**Chapter 1**

The Science of Life

* **Biology** unifies much of natural science
* Life ***defies*** simple definition
  + Living systems are the most complex chemical systems on Earth
  + Life is constrained by the properties of chemistry and physics
* Science is becoming more ***interdisciplinary***
  + Combining multiple fields

**7 characteristics of all living organisms**

* 1. Cellular organization
  2. Ordered complexity
  3. Sensitivity
  4. Growth, development, and reproduction
  5. Energy utilization
  6. Homeostasis
  7. Evolutionary adaptation

Living systems show **hierarchical organization**

* Cellular level
* Organism level
* Population level
* Ecosystem level
* Biosphere

Living systems show **hierarchical organization**

* **Cellular level**
  + Atoms, molecules, organelles, cells
  + Cell is the basic unit of life
* **Organism level**
  + Tissues, organs, organ systems
* **Population level**
  + Population, community
* **Ecosystem level**
* **Biosphere**
  + All the livable space on the planet
  + 99% of it is in the ocean!!!

As you move up the hierarchy, novel properties emerge

* Result from interaction of components
* Cannot be deduced by looking at parts themselves

***Science*** aims to understand the natural world through observation and reasoning

Science begins with **observations**, therefore, much of science is purely descriptive

* Classification of all life on Earth
* Human genome sequencing

Science uses both ***deductive*** and ***inductive*** reasoning

* **Deductive reasoning** uses general principles to make specific predictions
  + - If all mammals have hair and you find an animal that doesn’t, you might say that the animal you are looking at is not a mammal
    - Used to test the validity of general ideas in all branches of knowledge
* **Inductive reasoning** uses specific observations to develop general conclusions
  + - If poodles have hair and terriers have hair, then you might generalize that all dogs have hair
* Scientists use a systematic approach to gain understanding of the natural world

***Scientific Method***

* + Observation
  + Hypothesis formation
  + Prediction
  + Experimentation
  + Conclusion
* A **hypothesis** is a possible explanation for an observation
  + - Not just an “educated guess”
* A hypothesis
  + Must be tested to determine its validity
  + Is often tested in many different ways
  + Allows for predictions to be made
* Interactive
  + Hypotheses can be changed and refined with new data
* **Experiment**
  + Tests the hypothesis
  + Must be carefully designed to test only one variable at a time
  + Consists of a **test experiment** and a **control experiment**
* **Predictions**
  + Hypotheses should make predictions
  + Predictions provide a way to test the validity of hypotheses
  + Hypothesis must be rejected if the experiment produces results inconsistent with the predictions
  + The more experimentally supported predictions a hypothesis makes, the more valid the hypothesis

Philosophical approaches to science

* **Reductionism**
  + To break a complex process down to its simpler parts
  + For example
    - Cellular metabolism is very complex, reductionism is looking at one pathway and the function of that enzyme
    - However, that enzyme may work differently when not isolated from other enzymes and molecules within the cell
* **Systems biology**
  + Focus on emergent properties that can’t be understood by looking at simpler parts
* **Models** in science
  + Way to organize thought
  + Parts provided by reductionist approach
  + Model shows how they fit together
  + Suggest experiments to test the model
* **Scientific theory**
  + Is a body of interconnected concepts
  + Is supported by much experimental evidence and scientific reasoning
  + Expresses ideas of which we are most certain
  + When you say “theory” in science, it is as close to fact that you will get to with the information and technology we have available to us at the time
  + Compare to general meaning of theory
  + Different in everyday language, implies a lack of knowledge or a guess

**Darwin and Evolution**

* Example of how a scientist develops a ***hypothesis*** and a ***theory*** gains acceptance
* **Charles Darwin** served as naturalist on mapping expedition around coastal South America
* 30 years of observation and study before publishing *On the Origin of Species by Means of Natural Selection*
* Darwin was not the first to propose ***evolution***
  + Living things have changed over time
* Darwin’s contribution was a mechanism for evolution
  + **He proposed Natural selection**
* On the *Beagle*, Darwin saw that characteristics of similar species varied from place to place
* Galápagos Finches
  + 14 related species differ only slightly
  + “Descent with modification” or evolution
* Darwin studied Thomas Malthus’s *An Essay on the Principle of Population*
  + Populations of plants and animals increase **geometrically** (multiplicative, example x3)
  + Humans can only increase their food supply **arithmetically** (additive, example +2)
  + Populations of species remain constant because death limits population numbers
  + There are individuals that possess physical, behavioral or other attributes that give them an advantage

Darwin saw that:

* Every organism has the potential to produce more offspring
* But, only a limited number survive and reproduce themselves

Darwin made an important association:

* Individuals with attributes that give them an advantage in their environment are more likely to survive and reproduce
* Pass these characteristics on to their offspring
* The population will gradually change over time
* Darwin called this ***selection***
* Evidence supporting Darwin’s theory has only grown
  + **Fossil record**
  + **Earth’s age**
  + **Mechanism for heredity**
  + **Comparative anatomy**
  + **Molecular Evidence**
  + **Fossil record**
    - Transitional forms have been found at predicted positions in time
  + **Earth’s age**
    - Earth is very old – 4.5 billion years old
  + **Mechanism for heredity**
    - Mendel’s laws of inheritance were unknown to Darwin
    - At time of Darwin there was no concept of “genes” or how heredity worked
    - Darwin could not completely explain how evolution worked
    - Now have detailed understanding of **heredity**
  + **Comparative anatomy**
    - Vertebrate forelimbs all share the same basic array of bones
    - **Homologous** – same evolutionary origin but now differ in structure and function
    - **Analogous** – structures of different origin used for the same purpose (butterfly and bird wings)

**Cell theory**

* + All organisms composed of cells
  + Cells are life’s basic units
  + All cells come from preexisting cells
* **Molecular basis of inheritance**
  + Deoxyribonucleic acid (DNA)
  + Sequence of 4 nucleotides encode all of a cell’s information – A, T, C, G
  + Gene – discrete unit of information
  + Genome – entire set of DNA instructions
  + Continuity of life depends on faithful copying of DNA into daughter cells
* **Structure and function**
  + Study structure to learn function
  + Know a function – look for that structure in other organisms
  + Example
    - Receptor on human cell for insulin known
    - Find similar molecule in a worm
    - Might conclude this molecule functions the same in the worm
* **Diversity of life arises by evolution**
  + Underlying unity of biochemistry and genetics argues for life from the same origin event
  + Diversity due to evolutionary change over time
  + 3 domains
    - Bacteria – single-celled prokaryote, bacteria
    - Archaea – single-celled prokaryote, includes extremophile bacteria
    - Eukarya – single-celled or multicellular eukaryote; includes protists, fungi, plants, and animals.
* **Evolutionary conservation**
  + All organisms today descended from a simple creature 3.5 BYA
  + Some characteristics preserved
    - * Our DNA encodes everything
      * For example, you need certain enzymes for cellular respiration, those are encoded in your DNA; those same enzymes are used by other organisms for the same process
  + Conservation reflects that they have a fundamental role
* **Cells are information-processing systems**
  + Information in DNA used to direct synthesis of cellular components
    - Control of gene expression leads to different cells/ tissue types
  + Cells process environmental information
    - Glucose levels, presence of hormones
  + Cells in multicellular organisms must coordinate with each other
* **Nonequilibrium state**
  + Living systems are open systems
  + Constant supply of energy needed
  + Self-organizing properties at different levels
  + Emergent properties from collections of molecules, cells, and individuals