, but they lack a common ancestor. The evolution of the eyes in each is thought to have occurred independently, making their eyes *analogous* structures arising as a result of convergent evolution.

Other examples of analogous structures are found in the Australian echidna and the European hedgehog. They have both developed protective spines to discourage predation but, in terms of most other structures and their reproduction, they are quite dissimilar.

The presence of analogous features does not provide evidence for evolutionary relatedness, but rather for evolution of structures *to serve a common purpose* in a *common environment*, despite the fact that the organisms are distantly related and do not share a common recent ancestor.

#### Vestigial structures

Vestigial structures are thought to be evolutionary remnants of body parts that no longer serve a useful function within that population. The presence of vestigial structures provides evidence of common ancestry. For example, the presence of a reduced tail (coccyx) and an appendix (reduced caecum) in humans and the pelvic bones in snakes and whales are difficult to explain unless they are structures that have become reduced because they no longer carry out a useful function in that animal's lifestyle.

The investigation that follows allows students to gather their own evidence of evolution, based on a comparative anatomy study of vertebrate forelimbs (page xxx).

### Limitations of comparative anatomy

Because fossils are often incomplete and there is a bias in the animals represented, it is difficult (and sometimes impossible) to compare the anatomy of numerous structures in living organisms with those of extinct forms. One also needs to be aware that some superficial structural similarities may be analogous (or result from convergent evolution) and could cause confusion when looking for common ancestry.

### Conclusion

The greater the number of similarities in structure of organisms being compared, the more closely related the organisms appear to be. Numerous features need to be taken into account to arrive at this conclusion. Comparative anatomy is used to reinforce inferences about common descent derived from the fossil record and therefore shares similar limitations.

# Comparative anatomy investigation: vertebrate forelimbs

■ ***perform a first-hand investigation or gather information from secondary sources (including photographs/diagrams/models) to observe, analyse and compare the structure of a range of vertebrate forelimbs***

**FIRST-HAND AND SECONDARY SOURCE INVESTIGATION**

**BIOLOGY SKILLS**

H12.2; H12.3; H12.4

H13.1

H14.1; H14.2; H14.3

## Background information

Vertebrates display a similar distribution of organs, e.g. the distribution of bones of the forearm. This homology in structure suggests that they are related to one another and have arisen from a common ancestor.

Differences in features (variations), e.g. the size, fusion and shape of bones for muscle attachment, are evident. These differences may be attributed to divergent evolution, where natural selection has favoured certain features in particular forelimbs, to adapt that population of organisms to move more effectively in its particular habitat.

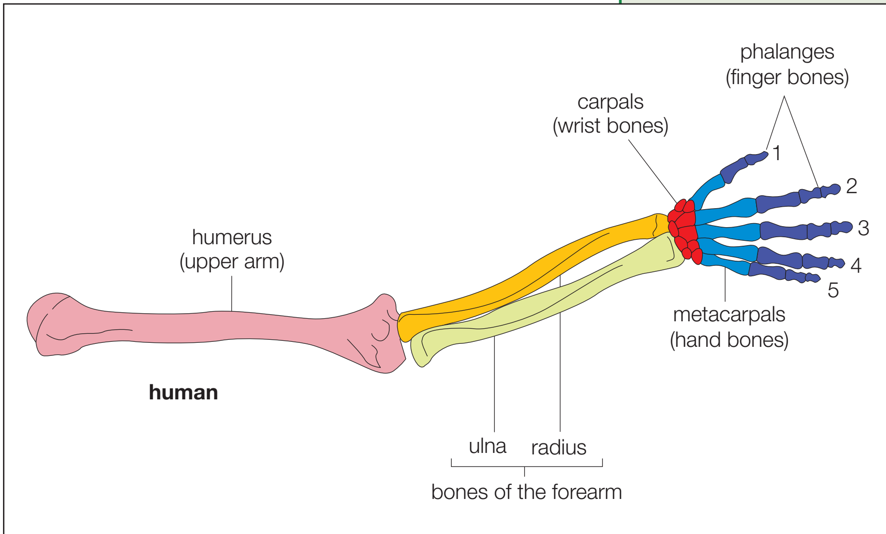



**Figure 1.10** Pentadactyl forearm of a human

### Basic structure

Investigations into the homologous nature of of a variety of forelimbs in vertebrates reveals that they are built on the same basic plan.

The forelimb of tetrapod vertebrates is built on a plan known as a **pentadactyl** limb. This means that it has five digits (*penta* = five; *dactyl* = digit)—five fingers. The bones of the forelimb (and hand) show a similar basic pentadactyl arrangement in all tetrapod (four footed) vertebrate limbs.

Students should be familiar with the structure of the *human* forelimb (from junior science), so the basic plan of this limb is a good starting point (see Fig 1.10).

In this investigation, students will look at a variety of skeletons of vertebrates, or pictures of these skeletons, to compare their anatomy and determine whether they are homologous structures—that is, whether they have arisen from a common ancestor. The five digits in a pentadactyl limb are considered to be the ancestral number of digits in tetrapods.

If the limbs are found to be built on the same basic pentadactyl plan:

- *similarities* in structure provide evidence that they have arisen from a common ancestor
- any *differences* evident suggest that evolution has occurred (change over a period of time). That is, the original plan has become modified in a particular population, because this variation has allowed the forelimb to be more efficiently used for movement in a different habitat.

## Aim

To gather evidence based on comparative anatomy studies of vertebrate forelimbs to investigate evolutionary relatedness (arising from a common ancestor).

