Chapter 3
The Theory of Evolution

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Abstract This chapter explores the meaning of evolution within the background of the recognition of the phenomenon as the single most dominant theme in present-day biology, and provides basic tenets that undergird its occurrence. This is followed by a discussion of the evidence of evolution through fossil record, anatomy and chemical composition, geographic distribution, and genetic changes, as well as the applications of evolution in medicine, agriculture and industry. There is an overview of the timeline of evolution, as well as some creationists' perspectives of Young Earth Creationism (YEC), Old Earth Creationism (OEC), Intelligent Design (ID) and Theistic Evolution (TE), with a warning that, in every case where creationist beliefs come up, teachers should exercise caution and handle this in such a way as to be respectful of students' views, especially where religious sentiments are apparent. The chapter ends with further advice for teachers to unequivocally impart the message that the theory of evolution is supported by an overwhelming body of evidence and is fully accepted by scientists.

Keywords Evolution · Adaptation · Natural selection · Survival of the fittest · Fossil record · Anatomy · Chemical composition · Genetic changes · DNA code · Humans · Young earth creationism · Old earth creationism · Intelligent design · Theistic evolution

Introduction

The process by which nature selects, from the genetic diversity of a population, traits that would make an individual more likely to survive and reproduce in a continuously changing environment is termed *evolution*. So, over several years and several generations, the full diversity of life on Earth is expressed. Evolution is the

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single most dominant theme in biology today. It is one of the most fundamental organising principles of the biological sciences. Evolution emphasises the *relatedness* of life rather than its differences. Evolution provides a scientific explanation for why there are so many different kinds of organisms on Earth and how all the organisms on our planet are part of an evolutionary lineage. It demonstrates why some organisms that look different are in fact quite related, while other organisms that may look similar are only distantly related. Evolution, indeed, accounts for the appearance of humans on Earth and shows our biological connections with other living things, as well as detailing how various groups of humans are related to each other and how we acquired the traits that we have. Evolution facilitates the development of effective new ways to protect humanity against bacteria and viruses that continue to evolve. It provides a *framework* through which we study and understand life on Earth and it is also a way of bringing together many diverse aspects of the complexity of life. A characteristic of life is the ability of organisms to *adapt* to their environments as they change over time. For instance, all bacterial pathogens have become at least somewhat resistant to antibiotics over the past six decades or so. Thus, over time, organisms may change in their appearance and other visible characteristics, as well as in their genetic structure. Still, over long periods of time, these changes become significantly different from what they were at the start. Since the changes take 10,000 s to millions of years to occur, no one has witnessed the origin of a major new animal or plant group. Even so, scientists do have an increasing amount of fossil data that show the evolution of one species from another, step by step and, currently, with molecular techniques it is possible to observe and measure the rate of evolution in many species.

The theory of evolution was developed by Charles Darwin in the mid-1800s after a lifetime of travel, observation and experimentation. Darwin made detailed notes on the variations in species as well as their relationship to fossil forms. He also looked at breeds of domesticated animals, such as dogs, and noted the variations caused by selective breeding (*human-directed evolution*). So, if humans can do this in thousands of years, nature can just as well do this given millions of years. Basically, the *theory of evolution by natural selection* hinges on the following ideas:

- all living things consist of a unique combination of chemicals organised in unique ways – variations occur in every species and no two individuals of a species are alike;
- species' populations are able to adapt to gradually changing environments – the same species in different parts of the world have different tolerances and slightly different characteristics to survive the local conditions in which they live;
- most of the variations have a genetic basis – variations can be passed on to the offspring;
- each species produces more offspring than will survive into maturity;
- those individuals whose variations best fit their environment will more likely survive and reproduce – there is a *struggle for existence*, with the *survival of the fittest*;

- by a process of natural selection, evolution sorts these numerous variations within a population and *chooses* the most fit combination – as the environment slowly changes and certain variations are selected over thousands of generations, new forms arise; and
- failure to evolve in response to environmental changes can, and often, does lead to extinction.

