

## Chapter 22: Evolution

1. Describe the major ideas on evolution and related topics that had a significant influence on Charles Darwin as he developed the concept of evolution by natural selection.
2. Describe the logical reasoning behind Darwin's concept of natural selection.
3. Explain the terms microevolution and macroevolution (in their true scientific meanings), and describe how microevolution can lead to macroevolution.
4. Discuss these major lines of evidence for evolution:
  - fossil record
  - anatomical evidence (comparisons, vestigial structures, “design” flaws)
  - distribution of organisms
  - developmental comparisons
  - molecular comparisons
5. Explain how fossils are dated.
6. Discuss how DNA sequence comparisons and “molecular clocks” work.
7. What is the “modern synthesis”?

### I. Historical perspective – ideas on evolution and related topics up to Darwin

#### A. divine design and perfection model

1. espoused by Aristotle, the ancient Greek philosopher (284-322 B.C.) whose ideas on biology dominated most thinking on the subject until the renaissance
2. species were viewed on a scale from simple to complex
3. all organisms were seen as moving toward perfection (which was associated with complexity)
4. based on divine intervention and design (thus supernatural, outside the true realm of science)
5. now discredited in biology, but still part of the social consciousness

#### B. fossils

1. fossils were known for centuries before Darwin
2. fossils reveal organisms unlike any living today, and the idea that some fossils represent species that had become **extinct** was recognized even by Leonardo da Vinci (1452-1519)

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### C. acquired traits

1. mostly associated with Lamarck (1744-1829)
2. still focused on a model of organisms driven toward complexity, but involved an explanation with natural causes
3. postulated that changes or “acquired characteristics” during an organism’s life could be passed on to offspring
4. famous example was Lamarck’s model for how giraffes developed long necks – he claimed that stretching of the neck in one generation would lead to offspring with longer necks
5. understanding of genetic inheritance has led to rejection of acquired traits models

### D. birth of modern geology – Lyell, **uniformitarianism**, and the ancient Earth

1. prior to the early 1800s, the world view of most was that the Earth is very young (around 6000 years old)
2. in the early 1800s, geologists began to apply scientific reasoning to studies of geological processes, and quickly recognized that these processes require that the Earth be very old (billions of years) to occur naturally
3. this “**uniformitarian**” model of geological processes was made famous by Lyell’s *Principles of Geology*, which influenced Charles Darwin
4. the uniformitarian model is essentially the basis of geology today; confirming tests of this model include dating rocks using radioisotope ratios (more on that later)

### E. artificial selection

1. it was well known that domesticated animals and plants had been breed over centuries by humans to produce different varieties, indicating that the characteristics of a species can be modified by selection
2. some examples are different breeds of dogs and the “wild cabbage” lineage of cabbage, broccoli, cauliflower, Brussels sprouts, collards, kale, etc.

### F. **population limits** that would allow selection to act naturally were recognized

1. Malthus (1766-1834) wrote the most influential works on this subject
2. mathematically, populations will grow geometrically if unchecked
3. food supplies rarely can be expected to grow faster than arithmetically, thus putting a limit on population growth

## II. Darwin’s voyage

- A. Charles Darwin (1809-1882) received a degree in theology, but also was trained in the type of field biology common in the early 19<sup>th</sup> century (most prominent biologists of the time were field biologists who studied and classified organisms in their natural environments)