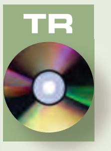
## Materials

- Student Resource CD—background information on vertebrate forelimbs.
- First-hand investigation: a range of vertebrate skeletons such as frog, toad, turtle, lizard, pigeon, rabbit, cat and human
- Secondary-source investigation: diagrams/photographs/websites showing the arrangement of bones in the vertebrate forelimbs. (See the Student Resource CD for recommended websites and/or use a search engine looking for 'homologies of forelimb'.)

SR

Additional information to assist students when examining vertebrate forelimbs


Comparative anatomy—vertebrate forelimbs and further websites




Further information and extension activity

## Method

- Using Figure 1.10 as a guide, draw a basic plan of a pentadactyl limb.
- Locate and identify the bones making up the pentadactyl forelimbs of a variety of tetrapods, including those used for swimming, walking, running and flying.
- As a group, discuss how these structures provide evidence of evolutionary relatedness (that these vertebrates may have a common ancestor). Describe in what ways they are different and identify the selective pressures to which they have been subjected.

## Results

Draw up a table to record the comparative information on three vertebrate forelimbs as outlined in the method above.

- A labelled sketch of the arrangement of bones in each forelimb.
- A description of the differences observed in each forelimb (make reference to the size, shape and arrangement of the bones).
- An explanation how the modified structure of each forelimb is suited to its type of movement in the habitat in which it lives (use Table XXX on the Student Resource CD to help you).
- On the worksheet provided on the Student Resource CD, use highlighters or coloured pencils to shade each type of bone for the forelimb of each animal drawn—colour-code your diagram to show any similarity in the arrangement of bones. Include an appropriate key.

  Complete the worksheet on animal forelimbs.

## Conclusion

Is it reasonable to conclude that tetrapod vertebrates could have evolved from a common ancestor?

## Discussion

- Provide reasons for your conclusion.
- Answer questions on the Student Resource CD.

## Comparative embryology

Comparative embryology is the comparison of the developmental stages of different species. Similarities may be used to infer relationships between organisms.

### Prediction

Species that are related show similarities in their embryonic development.

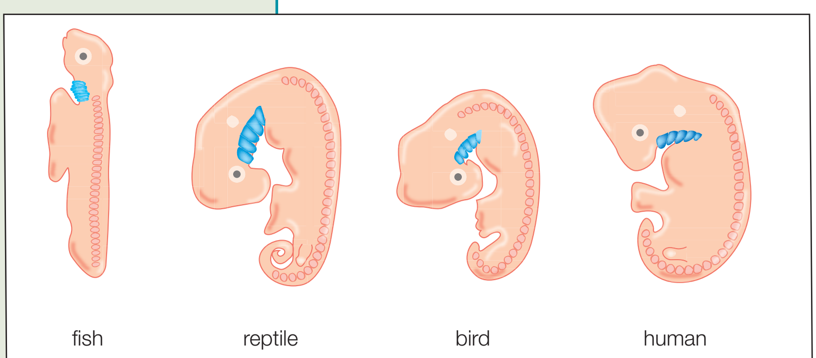
### Evidence

Studies of vertebrate embryos show similarities in their early development. For example fish, amphibians, reptiles, birds and mammals all show the presence of *gill slits* and *tails with distinct muscle blocks* during early embryonic life (see Fig. 1.11). This is best explained by common ancestry—that they are all descendents of a common form. The presence of gill slits suggests that the common ancestor of vertebrates lived in an aquatic environment. These gill slits develop into internal gills in fish only. They develop into external gills in tadpoles and some amphibians, but in other vertebrates no further gill formation occurs. Embryonic gill slits in mammals eventually develop into part of the Eustachian tube, an airway that connects the middle ear with the throat.

### Conclusion

Embryos of closely related organisms have homologous parts, providing independent evidence supporting the view that they shared a common ancestor.

**Figure 1.11** Comparison of embryonic development of vertebrates showing similarities in early development, such as gill slits (blue) and a tail



## Biochemical evidence

Biological evidence for evolution involves determining sequences of chemicals such as amino acids in proteins, or the sequence of base pairs in DNA and then comparing them in organisms that may share an evolutionary relationship.

**Biochemistry**, the study of chemicals found in cells, includes the study of molecular biology and genetics. All living things contain the same macromolecules such as **DNA** and **proteins**. This *similarity* in biochemistry among living organisms is in itself evidence for descent from a *common ancestor*. However, more recent and detailed evidence involves comparing the *sequence* of unit parts of these chemicals in species that may share evolutionary relationships:

- proteins—many amino acids linked in a particular sequence
- DNA—many nucleotides, linked in a particular sequence of base pairs

*Differences* in the sequence of these chemicals indicate changes that have arisen during the process of *evolution*.

(See Assumed Knowledge on the Student Resource CD.)

SR

Assumed Knowledge—DNA and protein structure

PFA H3

### Prediction

When the biochemistry of organisms are compared, the more closely related the organisms are, the more similar their DNA/amino acid sequences will be.

To test this prediction, advanced technology is needed to sequence these macromolecules.

Advances in the understanding of the biochemistry of cells has led to the development of new technologies that allow us to objectively measure similarities and differences between components of macromolecules (such as proteins or DNA) in living organisms to determine their evolutionary relatedness. The **quantitative** results obtained make it possible to reconstruct the evolutionary history of organisms, both living and extinct.

### Technology used to gather biochemical evidence to support the theory of evolution

#### Amino acid sequencing

- A protein that is found in a wide range of organisms, e.g. a cytochrome (protein in plants and animals, involved in chemical respiration) or haemoglobin (blood protein found in animals only) is studied.
- The sequence of amino acids in the protein is analysed and similarities and differences are identified.
- *Similarities* imply that the organisms may have shared a common ancestor.
- *Differences* imply that the organisms have evolved (changed over time).
- The *number of differences* is proportional to the length of *time since they separated*. This information is used to construct evolutionary trees.