Like other foundational theories (for example heliocentric theory, cell theory and the theory of plate tectonics), the theory of evolution is supported by numerous observations and confirming experiments, so much so that scientists are confident that the basic components of the theory will not be overturned by new evidence. However, like all scientific theories, the theory of evolution is subject to continuing refinement as new areas of science emerge, or as new technologies enable observations that were not possible previously. Indeed, the past and continuing occurrence of evolution is a scientific fact: since the evidence supporting it is so strong, scientists no longer question whether *biological evolution* has occurred and is continuing to occur. Instead, scientists investigate the mechanisms of evolution, how rapidly it can take place, as well as other related questions (NAS, 2008).

Evidence for Evolution

There are four primary sources of the evidence for the occurrence of evolution:

Fossil Record Scientists have examined remains of animals and plants that have been found in deposits of sedimentary rocks and have obtained records of past changes through vast periods of time that are impossible to doubt. Such discoveries confirm the fact that there has been a tremendously large variety of living things. Some of the discoveries show species now extinct but that were transitional between some groups of organisms. This shows that species of organisms are indeed not fixed but can, and do, evolve into other species over time. In fact, what have appeared as gaps in the fossil record are actually due to data collection that as yet is incomplete. Scientists are, thus, gradually filling in the *missing links* between transitional fossil specimens as more discoveries are made. O'Neil (2013) reports that one of the first of these gaps that have been filled involved small bipedal dinosaurs and birds. This happened barely two years after Charles Darwin had published *On the Origin of Species*. In this case, a 150–145-million-year-old fossil of *Archaeopteryx* was discovered in Germany. The species had jaws with teeth, as well as a long bony tail similar to dinosaurs, broad wings and feathers similar to those of birds and, interestingly, skeletal features of both dinosaurs and birds. The discovery confirmed that, over time, reptiles evolved into birds. According to O'Neil, after this discovery there have been several other evolutionary gaps that have been filled in the fossil record, the most outstanding one from the human perspective being that between apes and our own species. He reports that, since the 1920s, hundreds of dated intermediate fossils have been found in Africa that were in fact transitional species leading from apes to humans over the last 6–7 million years.

Similarities in Anatomy and Chemical Composition All living things are very similar in their chemical compositions, as well as in their anatomical structures. Scientists have discovered that all living things:

- begin as single cells that, through division processes, reproduce themselves;
- eventually grow old and die;
- share the unique ability to create about 99% of complex molecules of proteins, carbohydrates, fats and other molecules from just 6 (carbon, hydrogen, nitrogen, oxygen, phosphorus and sulphur) of the 118 elements;
- obtain their unique characteristics from their parents, inheriting particular combinations of genes that are actually segments of DNA, which contain coded formulas for creating proteins by linking together particular amino acids in specific order; and
- show evidence of fundamental molecular unity of life, in spite of the enormous diversity of life, in that the basic language of the DNA code is the same for all living things.

Furthermore, many living things show similarities as they derive energy for growth, reproduction and repair directly from sunlight through photosynthesis, or indirectly through the consumption of green plants as well as organisms that feed on plants. Indeed, many groups of species share similar body structures. For example, the arms of humans, the forelegs of dogs as well as cats, the wings of birds, and the flat broad limbs of whales/seals all have the same types of bones – ulna, radius and humerus – as they retained these traits from their shared common ancient vertebrate ancestor.

Geographic Distribution of Related Species Scientists have discovered that major isolated land areas and islands often evolved their own distinct plant and animal species. For instance, before the arrival of humans in Australia about 40,000 years ago, there were none of the more advanced *placental* mammals such as dogs, cats, bears and horses, although there were more than 100 species of kangaroo, koala and other marsupials. In the more isolated islands such as New Zealand and Hawaii, land mammals were entirely absent. Yet, these places had many plant, insect and bird species that were found nowhere else in the world, indicating that the life forms in these areas evolved in isolation from the rest of the world (*ibid*).

