PART I INTRODUCTION TO LIVING ANIMALS

CHAPTER 1 LIFE: BIOLOGICAL PRINCIPLES AND THE SCIENCE OF ZOOLOGY

CHAPTER OUTLINE
1.1. The Uses of Principles
   A. Underlying Principles Central to Understanding Zoology
      1. Laws of physics and chemistry underlie some zoology principles.
      2. Principles of genetics and evolution guide much zoological study.
      3. Principles learned from one animal group can be applied to others.
      4. Some science methods specify how to conduct solid research.
   B. Zoology, the Study of Animal Life (Figure 1.1)
      1. Zoologists studying many dimensions base research upon a long history of work.
      2. Two central principles are evolution and the chromosomal theory of inheritance.

1.2. Fundamental Properties of Life
   A. Defining Properties of Life
      1. Properties exhibited by life today are different from those at its origin.
      2. Change over time, or evolution, has generated many unique living properties.
      3. Definitions based on complex replicative processes would exclude non-life, but also early forms from which cellular life descended.
      4. We do not force life into a simple definition, yet we can readily recognize life from a nonliving world.
   B. General Properties of Living Systems
      1. Chemical Uniqueness (Figures 1.2, 2.11)
         a. Macromolecules in organisms are far more complex than molecules in nonliving matter.
         b. They obey the same physical laws as nonliving molecules but are more complex.
         c. Nucleic acids, proteins, carbohydrates and lipids are common molecules in life.
         d. Their general structure evolved early; thus the common amino acid subunits of proteins are found throughout life.
         e. They provide both a unity based on living ancestry and a potential for diversity.
      2. Complexity and Hierarchical Organization (Figures 1.3, 1.4; Table 1.1)
         a. Life has an ascending order of complexity: macromolecules, cells, organisms, populations and species.
         b. Each of these levels has an internal structure: macromolecules form ribosomes and membranes, etc. and cells form tissues.
         c. However, each level has unique abilities and requirements; cells can replicate but are not independent in an organism.
         d. New characteristics that appear at the next level of organization are emergent properties.
         e. Because of the interactions of the components, we must study all levels directly as well as together.
         f. Diversity of emergent properties at higher levels is a result of evolution (i.e., lower levels without hearing cannot develop language).
3. **Reproduction (Figure 1.5)**
   a. Life comes from previous life but had to arise from nonliving matter at least once.
   b. Genes replicate genes, cells divide to produce new cells and organisms produce new organisms sexually or asexually.
   c. Reproduction is not necessary of individuals, but is necessary for a lineage to survive.
   d. Reproduction is a combination of contradictory processes of copying traits, but with variation.
   e. If heredity were perfect, life would never change; if it were wildly variable, life would lack stability.

4. **Possession of a Genetic Program (Figure 1.6)**
   a. Structures of protein molecules are encoded in nucleic acids.
   b. Genetic information in animals is contained in DNA.
   d. The genetic code is correspondence between bases in DNA and sequence of amino acids.
   e. This genetic code was established early in evolution and has undergone little change.
   f. The genetic code in animal mitochondrial DNA is slightly different from nuclear and bacterial DNA.
   g. Changes in mitochondrial DNA (it contains fewer proteins) are less likely to disrupt cell functions.

5. **Metabolism (Figure 1.7)**
   a. Living organisms maintain themselves by acquiring nutrients from the environment.
   b. Breakdown of nutrients provides both energy and molecular components for cells.
   c. Metabolism is the range of essential chemical processes.
   d. Metabolism involves constructive (anabolic) and destructive (catabolic) reactions.
   e. Most metabolic pathways occur in specific cell organelles.
   f. The study of the performance of complex metabolic functions is physiology.

6. **Development (Figure 1.8)**
   a. Development describes characteristic changes an organism undergoes from origin to adult.
   b. It involves changes in size and shape, and differentiation within the organism.
   c. Some animals have uniquely different embryonic, juvenile and adult forms.
   d. The transformation from stage to stage is metamorphosis.
   e. Among animals, early stages of related organisms are more similar.

