1: Scientific Method

I. How is biology studied?
   Scientists collect information about nature using: THE SCIENTIFIC METHOD.

II. Steps in the Scientific Method:
    1. Observation
    2. Question
    3. Hypothesis (Guess)
    4. Test or Experimentation (gathering data)
    5. Conclusions – If the test do not confirm the hypothesis devise new ones.
    6. Theory

1. Observation = the awareness of a natural event or natural phenomenon directly or indirectly by means of our senses.
   1. Something that cannot be observed, is outside the realm of science; may be indirectly observed i.e., magnetism
   2. In addition, observations must be repeatable.
      One time events, "absolute" as they may have been are also outside science.
   3. "Correct" observation is a difficult art – people often see only what they want to see, hear only what they want to hear, they are often biased.

2. Question = a question about the observation
   1. Curiosity drives us to ask what is it? How did it happen?
      What causes it to occur? When does it happen?
   => Curiosity leads scientists to ask similar questions
      How did our universe originate?
      How does mate selection occur in two similar bird species?
   2. Good questioning is an art form.
      • to be scientifically valid the question must be relevant and testable
      • Observation - North slopes have heavier tree growth than south slopes.
         a. Question: What causes trees to grow more abundantly on north facing slopes?
            Question both relevant and testable, but very general.
         b. Not: What causes the slope to be north facing?
            May or may not be relevant.
         c. Better: Is evaporation of water less on north facing slopes than south facing slopes?
            More relevant and to the point.
         d. Probably not testable: Did Martians plant these trees 10,000 years ago?
   • Once a relevant and testable question is asked, the scientist prepares a "road map" for future research.

3. Hypothesis = a guess postulating an answer to the question
   1) a good hypothesis is also relevant and testable (a poor hypothesis cannot be tested)
   2) genius and experience often provide shortcuts to the probable answer
   3) Bias may enter - people may guess only what they should guess rather than what is possible based on evidence.
      • After the hypothesis -
         Often people stop there
         "My idea is so logical, so reasonable, it sounds so right, it must be correct."
         Other people listen and are convinced.
         Before long vast numbers acknowledge the "absolute truth of the matter."
• **Science** cannot stop at the hypothesis. "Where is the supporting evidence?"
Science requires that additional observations are made testing the hypothesis.

4. **EXPERIMENT** = additional observations gathered to **test** an hypothesis

• This can be the most difficult step in the scientific method -

• **Difficulties:**
  1) **Bias** - gather only evidence that supports the hypothesis - ignore other evidence
  2) **Sample size** too small - based on only one additional observation, usually little can be said. Need many observations.
  3) **Experimental errors**
     - limited senses
     - poor equipment (extension of our senses)
     - sick animals or plants etc.
     - poor experimental set-up - not testing for original hypothesis due to set-up

• **Use of a control**
  - must have double experiments
  - change 1 variable only and keep parallel experiments in original condition.
  - Fish Ick
    **Control** – the subjects are divided into an *experimental* group and a *control* group
    the two groups are treated exactly alike, except for the one variable the experiment is designed to test.
    Allows conclusion to be made as to the affect of the experimental manipulation.

• **Double Blind Studies**
  - a controlled experiment where no one knows which subject are receiving a given treatment

• when a hypothesis explaining a group of related phenomenon has been **solidly** supported by the evidence we then can say it is a **THEORY**

**Spontaneous Generation Dispelled**
– the discredited belief that living organisms can arise from non-living material
  A. Aristotle (4th century BC) – flies, worms and other small animals arose from decaying matter, without the need of parent organisms.
  B. 1600 prominent physician (van Helmont) added rats originate from old rags.
  C. 1670s – Francesco Redi – covered jars containing meat, proved flies laid eggs
  D. 1748 – John Needham– microorganisms arise in flasks;
    experimented by boiling broth → growth
  E. 1767 – Spallanzani– disproved by boiling then covering;
    Needham says “vital force” of life destroyed (oxygen)
  F. 1870s – Louis Pasteur– discredited spontaneous generation.
    Sterilized broth, then used S-shaped neck flask to trap dust and microorganisms but allowed O₂; broth not contaminated → microorganisms cause disease!
CONCEPT 2 – Characteristics of Life