For example humans and chimpanzees have the identical sequence of amino acids in their haemoglobin and so they are more closely related than humans and gibbons, which have three differences.

**Student activity website on amino acid sequencing: www.indiana.edu/~ensiweb/lessons/mol.bio.html**

#### DNA–DNA hybridisation

Both this technology and DNA sequencing (see page XXX) are based on the assumption that DNA molecules of closely related species have a similar nucleotide base order.

The procedure (see Fig. 1.12):

- DNA hybridisation involves splitting the double-stranded DNA molecule lengthwise to expose nucleotide bases on each individual strand. This is done by applying heat (usually 90–94°C) to cause the complementary strands to separate (*dissociation*).
- Separated segments of DNA from the two species that are going to be compared are mixed.
- The two strands from the different species combine (*re-association*) and form a 'hybrid' (mixed) DNA molecule. The more closely matched the base pairs are, the stronger the binding of the strands. Paring of DNA chains from different organisms is referred to as DNA–DNA hybridisation.
- Heat is once again applied, this time to determine how strongly the bases have combined: higher temperatures are required to separate hybrid strands that are more strongly combined. Closely related species have a very similar order of nucleotide bases and so their DNA strands combine more strongly than species that are distantly related. For example, the DNA of a human and a mushroom would be weakly combined and the DNA would be separated at lower temperatures that the DNA of a human and a chimpanzee.
- An expensive, advanced piece of nucleotide equipment called a *thermal cycler* is used to heat and cool molecules at exact temperatures.

### DNA sequencing

In this procedure, the exact order of nucleotide bases in the gene of one species is compared with the sequence in a similar DNA fragment of a second species.

The procedure:

- A piece of DNA (a gene) is isolated from each organism to be compared.
- Multiple copies of each gene are made, using fluorescent dyes to distinguish between the four bases in DNA.
- Computer-linked equipment called a DNA *sequencer* is used to graph

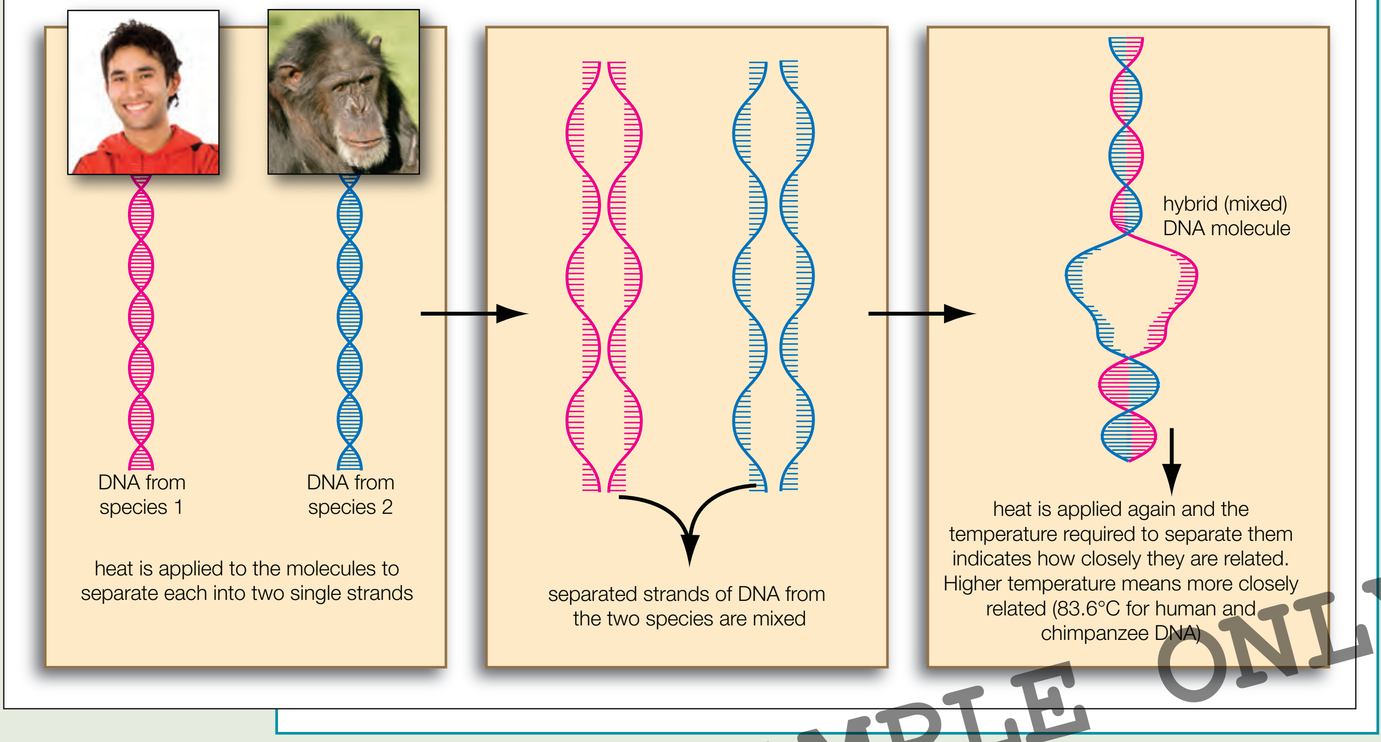



**Figure 1.12** The process of DNA hybridisation

and print out the entire sequence of bases, which are then compared. For example:

T T A C G T A C A T T C G
T T A C G A T T T A A G C

- There are fewer differences in base sequences in animals that are closely related.

**Task:** From the graph in Figure 1.13, determine whether humans diverged from kangaroos or rodents more recently. Justify your answer.

