Chapter l: An Evolutionary Framework for Biology

I. Organisms Have Changed over Billions of Years

- Count George-Louis Leclerc de Buffon, (1707-1788) wrote his Natural History of Animals.
- He observed the similarity of different mammals' limbs. *(See Figure 1.2)*
  - He noticed pigs had toes too small to be useful.
  - Buffon suggested the limbs of mammals where inherited from a common ancestor.
  - Pigs have functionless toes because they inherited them from ancestors with fully formed and functional toes.
- Lamark, a student of Buffon, suggested a mechanism of evolution.
  - Some structures become larger from continued use from generation to generation, others become smaller from disuse.
  - This theory is currently not believed by most scientists.
- By the middle of the nineteenth century, the theory of evolution by natural selection was proposed.
  - Charles Darwin and Alfred Russell Wallace independently proposed it in 1858.
  - It states the reproductive rates of all organisms are sufficiently high that populations would be enormous if mortality rates did not balance reproductive rates.
  - Differences among individuals influence how well those individuals survive and reproduce. Any traits that increase the probability that their bearers will survive and reproduce are passed on and on.
  - Darwin called the differential survival and reproductive success, natural selection.
  - The living world is constantly evolving.
  - Life has evolved without direction or goals from atoms and molecules into organisms, including some that can even understand the basic laws of the universe.

II. Evolutionary Milestones

A. Life arises from nonlife

- All matter is made of chemicals.
- Smallest units are atoms.
- Four billion years ago, interactions among small molecules that stored useful information eventually resulted in the synthesis of larger molecules.
- Some of these large molecules, carbohydrates, lipids, proteins and nucleic acids, are found in all living systems.

B. Cells form from molecules

- Around 3.8 billion years ago, molecules came to be enclosed in compartments.
- Control over entrance, retention, and exit of molecules was possible because of the compartmentalization by membranes.
- Under present conditions on earth, cells do not arise from noncellular materials, but must come from other cells.
- For 2 billion years, cells were tiny packages of molecules, each enclosed in a membrane.
- These were prokaryotic cells, which lived separately.
- These cells obtained raw materials and energy from their environment.
- The conversions of energy and matter are called metabolism.
- A major theme of evolution is developing diverse ways of capturing external energy and using it to drive biologically useful reactions.

C. Photosynthesis changes Earth's environment

- About 2.5 billion years ago, some prokaryotes acquired the ability to photosynthesize.
- Energy of the sun was captured and oxygen was generated as a waste product.
- Oxygen increased in concentration.
- The presence of oxygen gas made much more efficient metabolism possible.
- Another effect of O_2 was O_3 (ozone) accumulation in the upper atmosphere.
- Around 800 million years ago, ozone accumulation shielded the landmass from radiation adequately to allow the movement of organisms to the land.

D. Sex enhances adaptation

- Earliest organisms reproduced by doubling their hereditary material and then dividing into two new cells.
- This is called asexual reproduction.
- Sexual reproduction, the combining of genes from two cells, appeared early in the evolution of life.
- Sexual reproduction allows genes from surviving cells to combine to generate more variable offspring.
- Variation allows organisms to adapt to a changing environment.
- Because environments are constantly changing, organisms that produce variable offspring have an advantage over those that produce genetically identical "clones".

E. Eukaryotes are "cells within cells"

- Some prokaryotic cells became large enough to attach, engulf, and digest smaller cells. *(See Figure 1.5)*
- Some cells had surviving smaller cells within them.

- This was an advantage, so eukaryotic cells with organelles evolved.
- Modern eukaryotes also have compartmentalization of their genetic information in a nucleus.

F. Multicellularity permits specialization of cells

- Around 1 billion years ago, just single celled organisms existed.
- Two developments made the evolution of multicellular organisms possible.
  - One was cell differentiation: cells being able to alter their function. Bacteria can grow vegetatively or be dormant and become spores.
  - Another is the clumping of cells. After the cells divide, they stay together.
- Once organisms could be composed of many cells, it became possible for certain cells to specialize.
- Some cells might photosynthesize, while others might anchor.
- Specialization of sex cells made complex genetic transmission mechanisms possible.
- Meiosis provided a means for genetic information to be combined in an organized fashion.

G. Controlling internal environments becomes more complicated

- Organisms need to keep constant internal environments.
- Maintenance of a relatively stable internal condition in spite of changing external environments is called homeostasis.

H. Multicellular organisms undergo regulated growth

- Multicellular organisms must regulate cell division and differentiation to achieve their adult shapes.
- This process is called development.
- Some organisms, during their lives, undergo a radical change. Metamorphosis is an example.
  - Activation of gene-based information within cells cause striking changes.
  - Just a few genes can control processes that result in a dramatically different adult organism. *(See Figure 1.6)*

I. Speciation produces the diversity of life

- All organisms on Earth today descended from the original type formed around 4 billion years ago.
- Major evolutionary events have led to more complex living organisms with larger quantities of information and more complex mechanisms for using it.
- Genetically independent groups, called species, have evolved.
- If individuals of a species are separated into isolated populations, differences may accumulate, and groups may evolve into different species.

- Since all organisms evolved from the same original organisms, and have been evolving for the same length of time, terms like primitive and lower or advanced and higher are best avoided.
- All organisms alive today are the exceptional survivors of eons of generations of life, and have survived because of their appropriate adaptation to their environments.
- See Figure 1.1 for Life’s Calendar.