Lab Part II: Fundamental Characteristics of Life

1. Cellular organization-
   composed of 1 or more cells
   complex assemblages of molecules
   protoplasm surrounded by a membrane

2. DNA – directions for running cells (codes for proteins)
   all organisms possess a genetic system (DNA or RNA)
   A. Reproduction (self-renewing)
      formation of new life form from pre-existing,
      each organism must arise from 1 or more parents
      DNA guides development
   B. Heredity
      DNA codes for a new individual with certain characteristics
      Instructions in the DNA are passed between generations
   C. Evolution (self-transcending)
      DNA may undergo mutation
      most are harmful; all are tested by the environment
      allows for variation, adaptation and change

3. Metabolism
   energy – the ability to do work → all universal processes require energy
   energy cannot be created
   Metabolism is the transfer of energy between substances
   1) organisms obtain and convert energy from their surroundings
   2) an organism uses energy to maintain itself, grow and make more cells
   energy required to: assemble, breakdown, stockpile and dispose of waste
   ATP is used as energy currency in the cell
   Photosynthesis - produces ATP (energy) from the sun
   Aerobic Respiration - utilizes stored energy to make ATP
   Catabolism – breaking down of complex molecules to simpler molecules → releases ATP
   * Anabolism – synthesis of large molecules from simple ones → requires ATP

4. Growth
   irreversible change in volume w/ accompanying morphological (form) change results from energy transformation
   and synthesis of materials.

5. Response to stimuli
   organisms can't exist apart from their surroundings
   react to environmental stimuli,
   sense changes and make controlled compensatory responses to changes
   → movement or internal adjustments

   internal adjustments must be made to outside changes (CO₂/O₂; food;
   removal of toxic substances)
   homeostasis maintains a relatively stable internal environment
   rids cell of excess, sequesters if in short supply

Is fire alive?
   - it grows, reproduces, responds to stimuli, and can move
   - it can metabolize stored energy – catabolism but it cannot build new components - anabolism
   - it is not made up of cells nor,
   - can it: maintain homeostasis, reproduce variation or undergo evolution
Classification and Taxonomy

Classification or taxonomic systems are used to organize and keep track of large numbers of items. The Dewey Decimal system and Library of Congress numbers are classification systems for books in a library. Both of these systems first organize the books by subject (Biography, History, Fiction, etc.) and then subtopics within those subjects (U.S. History) and finally by author. Since there are over 1.75 million species of organisms, with more being discovered every year, we need a classification system for all the living organisms on earth. **Biologists use genetic relationships as the basis for our taxonomic/classification system.** All species on earth are broken up into categories based on their genetic similarity and therefore the closeness of relationship.

Criteria for Classification

This raises an important question: How do biologists decide which species are the most closely related? We could extract DNA and do a direct genetic comparison between all species on earth, but this is prohibitively expensive, time consuming, and difficult. Direct DNA comparisons are used, but usually for refining decisions that were based on other criteria. Instead biologists look at **characters** or traits that are under **genetic control**. If two species share that character or trait, then they have the same genetic material (DNA code) which they inherited from a common ancestor. Therefore they are genetically related.

Exercise 1: Consider the following organisms:
- humans
- a mushroom
- a tomato plant
- the bacteria that gave you a sinus infection
- a mosquito
- *E. coli* (like what caused a recent contamination of spinach)
- mold on bread

Try arranging them in three groups based on what you think are the closest relatives. For each group, make sure that you can state what you think is the shared character that indicates underlying genetic relations. Give it your best shot and don’t worry if your ideas don’t match what turns out to be the correct arrangement.

<table>
<thead>
<tr>
<th>Group</th>
<th>Members</th>
<th>Shared Character / Shared Genetic Trait</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td></td>
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<tr>
<td>2.</td>
<td></td>
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<tr>
<td>3.</td>
<td></td>
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<tr>
<td>4.</td>
<td></td>
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</tbody>
</table>
**Prokaryotes and Eukaryotes**

One thing that you might have noticed was how difficult it was to make the decision. The question that is at the heart of your decisions was: What are traits that indicate shared genetic material?