7. **Environmental Interaction (Figure 1.9)**
   a. Ecology is the study of an organism's interaction with the environment.
   b. Organisms respond to stimuli in the environment, a property called irritability.
   c. We cannot separate life and its evolutionary lineage from its environment.

8. **Movement**
   a. Energy extracted from the environment permits living systems to initiate controlled movements.
   b. These movements are essential for reproduction, growth, response to stimuli, and development.
   c. Animals are adapted for locomotion which has led to dispersal of entire populations from one geographic location to another over time.
   d. Movement of nonliving matter is controlled by external forces and thus is dissimilar to purposeful movements exhibited by living systems.

C. **Life Obey Physical Laws**
   1. Vitalism is the belief that life requires more than basic laws of physics; biological research has found no basis for vitalism.
   2. **First Law of Thermodynamics** (the law of conservation of energy)
      a. Energy cannot be created or destroyed; it can be transformed from one form to another.
      b. All aspects of life require energy.
      c. In animals, chemical energy in food is converted to chemical energy in cells and then converted to mechanical energy of muscle contraction.
3. **Second Law of Thermodynamics**
a. Physical systems tend to proceed toward a state of greater disorder, or entropy.
b. Energy obtained and stored by plants is released in many ways and eventually lost as heat.
c. It takes a constant input of usable energy from food to keep an animal organized.
d. The process of evolution does not violate the second law; complexity is achieved by constant use and dissipation of energy flowing into the biosphere from the sun.
e. Physiologists study survival, growth, reproduction, etc. from an energetic perspective.

1.3. **Zoology as a Part of Biology** (Figure 1.10)

A. **Characteristics of Animals**
1. Animals are a branch of the evolutionary tree of life.
2. Animals are part of a large limb of eukaryotes, organisms that include fungi and plants with nuclei in cells.
3. Animals are unique in nutrition; they eat other organisms and therefore need to capture food.
4. Animals lack photosynthesis; cell walls found in plants, and also lack absorptive hyphae of fungi.
5. Species of *Euglena* are examples of protists that combine properties of animals and plants.

1.4. **Principles of Science**

A. **Nature of Science**
1. Science is a way of asking about the natural world to obtain precise answers.
2. Asking questions about nature is ancient; modern science is about 2000 years old.
3. Science is separate from activities such as art and religion.
4. The trial over creation science provided a definition of science.
   a. Science is guided by natural law.
   b. Science has to be explanatory by reference to natural law.
   c. Science is testable against the observable world.
   d. Science conclusions are tentative; they are not necessarily the final word.
   e. Science is falsifiable.
5. Science is neutral regarding religion and does not favor one religious position over another.
6. The reappearance of “creation-science” in the guise of “intelligent-design-theory” may force further defense of the teaching of science.

B. **Scientific Method** (Figure 1.11)
2. **Hypotheses** are based on prior observations of nature or derived from theories based on nature.
3. The scientific method may be summarized in a series of steps: (1) Observation (2) Question (3) Hypothesis (4) Empirical test (5) Conclusions (6) Publication.
4. Testable predictions are made based on hypotheses.
5. A hypothesis powerful in explaining a wide variety of related phenomena becomes a theory.
6. Falsification of a specific hypothesis does not necessarily lead to rejection of a theory as a whole.
7. The most useful theories explain the largest array of different natural phenomena.
8. Scientific meaning of “theory” is not the same as common usage of theory as “mere speculation.”
9. Powerful theories that guide extensive research are called paradigms.
10. Replacement of paradigms is a process known as a scientific revolution; the evolutionary paradigm has guided biology research for over 130 years.