#### Conclusions for biochemical evidence

Closely related species have:

- fewer differences in DNA sequences
- fewer differences in amino acid sequences.

These are evidence that they have diverged more recently from a common ancestor.

#### Advantages of biochemical evidence for evolution

- It allows comparisons of organisms where homologous structures are not available.
- Results are quantitative and the degree of difference can be measured, allowing judgements to be based on scientific criteria rather than observation (such as comparative anatomy).
- DNA sequencing, a more advanced technique, reveals more detailed information than the other biochemical techniques.

#### Limitations of biochemical evidence

- Some changes in DNA/amino acid sequences may not be identified if a particular change that occurred in the past has reverted back to its original form in a more recent organism.
- The techniques are complex, expensive and rely on highly specialised micro-computer technology. They can therefore only be performed in high technology laboratories.

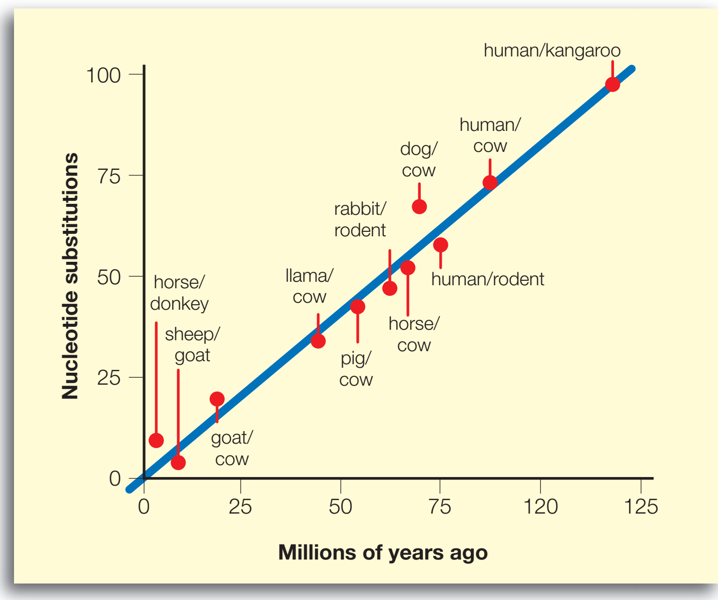
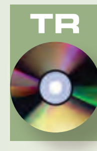
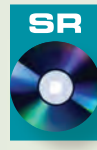


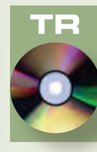

**Figure 1.13** DNA sequencing results for studies of genes for cytochrome c



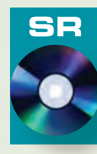

Photograph of DNA sequencer and its output




Extension activity—Immunology: antigen–antibody compatibility




Additional information on biochemical evidence




Extension activity—PFA H3 based task

# Changed thinking about evolutionary relatedness—the impact of technology

SECONDARY-SOURCE INVESTIGATION

BIOLOGY SKILLS

H12.4

H14.1; H14.2; H14.3

PFA H1

TR Student investigation websites

SR Scaffold—PFA H1

TR Table and answers

SR Recommend websites and extension activity

## Advances in technology have changed the direction of scientific thinking

- *use available evidence to analyse, using a named example, how advances in technology have changed scientific thinking about evolutionary relationships*

Biological explanations are provisional and biological views at any time depend on the evidence available to support these views. As technology advances and understanding increases, new evidence that is gathered may further support a view or it may refute that view, leading to the development of new biological thinking and, at times, new theories. In the example below, we examine how advances in technology have changed scientific thinking about the evolutionary relationships between humans, gorillas, chimpanzees and orangutans.

## Primate evolution

Primates are a group of mammals that include lemurs, monkeys, apes and humans. In Darwin's book *The Descent of Man* (1871), he dealt with the subject of the evolution of humans from apes. This concept was extremely controversial then and to some extent remains so today, not due to a lack of scientific evidence, but rather because of difficulties in finding a clear divide between where science (which relies on evidence) ends and religion (which encompasses faith) begins.

Darwin used evidence based on comparative anatomy, embryology and behaviour to support his idea of human evolution. There was not much palaeontological evidence available at that time, but subsequent fossil discoveries supported his views.

The classification of primates has changed within the last century, not only as a result of further fossil finds, but due to advances in technology which allow biologists to use a growing number of ways to analyse evolutionary relationships and infer ancestry. Data obtained by advanced molecular technology (including amino acid sequencing, DNA hybridisation and DNA sequencing) have revealed new biochemical evidence. This has had great significance in changing scientific thinking with regard to the evolutionary journey of apes and how they should be classified.

### Historical background to studies of evolutionary relationships in apes and humans

In the 1860s Ernst Haeckl classified orangutans, gorillas and chimpanzees in one family (*Pongidae*) and placed humans in a separate family (*Hominidae*) (see Fig. 1.14a). This was based on evidence of **structural anatomy** of the hind-limb, 'knuckle walking' and the enamel on their teeth. These studies showed that gorillas and chimpanzees were more closely related to each other than to humans or orangutans.

In the 1960s and 1970s, the advanced technology of **amino acid sequencing** was used. The expectation was that the structural anatomy findings would be confirmed. However, the amino acid sequencing of the proteins *cytochrome c* and *haemoglobin* revealed identical sequences in chimpanzees and humans, but one amino acid difference between these species and gorillas.

Further progress in the understanding of molecular biology led to the use of even newer technologies—**DNA sequencing** and **DNA hybridisation**. Biologists have compared hundreds or even thousands of base pairs by sequencing *entire genes* for comparison, as well as sequencing *mitochondrial* DNA. The use of *hybridised* DNA to further compare the these technologies confirmed the result of the amino acid sequencing techniques:

- African apes (gorillas and chimpanzees) are more closely related to humans than to orangutans, which diverged much earlier.
- Humans and chimpanzees have the smallest difference between the base sequences in their DNA (1.6–2.4% difference), whereas the DNA of

humans and gorillas show slightly more variation, but the greatest difference occurs when comparing these two species with orangutans.