Biologists look first for the trait that would indicate the largest genetic difference between two organisms. Put another way, what trait is the product of the biggest block of genes, and therefore shows two organisms are most closely related? The answer is:

**Cell Type:** There are two basic cell types.  
- **Eukaryotic** cells are large (10-100X larger than **prokaryotic cells**), have membrane bound structures such as a nucleus, mitochondria and possibly chloroplasts.  
- **Prokaryotic cells** are very small without separate membrane-bound compartments. The different cell types are the result of huge genetic differences.

Using this piece of information, we divide up organisms into those with Prokaryotic cells and those with Eukaryotic cells.

**Eukaryotes:** Human, mushroom, plant, mosquito  
**Prokaryotes:** bacterium causing sinus infection, *E. coli*
**Three Domains**

Dividing the world up into prokaryotes and eukaryotes is only a crude first step. It would be like leaving all the books in the library divided only by Fiction vs. Non-Fiction. Biologists turn to other characters to organize species further. We divide up the prokaryotes based on cell structures.

**Cell structures:** One example of this is the cell wall some organisms have around their cell membranes. Cell walls are more rigid, providing structure and support, but limiting mobility. Cell walls can be made from very different materials; cellulose, peptidoglycan or chitin. Again, the ability to make a cell wall and what it is made of, indicate a large number of very significant genetic characters. There are many other cell structures that differ between species and are used to distinguish genetic differences.

The Prokaryotes are divided up into two domains, Bacteria and Archaea, based on their cellular structures, such as cell wall materials, type of ribosomes, and DNA organization.

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**Domains:** This is the largest category or taxa for dividing up living organisms (analogous to dividing the library into fiction, non-fiction, and videos/DVDs). We will study primarily the Domain Bacteria and Domain Eukarya this semester.
Domain Eukarya: Four Kingdoms
This domain encompasses a huge diversity of species. We divide up the eukaryotes based on other characters and traits such as:

Level of organization: Some organisms have more complex organization of cells. The biggest difference is between those that are only single-celled, or unicellular, and those that can organize cells into complex arrays of many cells, or multicellular. Again, this indicates dramatically different genetic controls, and therefore genetic relationships.

Means of acquiring energy: The world of organisms is broken up into those that make their own food by capturing energy autotrophs (auto = self, troph = nurture), and those that need to get their food by eating others, heterotrophs (hetero = different or other, troph = nurture). Most of the autotrophs we will see use photosynthesis to get their own energy and food. This indicates a shared set of genes for accomplishing this complicated task.

Heterotrophy: heterotrophs get their food and energy from eating another organism. There are many ways to do this. Ingestive Heterotrophs, such as ourselves, put our food into our bodies (ingest) and then use digestive enzymes to break down the food. Absorptive heterotrophs, like fungi, secrete their digestive enzymes outside their bodies, break down the food and then reabsorb it all. This indicates very different sets of genes.

These characters are used to place all eukaryotes into one of four Kingdoms.

Animal Kingdom
Plant Kingdom
Fungi Kingdom
Protist Kingdom
Exercise 2: Consider the following organisms: a human, a mushroom, a redwood tree, a mosquito, a tomato plant, the mold on your bread, a paramecium. (Their genus and species name are listed in italics below their common names.)

Place each of these organisms into one of the four Kingdoms. Make sure that you can state which character or trait that they share in common that indicates closer genetic relationships. Consider the organism’s level of organization and their means of acquiring energy. Again, give it your best shot and don’t worry if you don’t match the correct classification. You can use more than one character for your decision.

<table>
<thead>
<tr>
<th>Kingdom</th>
<th>Members</th>
<th>Shared Characters / Shared Genetic Traits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal</td>
<td>Human: Homo sapiens</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mushroom: Agaricus augustus</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Redwood: Sequoia sempervirens</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mosquito: Culex pipiens</td>
<td></td>
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<tr>
<td></td>
<td>Tomato: Solanum lycopersicum</td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td>Paramecium: Paramecium caudatum</td>
<td></td>
</tr>
<tr>
<td>Fungi</td>
<td>Bread Mold: Rhizopus stolonifer</td>
<td></td>
</tr>
<tr>
<td>Protist</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Exercise 3: Fill-in examples (You can find examples on the previous pages or use what you know.)

