Chapter 1- Evolution, the Themes of Biology, and Scientific Inquiry*

*Lecture notes are to be used as a study guide only and *do not* represent the comprehensive information you will need to know for the exams.

Inquiring About Life

An organism adapts to its environment via **evolution**, the process that has transformed life on Earth. Evolution is the fundamental organizing principle of biology and the core theme of this book.

Biology is the scientific study of life. We recognize life by what living things do (Figure 1.2).

Concept 1.1 The study of life reveals common themes

Connect things you learn [in biology] to a set of themes that pervade all of biology. Focus on a few big ideas will help you organize and make sense of the information you will learn in biology. There are five (5) unifying themes as you proceed through the book: 1) Organization, 2) Information, 3) Energy and Matter, 4) Interactions, and 5) Evolution

1) Theme: New Properties Emerge at Successive Levels of Biological Organization

The study of life extends from the microscopic scale to the global scale; there are different levels of biological organization (Figure 1.3). *Reductionism* is the approach of reducing complex systems to simpler components that are more manageable to study, *e.g.*, studying the molecular structure of DNA to understand the chemical basis of inheritance.

Emergent Properties From Figure 1.3, **emergent properties** are novel properties that emerge at each level and are absent from the preceding level. **Systems Biology** is a system that is a combination of components that function together. Systems biology is an approach that attempts to model the dynamic behavior of whole biological systems based on a study of the interactions among the system's parts. Systems biology is relevant to the study of life at all levels.

Structure and Function is a major theme in biology - that form fits function. How a device works is correlated with its structure, like hummingbird wings. Analyzing biological structure gives us clues about how it works, and conversely, knowing its function gives insight into its construction.

The Cell: An Organism's Basic Unit of Structure and Function The lowest level of biological organization that can perform all activities required for life is the cell. Understanding how cells work is a major focus of biological research. Two main types of cells are eukaryotic and prokaryotic (Figure 1.4). A **eukaryotic cell** is large and complex. Its internal area, the cytoplasm, contains organelles. Each organelle carries out a specific function. A **prokaryotic cell** is comparatively smaller than a eukaryotic cell, and is simpler in its cytoplasmic organization.

2) Theme: Life's Processes Involve the Expression and Transmission of Genetic Information

The division of cells to form new cells is the foundation for all reproduction and growth of living organisms (Figure 1.5). In a dividing cell **DNA (deoxyribonucleic acid)** is replicated and then partitioned into two new daughter cells.

DNA, the Genetic Material **Genes** reside on DNA. Genes are the units of inheritance that transmits genetic information from parent to offspring (Figure 1.6). DNA controls the development and maintenance of the entire organism, and indirectly everything the organism does. DNA stores the genetic information. DNA is comprised of building blocks called nucleotides, abbreviated A, G, C, and T (Figure 1.7). DNA provides the information for making proteins. DNA controls the production of proteins through an intermediate molecule called RNA, which is then transcribed to make protein. This process is called **gene expression** (Figure 1.8 a and b). Not all RNA is transcribed into protein. Some RNA molecules are part of the structure of the ribosome and some are used to regulate transcription of genes.

Genomics: Large-Scale Analysis of DNA Sequences The entire "library" of genetic information in an organism is called its **genome**. The new area of **genomics** is studying whole sets of genes of a species. **Proteomics** is the study of the set of proteins and their properties. New technology has allowed for the rapid study of genomes. As a result, another major development in the area of biology has been **bioinformatics**, the use of computational tools to store, analyze and organize huge volumes of genetic information.

3) Theme: Life Requires the Transfer and Transformation of Energy and Matter

A fundamental characteristic of living organisms is their use of energy to carry out life's activities. Moving and growing require work, and work requires energy (Figure 1.9). Living organisms transform the forms of energy. For example, through the process of photosynthesis plants transform solar energy (sun light) into chemical energy (sugar). The flow of energy through living organisms starts with **producers** (plants), then to **consumers** (animals), and eventually decomposes (bacteria and fungi).

4) Theme: From Ecosystems to Molecules, Interactions Are Important in Biological Systems

Ecosystems: An Organism's Interactions with Other Organisms and the Physical Environment At the ecosystem level, each organism interacts with other organisms. Organisms also interact with the physical factors in their environment (Figure 1.10)

Molecules: Interactions Within Organisms Regulation of biological processes is crucial to the operation of living systems. The cell's chemical processes are mediated by proteins called enzymes. Each step of the chemical pathway in a cell is controlled by an enzyme. The ability of many biological processes to self regulate is done by a mechanism called **feedback regulation**. *Negative feedback* is where accumulation of the end product slows down the overall chemical reaction (Figure 1.11). *Positive feedback* is where the end product speeds up its own production.