Data from this advanced molecular technology were used to establish a new phylogenetic tree that represents humans and chimpanzees as the two groups to have diverged most recently from a common ancestor; gorillas appear to have diverged slightly earlier and orangutans are a 'sister' species to the other three groups and diverged from them much earlier. These results have therefore changed scientific thinking about evolutionary relationship, leading to the development of an alternate way of classifying these primates (see Fig. 1.14b).

Use the website below as a further secondary source to analyse information on the evolutionary relatedness of primates.

**Investigation tasks: relatedness of humans, chimpanzees and gorillas; and also to test and validate models, theories and laws: www.nap.edu/readingroom/books/evolution98/evol6-d.html**

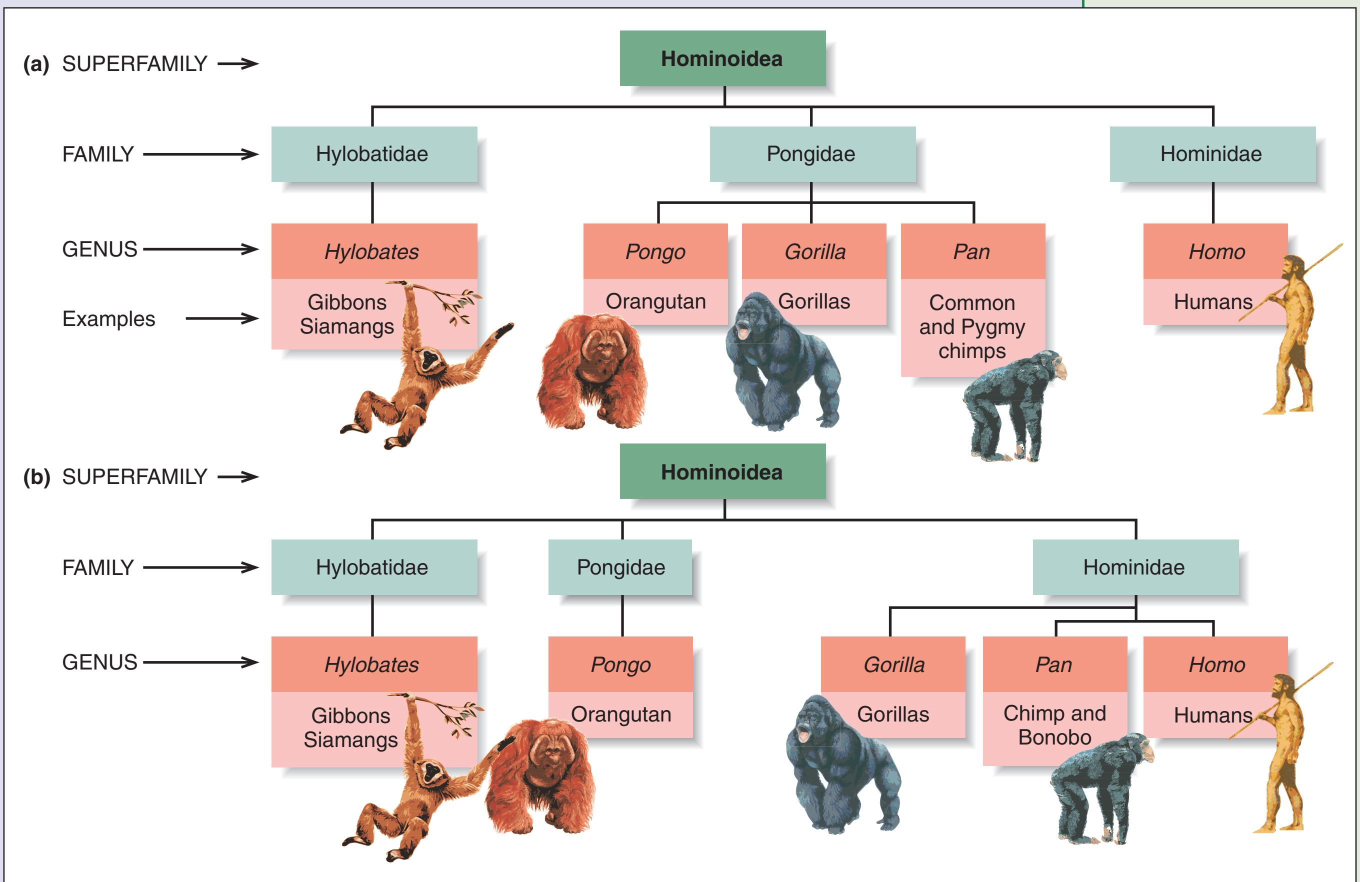



**Figure 1.14** Classification of great apes and humans: (a) traditional classification based on structural anatomy shows the great apes grouped in a family separate from humans; (b) modern alternate classification that groups gorillas, chimpanzees and humans in one family

# Development of the theory of evolution—history and social and political influences

SECONDARY-SOURCE INVESTIGATION

BIOLOGY SKILLS

TO COME

PFA

H1

- ***analyse information from secondary sources on the historical development of theories of evolution and use available evidence to assess social and political influences on these developments***

## Historical development of the theory of evolution

In order to look at the historical development of a theory, we need to examine the *past ideas* about the principle or concept compared with the *currently accepted ideas*.

### Early beginnings

The concept that we call 'evolution' today had early beginnings many thousands of years ago (during the time of Aristotle), when individuals such as Thales and Axanimander (550–620 BC) first considered the idea that organisms may change over time. These views, however, were not based on observation and there was no proposal of a testable theory or mechanism explaining how it could occur.