C. **Experimental Versus Evolutionary Sciences**
1. Questions can be divided into those that seek to understand proximate versus ultimate causes.
2. Studies that explore proximate causes are experimental sciences using experimental methods that:
   a. Predict the results of a disturbance based on current understanding.
   b. If current understanding is correct, then the predicted outcome should occur.
   c. If a different result occurs, our understanding is incorrect or incomplete.
3. Controls are repetitions of an experiment that lack disturbance or treatment.
4. The sub-fields of molecular biology, cell biology, endocrinology, developmental biology and community ecology rely heavily on experimental scientific methods.
5. Ultimate causes are addressed by questions involving long-term time spans.
   a. Evolutionary sciences address ultimate causes.
   b. Evolutionary questions are often explored using a comparative method.
   c. Patterns of modern similarities are used to establish hypotheses on evolutionary origins.
   d. Sub-fields include comparative biochemistry, molecular evolution, comparative cell biology, comparative anatomy, comparative physiology and phylogenetic systematics.

1.5. Theories of Evolution and Heredity (Figures 1.12)

A. Darwin’s Theory of Evolution
1. Ernst Mayr describes five central theories of “Darwinism.”
   a. Perpetual change: changes across generations are a fact documented in the fossil record.
   b. Common descent: branching lineages form a phylogeny that is confirmed by expanding research on morphological and molecular similarities. (Figure 1.13)
   d. Gradualism: small incremental changes over long periods of time cause gradual evolution, but current research is still studying if this explains all changes. (Figure 1.14)
   e. Natural selection: based on variability in a population, the inheritance of that variation, and different survival of those variants, explains adaptation. (Figure 1.15)
2. Darwin lacked a correct theory of heredity and assumed the current theory of blending inheritance was correct; Mendel’s theory of particulate inheritance became well known only in the very early 1900s.
3. Darwin’s theory as modified by incorporation of genetics is called “neo-Darwinism.”

B. Mendelian Heredity and the Chromosomal Theory of Inheritance (Figure 1.16)
1. Chromosomal inheritance is the foundation for genetics and evolution, as laid down by Mendel.
2. Genetic Approach (Figure 1.17)
   a. Mendel’s technique involved crossing true-breeding populations.
   b. Production of F1 hybrids and F2 generations showed lack of blending, and masking of recessive traits by dominant traits.
   c. Traits assorted independently unless on the same chromosome.
   d. Expanded research, especially with fruit flies, clarified genetic mechanisms.
3. Contributions of Cell Biology (Figures 1.18, 1.19)
   a. Improvements in microscopes allowed observation of sperm and location of germ cell line.
   b. Discovery of chromosome pairs in body cells and single sets in germ cells clarified mode of heredity.

Lecture Enrichment
1. From the Australian outback to interior New Guinea, all cultures regardless of science education level distinguish living from nonliving substances. Although this is the first day of classes and students may not have had an opportunity to read the assigned text, they can be led through a query of “what is life?” They will usually offer: growth, reproduction, response to the environment, metabolism, etc. Ask whether any one of these aspects alone distinguishes a living organism from nonliving organism. Note that it is not necessary for an individual organism to reproduce, and indeed most animals hatched or born do not survive to reproduce.
2. Clay is an example of self-replicating molecular assemblages that do not have the potential variety or the metabolism to be called living. Quartz is a molecule that can “grow,” “reproduce” and “respond” to light. Tardigrades can completely suspend metabolism for a century and dehydrate to ten percent of their living water content. These examples will appropriately muddle the definition of life. Nevertheless, it is critical in deciding that if we find life on Mars—would we recognize it? We continue attempts to confirm whether life has ever existed on Mars. What phenomena would we look for?
3. Levels of organization can seem rather abstract. Read job descriptions for biologists (e.g., histologist, population geneticist, community ecologist, etc.). Ask students what level of organization the scientist studies.
4. Virtually continuously throughout this course, students can be asked to design an experiment to test a particular hypothesis being discussed.
5. Ask students for examples of the scientific method in their everyday lives, such as fixing dinner, determining how to dress for the day’s weather and activities, or handling problems with a car that doesn’t work.