Genetic Changes Widespread deaths do occur among species due to environmental changes that most members of the species cannot endure. However, because natural populations do have genetic diversity, not all individuals perish. Individuals with characteristics that allow them to survive adverse environmental conditions will survive and reproduce and pass on their traits to the next generation, thereby ensuring that evolution has occurred. Similarly, the phenomenon of bacterial evolution in the human body is the cause of antibiotic resistance – when an antibiotic medicine is not able to completely cure a bacterial infection. Selective breeding of new varieties of animals and plants also occurs due to environmental changes, as individuals lacking the desirable characteristics are not allowed to breed, with the resulting generations more commonly having the desired traits. Species such as insects and microorganisms that mature and reproduce large numbers in a relatively short period of time have great potential for fast evolutionary changes. This has resulted, for example, in humans' inability to combat the menace of insects as the pesticides used against them become ineffective.

Timeline of Evolution

Here follows the approximate timeline for the evolution of life:

3.8 billion years ago: This is currently the best estimate for the beginning of life on Earth. It is thought that the first life might have developed in undersea alkaline vents based on ribonucleic acid (RNA) instead of deoxyribonucleic acid (DNA).
3.5 billion years ago: Single-celled organisms form.
3.4 billion years ago: Rock formations in Western Australia appear.
3 billion years ago: Viruses emerge.
2.4 billion years ago: *The Great Oxidation Event*, (also called the Oxygen Catastrophe, or the Oxygen Crisis) occurs as cyanobacteria living in the oceans start producing oxygen through photosynthesis. As oxygen builds up in the atmosphere, anaerobic bacteria are killed leading to the Earth's first mass extinction.
2.3 billion years ago: The first *snowball Earth* occurs when the Earth freezes over as a result of volcanic activity. When the ice subsequently melts, more oxygen is released into the atmosphere.
2.15 billion years ago: Evidence of cyanobacteria and photosynthesis emerges.
2 billion years ago: Cells with organelles (eukaryotic cells) come into being.
1.5 billion years ago: The eukaryotes divide into three groups: the ancestors of modern plants, fungi, and animals split into separate lineages, and evolve separately.
900 million years ago: Multicellular life occurs.
800 million years ago: Multicellular animals divide into *Sponges* and *Eumetazoa*. Later, thin plate-like creatures about 1 millimetre across, known as *Placozoa,* break away from the rest of the *Eumetazoa. Placozoa* are considered to be the last common ancestor of all animals.
770 million years ago: Earth freezes again.
730 million years ago: Ctenophores split from the other multicellular animals.
680 million years ago: Jellyfish and their relatives break away from the other animals.
630 million years ago: Some animals evolve *bilateral symmetry* – they have a defined top and bottom as well as front and back.
590 million years ago: The Bilateria (animals with bilateral symmetry) split into:

- deuterostomes: these include all vertebrates and ambulacraria; and
- protostomes: comprising all the arthropods (insects, spiders, crabs, shrimp, etc.), worms, and the microscopic rotifers.

540 million years ago: Sea squirts form.
530 million years ago: True vertebrates emerge.
500 million years ago: Animals explore the land.
465 million years ago: Plants grow on land.
460 million years ago: Fish split into two groups – bony fish and cartilaginous fish.
400 million years ago: Insects emerge.
397 million years: Four-legged animals (tetrapods) emerge on land and give rise to amphibians, reptiles, birds and mammals.
375 million years ago: Tiktaalik, an intermediate between fish and tetrapods, emerges.
250 million years ago: Greatest mass extinction in Earth's history occurs. Sauropsids – mostly in the form of dinosaurs, the ancestors of mammals – survive as small, nocturnal creatures.
180 million years ago: The monotremes, mammals that lay eggs rather than giving birth to live young, break apart from the others.
150 million years ago: Archaeopteryx (*first bird*) appears in Europe.
140 million years: Placental mammals appear.
130 million years ago: Flowering plants appear.
100 million years ago: Largest land animal in Earth's history, *Argentinosaurus*, lives around this time.
70 million years ago: Grasses evolve.
63 million years ago: Primates split into two groups:

- haplorrhines – these develop into monkeys, apes and humans; and
- strepsirrhines – these eventually become the modern lemurs and aye-ayes.