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- B. Darwin signed on as the captain's companion on board the H.M.S. *Beagle*, on which he took a five-year voyage from 1831-1836 exploring South America and surrounding islands, as well as islands in the South Pacific
- C. His private work on the voyage was as a naturalist, collecting and cataloging thousands of species
- D. He was most impressed by the similarities between species in the Galapagos islands (in the Pacific west of Ecuador) and their similarities to species from South America; this did not fit well with the divine design model that he had been trained under and that was still prominent at the time
- E. There was much discussion by immediate predecessors and contemporaries of Darwin about how the divine design model did not mesh well with observation of the extremes of variation among species, the idea of extinct species represented in the fossil record, and the functional similarities between the anatomy of extremely divergent species; the idea that evolution occurs thus was "in the air" at the time, but attempts to find a convincing mechanism fell short (such as Lamarck's acquired characteristics model)
- F. Recall Darwin's theological training – Darwin was well aware of the impact that a workable, testable theory of evolution would have, and the intense controversy and scrutiny it would draw; thus, while he worked out most of his theory of evolution shortly after his trip on the *Beagle*, he spent 20 years accumulating evidence and doing experiments before finally publishing the idea
- G. Darwin was spurred on to publish when Alfred Russel Wallace shared his independent work where he had reached similar conclusions to Darwin; they first presented the theory of evolution by natural selection together in 1858
- H. Darwin published his first version of the book *On the Origin of Species by Means of Natural Selection* in 1859; in it, he laid out the entire argument with all of the evidence that he had been gathering ever since his voyage on the *Beagle*
- I. Darwin's book had immediate and dramatic impact; the force of his argument and evidence convinced many scientists quickly, but of course it stirred tremendous controversy as well; Darwin made several revisions of his work in response to some of the most reasonable criticisms, as well as focusing on human evolution in *The Descent of Man* (1871)

### III. Darwin's theory: evolution occurs by **natural selection**

- A. Darwin proposed that species evolve by natural selection; his theory of evolution was based on four general observations:
  - 1. **overproduction** – each species produces more offspring than will survive to maturity
  - 2. **variation** – individuals in a population vary, and some of the variation is heritable (this was expanded by others later, as genetics came to be understood)
  - 3. **competition** – there is competition among the individuals of a population for limited resources (struggle for existence)

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4. **differential reproductive success** – individuals that possess more favorable characteristics (in the pool of variation) are more likely to survive and reproduce; those with less favorable characteristics are less likely to survive and reproduce
- B. thus, natural selection will produce a population of individuals more suited to their environment through time
- C. when populations are separated (such as the geographic separation of islands from each other and a nearby continent), natural selection on two separate populations can produce two distinct populations with different characteristics – resulting in two separate species
- D. note that for this theory to explain the current variety of species on Earth, there is a need for a long amount of time for natural selection to produce the variety observed; thus, the idea of an ancient Earth hundreds of millions to billions of years old is crucial
- E. note also that this theory really has two major branches: **microevolution**, or changes of a population over time, and **macroevolution**, or the formation of species

### IV. Evidence supporting the theory of evolution

- A. the fossil record
  1. fossils provide direct evidence for change over time
    - fossils range from mineralized casts or imprints (most commonly of bone, teeth, and shells, but sometimes of softer tissues) to actual body parts preserved in bogs, tar, amber, or ice
    - fossils provide evidence of intermediates between extant and extinct forms
    - many relatively complete examples of transitions in body forms are known, such as the evolutionary lineage of horses and the transition of terrestrial species to modern whales
    - the fossil record provides tests of evolution as an explanation for the history of life on Earth – fossils can be dated, and the age of fossils invariably matches the predicted place of those body forms in the history of life on Earth
  2. fossils most commonly form in sedimentary rocks in aquatic environments
    - the fossil record is biased toward organisms with hard parts that lived in aquatic or arid environments, where decay is slow and incorporation in rocks can occur with reasonable speed
    - organisms that lived in places of rapid decay are thus biased against in the fossil record
- B. dating fossils
  1. relative position in rock layers
    - sedimentary layers most commonly have the youngest layers nearer the surface, and are progressively older as you go deeper

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- large-scale geological events can be used to correlate rock strata from different sites; other dating methods are also used to correlate rock strata

2. association with **index fossils** that have been dated by other means from other locations

### 3. radiometric dating

- each radioisotope has characteristic, constant rates of decay
  - some allow for measurement of when a rock was formed or when an organism died
  - example: potassium-40 decaying to argon-40
    - when magma cools to solid rock, no argon is in the rock (escapes as the rock forms)
    - once the rock hardens, the radioactive clock begins – potassium-40 in the rock decays to argon-40
    - measurement of the amounts of potassium-40 and argon-40 in the rock today are used to determine an age range for when the rock could have been formed
    - **half-life** of 1.3 billion years: used for fossils tens of millions to billions of years old
  - another example: carbon-14 decaying to nitrogen-14 (half-life of 5730 years) – used for organic remains hundreds to tens of thousands of years old
4. there are hundreds of well-studied sites with fossils that have been dated in some way; no truly incongruous fossils have been found