6. Students can search local newspapers for examples using the scientific method (e.g., testing consumer products, recalls, reports on medical research, jury decisions based on forensic evidence, etc.). Bring in a tabloid newspaper making fabulous claims and ask why it does not meet science standards.

7. Discuss the difference between scientific observations of the natural world and superstitions such as those associated with Friday the thirteenth and black cats. Examples involving Bigfoot, the Loch Ness Monster, spontaneous human combustion, living dinosaurs in remote areas, and other modern misbeliefs related to animals are given in the *Skeptic* and *Skeptical Inquirer* magazines.

8. Discuss why it is possible to prove a hypothesis or theory false but not prove it true. Be careful not to fall into the postmodernist or constructivist view of science knowledge being merely a mental construct, no better or worse than tribal beliefs, etc. or being tentative to the point of merely awaiting falsification.

9. Most students believe the world is spherical. Only students who have flown in the Concorde jetliner have direct observational evidence for this. Yet they believe the photos by astronauts, and phoning a person in China awakes them in a time zone 12 hours different from us. Such indirect evidence fortifies the model of a spherical earth. This illustrates science relies on *reasoning* to make sense of observational data.

**Commentary/Lesson Plan**

**Background:** Professors that are new to a college or university may consult with veteran professors about the state’s high school biology and other science requirements. In addition, the proportion of students that come from farm or urban backgrounds will provide a major indicator of student experiences. Most high school science texts discuss the “scientific method” as a very cookbook or lock-step method. And most college undergraduates do not have genuine experience with open-ended and purposeful science research, nor the breadth of experience to place limited research experience in a full perspective.

**Misconceptions:** Many students see science as a body of encyclopedic knowledge and authority, and do not recognize an underlying scientific attitude or process. Some students have been told that science is only process, and have no appreciation for the role of the general public recognizing germ theory, for instance. Most citizens view science practiced only by scientists and do not recognize that experiments often close the door to hypotheses that don’t work out. In many states, physics classes are not commonly taken in high school; this may be their first exposure to physics and many students will misunderstand the laws of physics as preventing evolution. A large portion of college students believe that dinosaurs and humans were on earth at the same time, and a similar proportion question the validity of the theory of evolution without much depth of knowledge about it. A large proportion view evolution as “survival of the fittest” without recognizing that survival is only useful if it promotes reproduction.

**Schedule:** Students may lack the book assignment the first day of class, but this is the point where an instructor establishes the ground rules of quizzes, testing, whether notes will be given in outline form, etc. If you use in-class questioning, beginning with “What is Life?” as in Lecture Enrichment #1 above, which can set the pace.
1.5. Theories of Evolution and Heredity
   A. Darwin’s Theory of Evolution
   B. Mendelian Heredity and the Chromosomal Theory of Inheritance

ADVANCED CLASS QUESTIONS:
1. Recent satellite probes as well as meteorite discoveries have been used to search for the possibility of life on Mars. What properties would scientists look for in currently living life forms? If life once existed but became extinct, what evidence would still exist that life once existed?
2. Scientists use the scientific method to gather information about the natural world. Can this include the past? Does how a forensics expert reconstructs a crime scene differ in substance from how an evolutionary biologist reconstructs ancient ecology from fossil evidence?
3. When utilizing the scientific method, hypotheses can be proven false, but not true. Does this mean all science is conjecture until disproven? Can anyone explain the “uncertainty principle” and the ability of scientists to calculate the tolerance limits of their knowledge?
4. What evidence exists that all living things evolved from a common ancestor? How does this concept explain the unity of life forms?
5. Animal ecology experiments can be classified in two general categories: Ecologists can bring an animal into the laboratory, isolate it in a chamber where they can determine all the environmental conditions affecting it and then alter one variable. Or, they can study the animal in the wild and attempt to determine why it occurs in certain natural habitats. Using terms given in the text for science methodology, explain the benefits of both systems.