50 million years ago: Whales appear.
40 million years ago: New World monkeys appear.
25 million years ago: Apes split from the Old-World monkeys.
14 million years ago: Orangutans emerge from other great apes, spreading across southern Asia, leaving their cousins in Africa.
6 million years ago: Humans diverge from their closest relatives, the chimpanzees and bonobos. Shortly afterwards, hominins begin walking on two legs.

Applications of Evolution

Knowledge of evolutionary trends has been used in many areas of human endeavour, including the following areas:

Medicine An understanding of evolution has been applied widely in the medical field. For example, the identification of the *severe acute respiratory syndrome*

(SARS) in 2002 was facilitated by using a technique, the *DNA micro-array*, which is based on knowledge of evolutionary trends. The technique identified the virus as a previously unknown member of a particular family of viruses. The genetic material in the SARS virus was similar to that of other viruses because it had evolved from the same ancestor. Following the identification, blood tests were carried out to identify people with the disease. Further efforts resulted in the identification of appropriate medicines for treatment of infected persons and the production of vaccines to prevent future infections. Knowledge of evolutionary pathways of viruses will be useful in future as these pathogens evolve into more resistant forms.

Agriculture Scientists have applied an understanding of evolution to find out the relationships existing among plants and to identify the traits that can be employed in the improvement of crops. They have therefore been identifying the genes in the DNA of plants that are responsible for their advantageous traits so that these traits can be incorporated into other crops. Indeed, processes of evolutionary change have been used to transform many wild plants and animals into crops and domesticated animals. Farmers do save seeds from plants with particularly favourable traits. They later plant those seeds in the next growing season. This process of artificial selection creates a variety of crops with characteristics particularly suited for agriculture. According to NAS (2008), farmers have modified wild wheat so that seeds remain on the plant when ripe and so can be separated with ease from their hulls.

Industry Natural selection principles have found wide applications in industries. Chemists, for instance, have applied these principles in the development of new molecules with specific functions. They start by creating variants of an existing molecule. The variants are then tested for the desired function. New variants are generated from the variants that do the best job. By continually repeating this selection process, chemists obtain molecules that have a greatly enhanced ability to perform a particular task. For example, new enzymes that can convert cornstalks and other agricultural waste into ethanol with improved efficiency have been created through the application of this technique.

Creationist Perspectives

Creationism is the belief that life originated through a process governed by a supernatural entity. In contrast, the theory of evolution holds that humans and other species are products of natural selection and random mutation that gradually, over long periods of time, produce life forms that are more complex from simple life forms. Henry Morris is generally regarded as the father of modern creationism. Dr. Morris, a hydraulic engineer, in liaison with the theologian, John Witcomb, published *The Genesis Flood* in 1961, which has been widely regarded as the handbook of creationism (Rudoren, 2006). There are different perspectives on creationism and it is to these that I now turn:

Young Earth Creationism (YEC) Young Earth Creationists believe that the Earth, as well as its lifeforms, were created in their present forms by a divine entity approximately 6000 to 10,000 years ago. YEC is thus based on literal interpretations of the Book of Genesis.

Old Earth Creationism (OEC) Old Earth Creationists maintain that the Earth and its lifeforms were created by a supernatural entity, much like the YEC. However, OEC accepts the scientific evidence for the age of the Earth and of creation in the Book of Genesis as being of unspecified length, thus stretching out to fit the results of scientific studies.

Intelligent Design (ID) Intelligent Design accepts an old Earth and most science, but maintains that some features of living things as well as the universe are best explained from the perspective of an *intelligent cause* rather than an *undirected process* such as natural selection. So, while science provides two explanations for evolutionary trends (that is, necessity or *natural law* and chance or *variation*), ID adds a third explanation, *design*, which takes it out of the world of science. ID, thus, takes the position that scientific explanations are insufficient in explaining the apparent design in nature. ID does not accept that genetic mutation and natural selection (both totally unguided processes) could have brought about life as we know it. ID, therefore, postulates the intervention of a transcendent intelligent designer as the best explanation. Mulherin (2014) thinks that the argument for ID is more of the *god-of-the-gaps* argument and that, as science develops, the gaps in knowledge shrink and squeeze out the need for a designer. Indeed, the tenets of ID are not in agreement with scientific findings. Scientists have examined the various molecular systems that are claimed to result from design and have found that they could have arisen through natural processes. NAS (2008) weighs in:

