Lecture One: The Scientific Method

WHAT IS SCIENCE? It is a method used by humans to try to make sense of the world (and universe) in which they live.

APPLIED SCIENCE (a.k.a. "technology") - The seeking of information that is of immediate use and benefit.

PURE SCIENCE - The seeking of information for its own sake. The pursuit of knowledge for the sake of knowledge.

Biology is the study of living organisms. Within biology, there are several subdisciplines that are more narrow in focus. Here are just a few of the subdisciplines of biology…

Microbiology - the microbiologist studies microorganisms, such as bacteria
Genetics - the geneticist studies genes and inheritance
Physiology - the physiologist studies metabolism and function of organisms
Ornithology - the ornithologist studies the biology of birds
Herpetology - the herpetologist studies the biology of amphibians and reptiles
Mammalogy - the mammalogist studies the biology of mammals
Botany - the botanist studies the biology of plants
Mycology - the mycologist studies the biology of fungi
Ecology - the ecologist studies the functioning of ecosystems

…and even within these subdisciplines there are still more specific areas of study!

Scientists all start their work by making OBSERVATIONS and noticing interesting things. That's what you all did when you went out and took pictures. But this is only the first step in a very proscribed procedure we call...

THE SCIENTIFIC METHOD

"The process known as the Scientific Method outlines a series of steps for answering questions, but few scientists adhere rigidly to this prescription. Science is a less structured process than most people realize. Like other intellectual activities, the best science is a process of minds that are creative, intuitive, imaginative, and social. Perhaps science is distinguished by its conviction that natural phenomena, including the processes of life, have natural causes--and by its obsession with evidence. Scientists are generally skeptics.” (from Biology by Neil A. Campbell)

So don't confuse The Scientific Method with Science, in general. Also note that if something is outside the realm of scientific testability, the wise scientists will not presume that it is not true, nor that it does not exist. Some things simply are outside the realm of Science, and cannot be addressed via the Scientific Method.

*Induction* - reasoning from a specific case to the general.

For example:
> my experimental caterpillars grow faster at warm temperatures
> all caterpillars grow faster at warm temperatures

* **Deduction** - reasoning from a general observation to a specific conclusion.
  For example:
> All animals are composed of cells
> Humans are animals
> Therefore, humans are composed of cells.

A common theme in scientific endeavors is the use of **HYPOTHETICO-DEDUCTIVE reasoning**: The formulation of an **hypothesis** (a tentative answer to a question) and the execution of experiments from which one may deduce a general answer to the hypothesis. The steps in this process include:

1. Observation
2. Asking a critical question
3. Develop Hypothesis
4. Make a prediction that can be tested
5. Perform experiments to test the prediction
6. Collect and analyze data
7. Make logical conclusion based on experimental results

**EXAMPLE**

1. **OBSERVATION**: Flamingos eat a variety of invertebrates that they strain from the silt. Interestingly enough, flamingo feather color is similar to that of the shrimps they eat.

2. **CRITICAL QUESTION**: Is the color of the flamingo related to the color of the shrimp in their diet?

3. **DEVELOP HYPOTHESIS**: Flamingo color is derived from shrimp pigments.
   a. Null Hypothesis: There will be no significant difference in feather color between groups of flamingos fed different diets.
   b. Alternate Hypothesis There will be a significant difference in feather color between groups of flamingos fed different diets.

4. **MAKE PREDICTION**: If flamingo diet is changed, its feather color will change.

5. **PERFORM EXPERIMENTS**:
   a. One group of flamingos gets a diet consisting of all items, including shrimp. (Control)
   b. Other group of flamingos gets the same amount and type of food, but without shrimp. (Treatment)

   All other variables (habitat, light period, amount of food, etc.) are held CONSTANT in both groups.
6. COLLECT AND ANALYZE DATA:
   a. Possible result #1: No difference in color between treatment and control groups.
   b. Possible result #2: Significant difference in color between treatment and control groups.

7. CONCLUSION:
   a. If you get result #1, then the null hypothesis cannot be rejected.
   b. If you get result #2, the null hypothesis is rejected, and the alternative hypothesis is accepted.

The results of your study may suggest further experiments. (What component of the shrimp is responsible for the color of the flamingo's feathers? How does the flamingo metabolize nutrients in the shrimp into pink pigments?)

**Important aspects of hypotheses...**
* A hypothesis is nothing more than a TENTATIVE EXPLANATION of a particular phenomenon.
* A hypothesis is based on past experience about the phenomenon. It's an "educated guess."
* Multiple hypotheses make good science. (If you have only one possible answer, you may bias your experiment and your analysis.)
* Hypotheses should be testable via experimental procedures or field studies based on the hypothetico-deductive approach.
  * A hypotheses can be refuted (proven wrong, or falsified), but it CANNOT BE PROVEN CORRECT. (It is impossible to perform enough experiments to be certain that the answer will always be the same, and that the same explanation will hold true.)

**A word about the THEORY...**
* A THEORY is an hypothesis that has stood the test of time. It is a well-substantiated explanation of some aspect of the natural world. It is an organized system of accepted knowledge that applies in a variety of circumstances to explain a specific set of phenomena.
  A theory is constantly subject to testing, modification, and refutation as new evidence and ideas emerge. Theories also have predictive capabilities that guide further investigation.

**And the LAW...**
A LAW is described by a sequence of events in nature that has been observed to occur without variation under the same conditions. Natural law is the basis of the experimental method in science, and is dependent upon cause and effect.
   Example: The Laws of Thermodynamics
THE MYSTERY OF THE GLASS FROGS: A slide show and exercise.

Now that you are experts on how to ask critical questions, take your photos from yesterday and ask questions about the phenomena therein. BE SURE YOU PHRASE THEM IN SUCH A WAY THAT YOU CAN CONSTRUCT A NULL AND ALTERNATE HYPOTHESIS, AND EXPERIMENTS TO TEST THEM!

DEDUCTIVE REASONING: From the general case to the specific
(All birds have feathered wings. We know that sparrows have feathered wings. Therefore, we can deduce that "Sparrows are birds.")

INDUCTIVE REASONING: From a specific case to the general principle.
(Sparrows have can fly and are birds. We also note that robins, flamingos, owls, eagles and penguins have wings and can fly. We can induce that "ALL BIRDS CAN FLY").

The problem with the latter is the ol' "inductive leap": When you make the jump from many observations to saying that your observation is true in all cases, you are making a generalization. Although this is useful, we must be aware that there might be EXCEPTIONS to the general rule, and to the possibility that it will eventually be found that the general rule is not true.

Let's take the example above. You suddenly come upon an ostrich. It has wings, and all the other characteristics you'd ascribe to a bird--BUT IT CANNOT FLY!

Does this mean that your general rule is always wrong? No. But it does mean that there are exceptions, and you must be ready to find them! The human mind is creative in its inductive reasoning, but it is not omniscient and infallible!