### C. comparative anatomy of related species

1. organs or structures that have similar form due to a common evolutionary origin are called **homologous** features
  - example: the similarity between the human arm, the dolphin's flipper, the bat's wing, and the bird's wing
  - example: plant leaves, cactus needles, flower sepals and petals
2. **vestigial structures** – a feature that once had a role in the evolutionary history of a species but that no longer functions
  - natural selection will logically lead to degeneration of unused features
  - however, it is not easy to completely remove by natural selection – thus, vestiges are left behind
  - examples: human appendix, wisdom teeth; whale pelvis and hind legs
3. not all organs or structures with functional similarity have a common origin
  - such cases are called **homoplastic** features, or analogous features
  - resemblance between homoplastic features is superficial – consider an insect's wing and a bird's wing
  - independent evolution of similar features in distantly related organisms is called **convergent evolution**

### D. distribution of plants and animals

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1. **biogeography** – the study of the past and present geographical distribution of organisms
2. organisms on islands are most closely related (in form and genetically) to those from the nearest mainland, not those from similar islands in different parts of the world
3. the modern theory of plate tectonics and reconstruction of the history of land masses on Earth explains much of the observed fossil distributions matching with timings of geographic isolations that would be expected for some modern distributions of species (example: the dominance of marsupials in Australia)

### E. related species have similar patterns of development

1. very young embryos of reptiles, birds, mammals, and humans are indistinguishable
2. studies of developmental biology are revealing the common genetic basis for such similarities – “devo/evo” study is one of the hottest fields in biology today

### F. molecular comparisons between organisms

1. the “big test” for the theory of evolution by natural selection was this:
  - evolution by natural selection on inherited traits predicts that genetic sequence information will provide a record of evolutionary change and evolutionary relationships
  - these genetic records should correlate with evolutionary relationships that have been established by other means, such as biogeography and comparative anatomy
  - evolution has passed this test with flying colors
2. the virtual universality of the genetic code is compelling evidence of a common ancestor
3. changes in proteins and nucleic acids provide a record of evolutionary change
  - DNA sequencing provides a means to measure genetic similarities and differences between species
  - sequences of amino acids in proteins can also be used – these provide an indirect comparison of DNA sequences
  - DNA and protein sequencing can be used to create a **phylogenetic tree**, diagrams showing the relatedness between species and lines of descent
  - DNA sequencing can also be used in some cases as a **molecular clock** to make some inference about when any two species **diverged** from each other (last shared a common ancestor)
    - example – humans and chimpanzees: ~98% sequence identity, diverged about 6 million years ago
4. detailed molecular studies have clearly documented microevolution in the case of the emergence of antibiotic-resistant bacteria

## V. The modern synthesis of evolutionary theory combines Darwin’s concept of natural selection with genetics

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- A. although Mendel was a contemporary of Darwin, remember that his work was largely unrecognized until around 1900
- B. how traits are inherited was central to Darwin's theory of evolution, and thus Darwin (and others) were keenly interested in finding working models of inheritance
- C. when genetic mechanisms came to be widely understood, they were quickly combined with Darwin's model in the modern synthesis, also called Neo-Darwinism or the synthetic theory of evolution
  - 1. this model emphasizes the genetics of populations
  - 2. evolution is seen as working by natural selection on individuals to change the genetic makeup of populations over successive generations
- D. mutations play a key role in providing a source of genetic variation
  - 1. without genetic variation, evolution cannot occur
  - 2. mutations are necessary to produce genetic variation
  - 3. while many mutations have no impact and many others are harmful, it is critical to recognize that some mutations are advantageous

### **VI. The central role of evolution in modern biology**

- A. the modern synthetic theory of evolution is accepted today by most biologists as a robust and well-supported model that can be trusted enough to form the central framework for the study of life
- B. nearly all biologists today agree with the famous statement by the evolutionary geneticist T. Dobzhansky: "Nothing in biology makes sense except in the light of evolution."
- C. studies of evolution itself today focus largely on the causal processes of evolution, such as the speed of evolutionary change and the role of chance in evolution, and on molecular comparisons between and within species by DNA sequencing