<table>
<thead>
<tr>
<th>Domain</th>
<th>Kingdoms</th>
<th>Characters</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Archaea</strong></td>
<td>many</td>
<td>Prokaryotic cell type, tiny single cells, but with cell structures more similar to eukaryotes. Cell wall unlike those of Bacteria and Eukaryotic cells.</td>
<td>Often found living in extreme environments such as salt flats and hot springs; many more are being discovered in oceans, soils, etc.</td>
</tr>
<tr>
<td><strong>Bacteria</strong></td>
<td>many</td>
<td>Prokaryotic cell type, with peptidoglycan cell walls and cell structures markedly different than eukaryotes.</td>
<td></td>
</tr>
<tr>
<td><strong>Eukarya</strong></td>
<td></td>
<td>Eukaryotic cell type.</td>
<td></td>
</tr>
<tr>
<td>Animal</td>
<td></td>
<td>Multicellular, ingestive heterotrophs, lack cell walls, and most can move.</td>
<td></td>
</tr>
<tr>
<td>Plant</td>
<td></td>
<td>Multicellular, autotrophic (photosynthesis), cell wall of cellulose, and non-motile.</td>
<td></td>
</tr>
<tr>
<td>Fungi</td>
<td></td>
<td>Multicellular, absorptive heterotrophs with cell wall of chitin, and non-motile.</td>
<td></td>
</tr>
<tr>
<td>Protist</td>
<td></td>
<td>Diverse characters. All the eukaryotes that don’t fit into the other 3 Kingdoms. Single-celled or simple multicellular, autotrophic or heterotrophic. Diversity of cell structures (cell walls, etc.).</td>
<td></td>
</tr>
</tbody>
</table>

Exercise 4: Observe the illustrations of the specimens that follow. Place each in one of the four **Eukarya Kingdoms**. Consider which specific traits or characteristics the specimen possessed that led to your choice.

Use the following definitions to help you:

- **Prokaryotic cells** – A simple cell lacking a nucleus and membrane-bound organelles. Much smaller than eukaryotic cells.
- **Eukaryotic cells** – A cell with a membrane-bound nucleus and other organelles. At least ten times larger than prokaryotic cells.
- **Motile** – Able to initiate its own movement.
- **Autotrophic** – An organism that makes its own food. Most autotrophs use a process called photosynthesis to make sugar molecules from light energy, CO₂, and water. Photosynthetic autotrophs contain green pigments.
- **Heterotrophic** – An organism that obtains nutrients by consuming other organisms or organic material. They may either ingest (eat) food or absorb nutrients through their surfaces.

1. How would you distinguish prokaryotic and eukaryotic organisms? How are their cells different?

2. What two domains have prokaryotic cells (it may help to refer back to “Three Domains”)?
3. Domain. __________________ Kingdom ___________________
   How do you know this illustration is not an archaea or bacteria?

   How do you know this illustration is not an animal?

   How do you know this illustration is not a fungus?

   How do you know this illustration is not a protist (this may be more difficult to answer)?

   Name another organism that you are familiar with that is in this kingdom?

4. Domain. __________________ Kingdom ___________________
   How do you know this illustration is not an archaea or bacteria?

   How do you know this illustration is not a plant?

   How do you know this illustration is not a fungus?

   How do you know this illustration is not a protist?

   Name another organism that you are familiar with that is in this kingdom?
5. Domain. __________________ Kingdom __________________
   How do you know this illustration is not an archaea or bacteria?

   How do you know this illustration is not an animal?

   How do you know this illustration is not a plant?

   How do you know this illustration is not a protist?

   Name another organism that you are familiar with that is in this kingdom?

6. Domain. __________________ Kingdom __________________
   How do you know this illustration is not an archaea or bacteria?

   How do you know this illustration is not a plant?