Fourteenth Edition Changes: Outside of minor editorial changes, there are no major additions or deletions to this chapter.

1. A new reference by M. Pigliucci (2002) regarding creationism, scientism and the nature of science has been added. New references by J. M. Groves (1997) and E.F and J. Paul (2001) concerning the animal rights controversy have been added.

Source Materials [Bold = recommended]
*All About Science II* (Q), Mac, MS-DOS CD
*The Best Mind Since Einstein* (WGBH), 60-min. video
*Biologists at Work* (HH), 44-min. video
*BioFlash Series* (PLP), MS-DOS
*Biology: Form and Function* (CPB), 12 24-min. videos
*Biology: The Study of Life* (CAM) (CYBER), Mac, MS-DOS CD
*BioQUEST 3.0* (CPB), Mac CD
*The BioQuest Library V* (A-CPB), 54 Mac modules and 25 Win modules on CD
*BioSci II* (VDISC) laserdisc
*A Brief History of Biology* (HH), 18-min. video
*Clinical Trials* (FH), 25-min. video
*Comprehensive Review in Biology* (Q), Mac, MS-DOS CD
*Cycles of Life: Exploring Biology—The Unity and Diversity of Life* (A-CPB), 26 30-min. videos
*Energy Flow in the Ecosystem* (FH), 10-min. video
*Experiment: Biology Series* (CBSC), 6 15-min. videos
*The Experimental Conditions* (UC), 36-min. video
*Exploring Biology: Careers and Issues* (CYBER), Mac, MS-DOS CD
*Five Kingdoms of Life Series: The* (CBSC), Mac, Win, MS-DOS CD
*General Biology Data Simulation* (OAK), MS-DOS and Mac, video
*Generation Upon Generation [Ascent of Man Series]* (AVP), 52-min. video
*God, Darwin, and Dinosaurs* (WGBH), 60-min. video
*Introduction to General Biology Series* (FISH), Mac, MS-DOS
Knowledge or Certainty [Ascent of Man Series] (AVP), 52-min. video
Learning All About Cells and Biology (Q), Mac, Win CD
Life Itself (FH), 23-min. video
The Multimedia Book of Biology Concepts (PLP), MS-DOS
NOVA: The Bermuda Triangle (WGBH), 60-min. video
NOVA: The Best Mind Since Einstein (WGBH), 60-min. video
NOVA: Kidnapped by UFOs? (WGBH), 60-min. video
NOVA: Last Journey of a Genius (WGBH), 60-min. video
NOVA: Secrets of the Psychics (MBI) (WGBH), 60-min. video
NOVA: UFO’s–Are We Alone? (MBI) (WGBH), 60-min. video
NTSYS-pc (SciT), Mac, MS-DOS
Powers of Ten (PYR), 10-min. video [levels of organization]
Preserving the Rain Forest (FH), 24-min. video
Scientific Method (EVN), video
The Scientific Method, Graphs and Statistics (PLP), MS-DOS
Scientific Methods and Values (HH), 34-min. video
SimLife (FISH), Mac, MS-DOS
The Soul of Science (HH), 4-parts total 78-min. video
Statistics and the Sciences (FH), 25-min. video
Survey of Biology (JLM), slide set (200)
TAADS (INT), Mac
Think For Yourself: Critical Thinking on Pivotal Issues of Our Time (INT) CD, Mac
Thinking Like a Scientist (GA), CD, Mac
Through Fish Eyes (FH), 30-min. video
The Tropical Rain Forest (FH), 28-min. video
Urban Ecology (FH), 24-min. video
When Scientists Cheat (WGBH), 60-min. video
Why Use Statistics? (FH), 4-part series of 20–25-min. videos
Women in Science (HH), 33-min. video