### Social and political influences

Science is greatly influenced by society, including cultural and personal beliefs and the general way in which the world is viewed. These world views are in turn influenced to a large extent by politics, which determines the framework that governs everyday life. In this investigation we will look at the way in which social and political factors influenced the historical development of theories of evolution.

## Part 1: History of the theory of evolution (group work is recommended)

Research (and record in the form of a table) the main contributions of the following biologists to the theory of evolution. Analyse information from the textbook on pages xxx–xxx as well as information from recommended websites (see the Student Resource CD). Suggested headings that may be used to structure your answer follow (and the table provided on the Student Resource CD may be used to complete this activity).

**Scientists**

- Jean Baptiste Lamarck
- Charles Darwin
- Alfred Russell Wallace
- Stephen Jay Gould and Niles Eldridge

### Suggested headings for information on the contribution of each scientist

- Name and outline of the theory proposed
- Evidence on which the theory is based
- Contradictory evidence against the theory
- The response of scientists (whether they accepted or rejected the research and reasons)
- Social and political background (see Part 2).

This information may be presented in the form of a table (see the Student Resource CD for the table and recommended websites).

## Part 2: Social and political influences

- Investigate the social background and the political events and thinking prior to, and at the time of, developments in the theory of evolution. Use information on pages xx–xx that follow as well as the information and recommended websites on the Student Resource CD to do the tasks below.

1. List the dates of influential events at the time (listed below) and define each one:
   —the Enlightenment ('the Age of Reason')
   —the Industrial Revolution
   —The French Revolution
   —the rise of Great Britain as a world power
   —the American Civil War.
2. Summarise the scientific thinking (philosophy)/acceptance by society during:
   —The Enlightenment
   —the 1600s and 1700s in France
   —the 1800s in Europe (and particularly in England)

**3. Timeline activity**

Draw a timeline showing the chronological order of the historical development of the theory of evolution. Draw lines above the line to list developments in the theory of evolution. Include the name, date and contributions of each scientist. Below the line, insert lines at the

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Tables for use in the investigation

appropriate dates with details of the social and political influences prevalent at the time.

### 4. Answering the dot point

Assess the social and political influences on the development of the theory of evolution, using the available evidence.

The information summarised in your timeline (as well as any other information you have collated) provides the evidence you need. Answer the questions below as a guide to answering the dot point:

*'Then and now'*

Describe:

- the *accepted scientific thinking* at the time prior to the current theory of evolution
- the *current scientific thinking*/theory
- *new discoveries and ideas* that led to the proposal of the new theory (including when the discoveries were made and by whom).

Discuss:

- the *response of scientists and society* (whether they accepted or rejected the research and reasons) and the social and political thinking at the time.

Assess:

- the social and political influences on developments in the theory of evolution (*or* use the 'assess' verb scaffold—see the Teacher's Resource CD).

### Conclusion

Students should write their own conclusion, making sure they 'assess' (i.e. sum up their judgement based on the criteria they have discussed).

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Answers to activities, relevant websites and teacher resources

## Secondary source information

### Lamarck

Evolutionary theory, based on observable evidence that living things seem to change over time, had its beginnings in the mid to late 1700s. However, it was only in the early 1800s that the theory of evolution was widely acknowledged or given serious consideration, when Jean Baptiste Lamarck proposed a mechanism for evolution. Lamarck was involved in research in the 1790s at the height of the French Revolution and it was in 1800 at his *Floreal* lecture that he outlined his theories regarding evolution for the first time. He then followed this up with three scientific publications (published 1802–22).

Lamarck and some of his predecessors understood evolution to encompass two driving forces:

1. a change in animals from simple to complex forms
2. adaptation of animals to their local environments (making them different from each other).

These ideas challenged the comfortable idea at the time that species were created independently and did not change over time. The assumptions outlined above form the basis for all evolutionary thinking, but the *mechanisms* proposed (that is, the ways in which this change could take place) were open to discussion and questioning, to be accepted or discredited. Lamarck's mechanism for evolution was by '*the inheritance of acquired characteristics*' based on '*use and disuse*' of body parts. His theory