> In the case of the bacterial flagellum, there is no single, uniform structure that is found in all flagellar bacteria. There are many types of flagella, some simpler than others, and many species of bacteria do not have flagella to aid in their movement. Thus, other components of bacterial cell membranes are likely the precursors of proteins found in various flagella. This similarity indicates a common evolutionary origin where small changes in the structure and organisation of secretory proteins could serve as the basis for flagellar proteins. Thus, flagellar proteins are not irreducibly complex (pp. 40–41).

Indeed, existing systems may be capable of acquiring new functions such that a particular system having one task in a cell becomes adapted through the process of evolution for a different use. The *Hox genes*, a family of regulatory genes that encode transcription factors and are essential during embryonic development, are an important case demonstrating how evolution finds new uses for existing systems. Molecular biologists have discovered that gene duplication provides an important pathway in which biological systems acquire additional functions. It is, however, important to note, as Poole (2008) opines, that, in the interests of proper science education, the rejection of the *ID argument for design* as a bad argument should not be presented as dismissing the *traditional belief in design* itself. This is because biological evolution anchored on the concept of *chance* and *selection* does not preclude design, especially in consideration of genetic algorithms where experts use computers to mimic the molecular processes involved in sexual reproduction to work out optimum conditions for solving a wide range of problems.

Theistic Evolution (TE) TE takes the position that, although evolution occurred, a Creator or intelligence was involved in the process. It is the view of those who believe that God is responsible for life, the universe and everything ultimately, but who also accept the findings of science. While they accept that evolution is the best explanation of the data, they nonetheless do not accept the naturalistic philosophy that embodies scientific explanation.

Concluding Remarks

Biological evolution provides the key to understanding the principles governing the origin and extinction of living things. It allows scientists to determine how and why organisms have become the way we find them, as well as the processes currently acting to modify their present state. Evolutionary biology has the capacity to contribute to humanity's awareness of the consequences of environmental disturbances such as deforestation, application of pesticides and global warming. Biological evolution is therefore one of the most important ideas of modern science, as it provides the basis of the modern biological sciences with applications as well in many other scientific and engineering fields. Since evolution has the potential to serve as an important foundation of some key science disciplines, it is important that students are assisted to learn about and understand the evidence, mechanisms and implications that undergird it. Even so, it is sometimes the case that, when teaching evolution, situations arise indicating some doubts among the students based on cultural or religious backgrounds. Reiss (2008) advises that if questions or issues about creationism and intelligent design arise in the course of a lesson, such opportunities could be utilised to illustrate a number of aspects of how science works, to wit: need for evidence to test ideas and develop scientific theories; that there are some questions that science cannot currently answer; that scientific knowledge and ideas change over time; and that the scientific community plays a leading role in validating these changes. In every case where creationist beliefs come up, teachers should exercise caution and handle the situation in such a way as to be respectful of students' views, especially where religious sentiments are apparent. However, the teacher should unequivocally impart the message that the theory of evolution is supported by an overwhelming body of evidence and is fully accepted by scientists.

Summary

In this chapter, I have discussed the meaning and tenets of evolution as well as evidence, timeline, and applications of evolution. Evolution is the single most dominant theme in biology today. It is one of the most fundamental organising principles of the biological sciences. It emphasises the relatedness of life rather than its differences. Evolution provides a scientific explanation for why there are so many different kinds of organisms on Earth and how all the organisms on our planet are part of an evolutionary lineage. Other topics discussed in the chapter include young Earth creationism, old Earth creationism, intelligent design, and theistic evolution.

Recommended Resources

European society for evolutionary biology https://www.scientia.global/the-european-society-for-evolutionary-biology/

Society for integrative and comparative biology https://sicb.org/

Society for the study of evolution https://www.evolutionsociety.org/

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