III. The Hierarchy of Life

- Two ways biologists study life: study processes and structures, and study patterns of life's evolution.
- Hierarchy of interactions among the units of biology from cells to the biosphere and hierarchy of evolutionary relationships among organisms are studied.

A. Biologists study life at different levels

- Biology can be visualized as a hierarchy of units that include atoms, molecules, cells, tissues, organs, organisms, populations and communities.
- Each level of biological organization has its emergent properties.
  - Molecules have properties not found in the component atoms; organelles have properties not found in the individual molecules of which they are composed.
  - *Buildings have properties different from the steel, glass and mortar of which they are composed.*
  - These are emergent properties.
- Emergent properties exist because of interactions of many parts, and because aggregations have collective properties.
- Emergent properties do not violate the principles that operate at the lower levels of organization.

B. Biological diversity is organized hierarchically

- As many as 30 million different species inhabit Earth.
- Organisms are grouped in ways that attempt to define their evolutionary relationships, or how recently the different members of the group shared a common ancestor.
- Fossils, physical structure, and gene similarity are used to attempt an understanding of the relationships.
- Three major domains begin the scheme. These are Archaea and Bacteria (prokaryotes) and Eukarya (eukaryotes).
- Eukarya are then divided into four groups: protists, and the kingdoms of Plantae, Fungi and Animalia.
- Some bacteria, some protist, and most members of Plantae convert light energy to chemical energy by photosynthesis.

- Fungi and Animalia are also heterotrophs.
- See *Figure 1.10* for a simplified version of the hierarchical levels.
- Each individual species is identified by two names.
    - The first, genus, is a group of species that share a recent common ancestor.
    - The second name is specific to the species.
    - Modern humans are *Homo Sapiens*.
- See Figure 1.9.

IV. Asking and Answering "How?" and "Why?"

- Two major questions of biologists are how does it work and why has it evolved to work that way.
- For example: "How do these animals crawl?", "Why do they crawl?".

A. Hypothesis testing guides scientific research

- Underlying all scientific research is the hypothetical deductive (H-D) approach.
- The H-D approach allows scientists to modify and correct their beliefs as new observations and information become available.

There are six parts of the system:

1) making observations
2) asking questions
3) forming hypotheses, or tentative answers to the questions
4) making predictions based on these hypotheses
5) testing the predictions by making additional observations or conducting experiments
6) evaluating if the results of the experiments or additional observations could be expected even if the hypothesis was not true. If so, further verification is required.

B. Applying the hypothetics - deductive method

- Start out with an observation that generates a question.
- "Why do amphipods crawl on the surface of the mud rather than staying hidden within?"
- Assemble available information of amphipods and the species that eat them.
    - Sandpipers assemble once yearly on the mudflats.
    - Sandpipers feed mostly on amphipods.
    - Nematodes parasitize both the amphipods and the sandpipers.
    - Nematodes mature within the sandpipers' digestive tracts, mate, and release their eggs in the birds' feces.
    - Larvae hatch and inject amphipods.
    - Sandpipers are reinfected when they eat parasitizes amphipods.

- Generating a hypothesis and prediction: Nematodes alter the behavior of their amphipod host in a way that increases the chance that the worms will be eaten by the sandpiper.
  - Predict that infected amphipods increase activity at the surface during the day when sandpipers feed by sight.
  - Predict that only amphipods with late stage nematode larvae, those that can infect sandpipers, have this modified behavior.
- All hypotheses have a corresponding null hypothesis, which asserts there will be no such effect.
  - No differences would exist in infected versus non-infected amphipods in terms of behavior.
  - All larval stages affect their hose in the same manner.
- Testing predictions:
  - Amphipods were collected in the mud and surface, during day and night.
  - More infections were found in those found at the surface than those in the mud.
  - No such difference was found at night.
  - Collected at the surface versus the mud, amphipods were more likely to be infected by late not early stage nematode larvae.
  - This agreed with the second prediction.
- See Figures 1.11 and 1.12.

C. Experiments are powerful tools

- The essential feature of experimentation is the control of most factors, so that the influence of a single factor can be seen clearly.
- For the amphipod experiment, all were infected with nematodes at the same time or were left uninfected.
  - Those amphipod that were infected <u>and</u> were late, infective stage, were more likely to expose themselves at the surface.
  - The nematodes manipulate their host to increase their likelihood of survival. *(See Figure 1.14)*
- Experiments help isolate specific variables, but sometimes organisms behave differently in nature.
- Combinations of laboratory and field experiments are needed to test biological science related hypotheses.

D. Accepted scientific theories are based on many kinds of evidence

- Statements of biological "fact" are mixtures of observations, predictions and interpretations.
- No amount of observation can substitute for experimentation.

E. Not all forms of inquiry are scientific

- Creation science is not science.

- Science begins with observations and the formulation of hypotheses that can be tested and that will be rejected if significant contrary evidence is found.
- Creation science begins with assertions that the Earth is just 7,000 years old and that all species were created in their present forms.
- Evidence presented in the text supports that Earth is approximately 4 billion years old.

V. Biology and Public Policy

- After W.W.II, physical sciences were highly influential in shaping public policy.
- Recently, biological science has moved to the forefront.
- One reason is the importance in understanding mankind's impact on the biosphere.
- Another is the development of genetics, which provides a means to control human diseases and agricultural productivity.
- Currently, biological science is positioned between the horns of many social dilemmas.