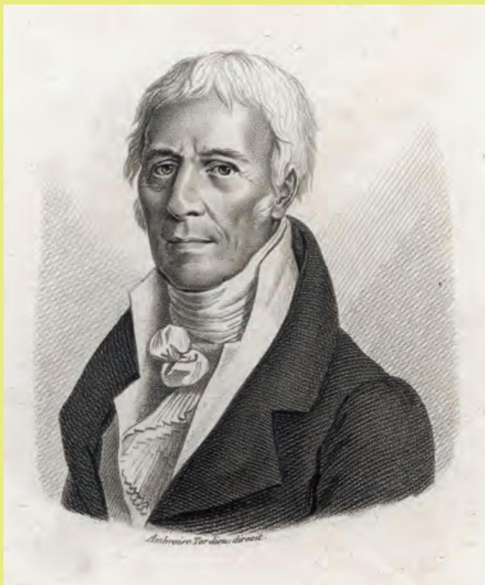
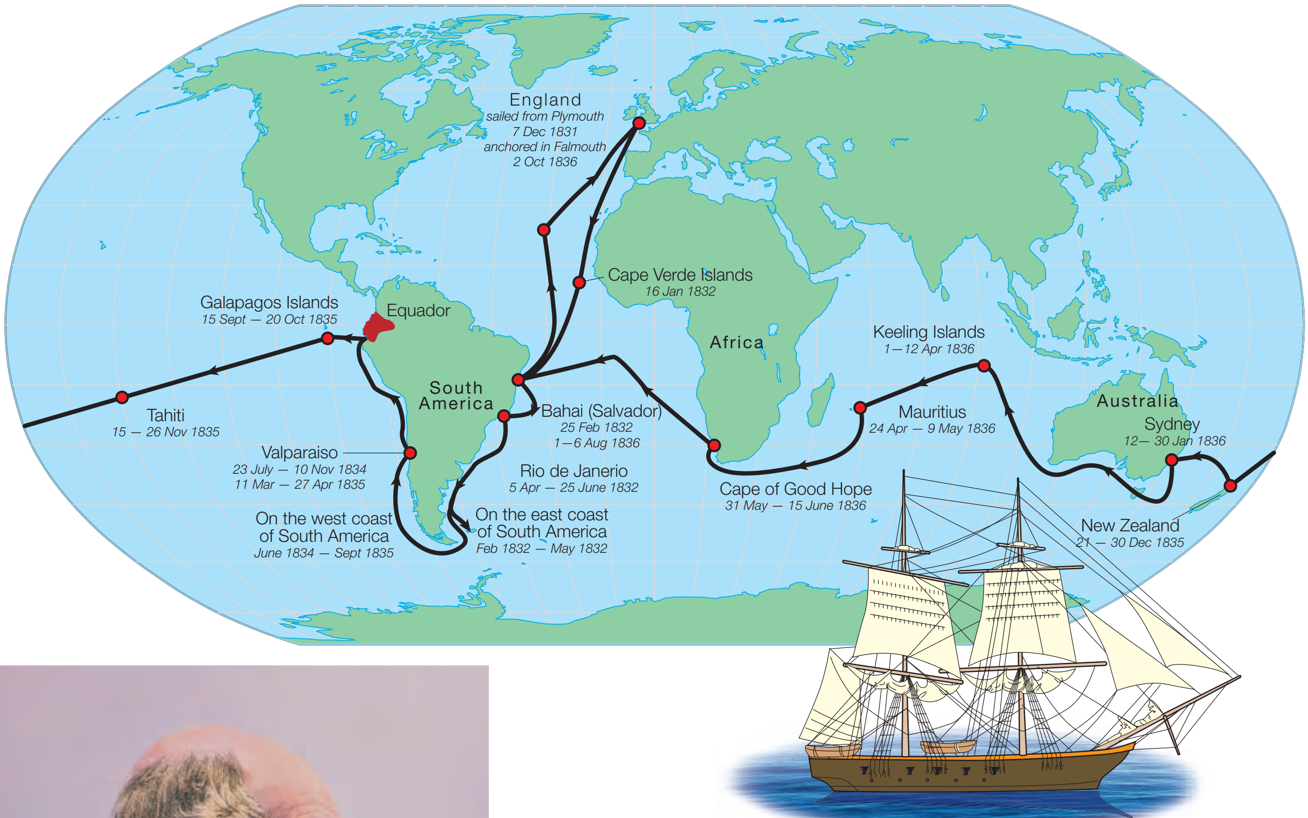


**Figure 1.15** Jean Baptiste Lamarck

was rejected on the grounds that acquired characteristics cannot be inherited. Despite the eventual rejection of his theory, Lamarck's ideas challenged the religious and social order of the times and opened the way for new ideas to be put forward, the end result of which was the currently accepted theory of evolution by natural selection, proposed by Charles Darwin and Alfred Wallace in the late 19th century.

### Darwin and Wallace

Charles Darwin was born in England, educated at a local public school and began his university education in Edinburgh, studying medicine, but found it rather gruesome, so he spent much of his time



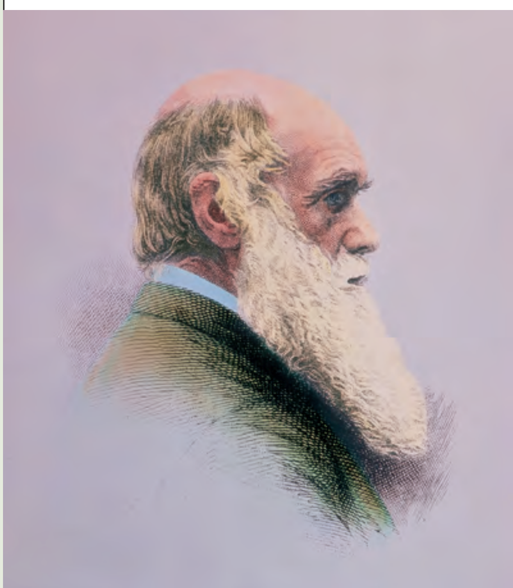



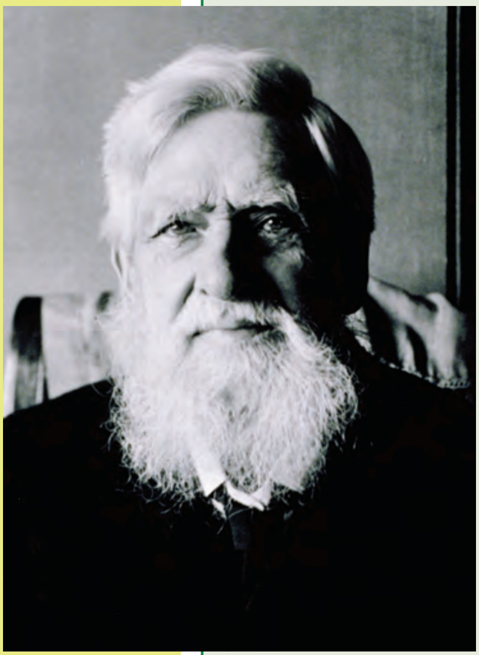
**Figure 1.16** Charles Darwin on his voyage on the HMS *Beagle* to the Galapagos Islands, off the coast of Ecuador

instead with the zoologist Robert Grant, a follower of Lamarck's ideas. Darwin changed his course of study to Divinity at Cambridge University, but once again his interest in nature resulted in a professional association with a professor and naturalist, John Henslow. It was common back then for a naturalist to accompany the captain of a ship on his voyages and so Henslow recommended Darwin for the position of naturalist on the ship HMS *Beagle*, resulting in his 5-year voyage (1831–36) as companion to the captain.