   How do you know this illustration is not a fungus?

   How do you know this illustration is not an animal?

   Name another organism that you are familiar with that is in this kingdom (you can refer to an organism in this document)?
Exercise 5: Biological Classification: Taxonomy

Taxonomy is the science of naming and classifying organisms. Beyond domains and kingdoms, there is a hierarchical system of classification categories, called taxa, to which organisms are assigned:

- Domain
- Kingdom
- Phylum
- Class
- Order
- Family
- Genus
- Species

Each proper name in the taxonomic hierarchy, for example Class or Family, is called a taxon (plural, taxa). There is not time in this lab to learn something about each of the taxa named above. You should, however, learn the names of the taxa, and their correct order. This is often aided by memorizing a sentence each of whose words begins with the same letter as one of the taxa. One such sentence is: Do Kings Play Chess On Fine Green Sand?

Naming Organisms

Organisms are given specific names so that scientists all over the world will have one name for each organism used by everyone. The names are assigned according to a system devised by Carolus Linnaeus in the eighteenth century. Each organism is given two-part name, hence the system is called binomial nomenclature. The first is a generic name descriptive of a group of similar organisms, called a genus, and a specific name, which refers to only one organism, the species. Although there are eight taxa (or categories), when scientists refer to an organism we use the genus and species names. For example the scientific name for humans is:

\[
\text{Homo sapiens} \\
\text{genus species}
\]

1. What do we call the naming system that Carolus Linnaeus devised?

2. Which two taxa are used for giving scientific names to organisms?

3. Which are more closely related: organisms that share a genus or a class?

Which are more closely related: organisms that share domain or kingdom?

Which are more closely related: organisms in the same kingdom and phylum or genus and species?
4. Using the table of classification below identify the following:
Give the scientific name for these organisms and their common name

| #1     | _____________________________ | _____________________________ | human       |
| #2     | Quercus                      | lobata                       |             |
| #3     | Sequoia                      |                             |             |
| #4     |                             |                             | bobcat      |
| #5     |                             | latrans                     |             |

Table of Classification

<table>
<thead>
<tr>
<th></th>
<th>Human</th>
<th>Bobcat</th>
<th>Coyote</th>
<th>Coast Redwood Tree</th>
<th>Oregon Oak Tree</th>
<th>Valley Oak Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Eukarya</td>
<td>Eukarya</td>
<td>Eukarya</td>
<td>Eukarya</td>
<td>Eukarya</td>
<td>Eukarya</td>
</tr>
<tr>
<td>Kingdom</td>
<td>Animal</td>
<td>Animal</td>
<td>Animal</td>
<td>Plant</td>
<td>Plant</td>
<td>Plant</td>
</tr>
<tr>
<td>Phylum</td>
<td>Chordata</td>
<td>Chordata</td>
<td>Chordata</td>
<td>Pinophyta (Conifer)</td>
<td>Anthophyta (Flowering Plants)</td>
<td>Anthophyta (Flowering Plants)</td>
</tr>
<tr>
<td>Class</td>
<td>Mammal</td>
<td>Mammal</td>
<td>Mammal</td>
<td>Pinopsida</td>
<td>Magnoliopsida</td>
<td>Magnoliopsida</td>
</tr>
<tr>
<td>Order</td>
<td>Primates</td>
<td>Carnivora</td>
<td>Carnivora</td>
<td>Pinales</td>
<td>Fagales</td>
<td>Fagales</td>
</tr>
<tr>
<td>Family</td>
<td>Hominidae</td>
<td>Felidae</td>
<td>Canidae</td>
<td>Cupressaceae</td>
<td>Fagaceae</td>
<td>Fagaceae</td>
</tr>
<tr>
<td>Genus</td>
<td>Homo</td>
<td>Lynx</td>
<td>Canis</td>
<td>Sequoia</td>
<td>Quercus</td>
<td>Quercus</td>
</tr>
<tr>
<td>Species</td>
<td>sapiens</td>
<td>rufus</td>
<td>latrans</td>
<td>sempervirens</td>
<td>oregana</td>
<td>lobata</td>
</tr>
</tbody>
</table>