5) Theme: Evolution, the Core Theme of Biology

Organisms exhibit unity and diversity as a result of evolution. There are shared traits among living organisms (unity), and yet each organism is well suited for its environment (diversity). All organisms descended from a common ancestor, and the organisms that we see today are modified descendants from the common ancestor.

Concept 1.2 The Core Theme: Evolution accounts for the unity and diversity of life

Classifying the Diversity of Life

Diversity is a hallmark of life.

Grouping Species: The Basic Idea Taxonomy is the branch of biology that names and classifies species, formalizes the ordering of species based on shared characteristics (Figure 1.12).

The Three Domains of Life The highest level of classification (higher than kingdoms) is domains. There are three domains: **Bacteria, Archaea** are prokaryotic cells**, and Eukarya** are eukaryotic cells (Figure 1.13).

Unity in the Diversity of Life Unity is obvious in many features of cell structure (Figure 1.14). Similarities between organisms are evident at all levels of biology.

Charles Darwin and the Theory of Natural Selection

Life has evolved on Earth over last billions of years (Figure 1.15). The author of *The Origin of Species* is Charles Darwin (Figure 1.16). He articulated two main points: 1) descent with modification, contemporary species arose from a succession of ancestors (Figure 1.17), and 2) the mechanism for descent with modification is "natural selection". **Natural selection** is the evolutionary adaptation where the natural environment "selects" for certain traits among the population (Figures 1.18 and Figure 1.19).

The Tree of Life

Biologists diagram evolutionary relationships that look like a "family tree". Each species on a "twig" is part of a branching pattern that extends back in time (Figure 1.20).

Concept 1.3 In studying nature, scientists make observations and form and test hypotheses

Science is a way of knowing, an approach to understanding the natural world. At the heart of science is **inquiry**, a search for information and explanation, focusing on specific questions. Scientists attempt to understand how natural phenomena work using processes that include making observations, forming logical hypotheses, and testing them. The process is repetitive.

Making Observations

Scientists describe as accurately as possible natural processes through careful observation and analysis of data. Recorded observations are called **data** (singular, datum). Not all data are numbers (quantitative), some data is *qualitative*. Qualitative data is in the form of descriptions (Figure 1.21). Collecting and analyzing observations can lead to important conclusions based on a type of logic called **inductive reasoning**. Through induction we derive generalizations from a large number of specific observations.

Forming and Testing Hypotheses

In science a **hypothesis** is a tentative answer to a well framed question – an explanation on trial. A hypothesis can lead to predictions that can be tested by observations and experiments (Figure 1.22).

> *Deductive Reasoning* **Deductive reasoning** is generally used after the hypothesis has been developed and involves logic that flows from the general to specific. A hypothesis gains credibility by surviving multiple attempts to falsify it while alternative hypotheses are eliminated by testing.
>
> *Questions That Can and Cannot Be Addressed by Science* Science requires natural explanations for natural phenomena. It cannot support or falsify elements of the supernatural world like angels and ghosts.

The Flexibility of the Scientific Method

Not every scientific inquiry will adhere to the scientific method. Sometimes scientists have to re-direct their research when they realize they have been asking the wrong questions. A more realistic model of the scientific process is shown on Figure 1.23.

Experimental Variables and Controls

An **experiment** manipulates one factor in a system to understand the changes it makes. **Variables** are factors that vary in an experiment. A **controlled experiment** is an experiment that compares an experimental group with a control group. The experimental group and the control group only differ in one factor – the one being tested. Experimental results must be repeatable. The **independent variable** is determined by the researcher. The **dependent variable** is measured by the experiment.

Theories in Science

A scientific **theory** is much broader in scope than a hypothesis. A theory is generally supported by a much greater body of evidence. Scientists reject or modify theories when new research methods produce results that don't fit.

Concept 1.4 Science benefits from a cooperative approach and diverse viewpoints

Scientists work in teams which includes the professor, graduate and undergraduate students (Figure 1.28). To succeed in science one needs to be a good communicator. Research results are shared with the community of peers through websites, conferences, and publications.

Building on the Work of Others

The validity of experimental data is key to designing further lines of inquiry. Scientists often use **model organisms** - species that are easy to grow in the lab and study. For example, *Escherichia coli*, a bacterium.

Science, Technology and Society

The connection between science and society is through **technology**, which applies scientific knowledge for a specific purpose. In the field of forensic science DNA technology has been used in crime scene investigations (Figure 1.26).

The Value of Diverse Viewpoints in Science

Over the last few decades science has seen the inclusion of women, minorities, and people from different countries, all reflecting different cultural standards and behaviors.