During this time, Darwin read widely, made numerous observations and collected an enormous number of specimens which he used as evidence for his theories. His well-documented observations included studies on the Galapagos Islands (off the coast of Ecuador, a country in the north-west of South America, on the equator) and in Australia. Darwin had read books and papers by eminent geologist Charles Lyell and economist Thomas Malthus; these probably influenced his thinking. On his return to England, Darwin spent more than 20 years studying the specimens that he had collected, questioning their origins, comparing their variations, experimenting and writing up his theory. Darwin's ideas developed gradually over many years, but he kept his theory to himself (probably because he was aware of the uproar such ideas would cause among theologians at the time) until he received a letter outlining a similar theory from Alfred Wallace.

Alfred Russell Wallace, also born in England, was 14 years younger than Darwin. He was an English teacher and interested in collecting specimens of plants and animals. He had read books and papers published by numerous scientists of the time and his travels included trips to South America (1848–52) and to the Malay islands in Indonesia (1854–62). In 1858, while suffering from malaria on one of his trips to Indonesia, Wallace wrote a letter to Charles Darwin in which he outlined his own theory of evolution by natural selection. This theory was


**Figure 1.17**
Alfred Wallace and the 'Wallace line' which separates the Asian-type fauna from the Australian-type fauna, supporting the idea of species isolation in evolution



remarkably similar to one that Darwin had formulated independently 12 years previously and never published, probably due to his awareness of the social and political upheaval it would cause. Wallace's letter was the trigger that prompted Darwin to present his ideas of evolution by natural selection. With the encouragement of colleagues, Darwin and Wallace's papers were presented jointly at a seminar in London. Darwin felt the urgent need to complete his book, *On the Origin of Species*, which was published in 1859, detailing the evidence of his findings and the formulation of his theory of evolution by natural selection.

### Neo-Darwinism

Scientists more recently have applied concepts of Mendelian genetics to support and explain Darwin and Wallace's ideas on random genetic variation leading to gradualism and the formation of new species. It was only in the first decade of the 20th century, after Mendel's experimental results were confirmed and accepted, that the Darwinian theory of evolution was extended to include the genetic processes involved in natural selection. Therefore the explanation of Darwinian evolution based on modern genetics is what we term 'Neo-Darwinism'.

In Chapter 2, we will learn in greater detail about Mendel's 'heritable factors', which could later be explained in terms of genes, marking the beginning of modern-day genetics. Based on his research, Mendel became known as the '*father of genetics*'.

### Punctuated equilibrium

This is addressed later in the text (see page XXX).

# 1.5 Punctuated evolution

■ ***describe the concept of punctuated equilibrium in evolution and how it differs from the gradual process proposed by Darwin***

The theory of punctuated equilibrium proposes that evolution occurs in short bursts of rapid change, followed by long periods of stability within populations. It has become popular over the last 30 to 40 years and, like all science, requires that old knowledge be re-examined in the light of new evidence. The theory of punctuated equilibrium was put forward in the 1970s by Stephen Jay Gould (Museum of Comparative Zoology of Harvard University) and Niles Eldridge (American Museum of Natural History), based on fossil evidence. They suggest that if evolutionary change is gradual, it could be predicted that there would be fossilised remains showing these ongoing changes. Darwinists use transitional forms to support their perspective of 'gradualism' (a gradual change over an extremely long period of time). Interestingly, Gould and Eldridge also use fossil evidence to support their theory. Many fossilised remains show millions of years going by without any noticeable evolutionary change to most species. For example, soft-bodied organisms dominated the seas for hundreds of millions of years and then, in a period of a few million years, they disappeared and were replaced by organisms with shells and skeletons. Horseshoe crabs have remained almost unchanged for 200 million years. Supporters of punctuated evolution argue that if evolution occurs gradually, as proposed by Darwinists, there should be a much greater diversity among living organisms than actually exists. Because the fossil record is incomplete, it is difficult to come to an agreement on the rate of evolutionary change. However, the theory of punctuated equilibrium does not call into question the basis of the Darwin-Wallace theory of evolution—that it occurs by natural selection, the question asked is whether it occurs in short bursts of rapid change, or gradually over a long period of time.

**Figure 1.18** Stephen Jay Gould, one of the proponents of the theory of punctuated equilibrium

## REVISION QUESTIONS

1. Distinguish between the terms 'selective pressure' and 'competition'.
2. Outline the role of heredity and variation in the process of evolution by natural selection.
3. Describe one example of a transitional form and explain how it supports the theory of evolution.
4. Compare convergent and divergent evolution, using one example of each.
5. Distinguish between the terms 'analogous' and 'homologous' in relation to limb structure.
6. Discuss the advantages and limitations of using biochemical technology to determine evolutionary relatedness between living organisms.
7. Compare the concept of punctuated equilibrium in evolution with Darwinian evolution. Present your answer in the form of a table.
8. Chimpanzees are more closely related to humans than to orangutans. Explain how advances in biochemical technology have changed scientific thinking about the relationships between the organisms described above and use evidence to justify the statement.
9. Critically evaluate the impact of Lamarck's and Wallace's work on that of Charles Darwin.
10. Analyse the ways in which theories in biology are tested and validated, using the theory of evolution as an example.

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Answers to revision questions