**BIOL 300 – Foundations of Biology**
**Fall 2017 – Telleen**
**Lecture 2**

# I. Science and the Scientific Method

### A. What is science?

1. Broadly, it is any system of objective knowledge.
2. However, it usually refers to the system of acquiring knowledge based on the scientific method
3. or to the body of knowledge gathered by humans using this method.

### B. Goals of Science

1. Interrogation of the world around us to figure out how it works.
2. A way to describe how the world around us works.

### C. Classification of science

1. Natural Science - which seeks to study and describe natural phenomena.
2. Social Science - which studies human behavior and societies.
3. Formal Science (e.g. Mathematics) is sometimes included, but it differs from the other two in that it is not empirical, and instead verifies its knowledge using *a priori* methods
4. In common usage, Science usually refers to natural science, though the boundary between social and natural sciences is becoming increasingly blurry in some areas, since we now think that humans and societies are natural phenomena.

### D. Empirical Sciences

1. Both natural and social sciences are **empirical**, that is the knowledge they generate must be based on observable phenomena and be capable of being verified by other researchers.

### E. Models and Predictions

1. Scientists construct **models** to describe observed phenomena, which can be used to make predictions about future events, behavior of systems, etc.
2. These predictions can then be verified experimentally, or rejected experimentally, which in turn leads to tentative acceptance, rejection, or refinement of the original model.
3. Thus, science as a body of knowledge is ever changing. The scientific method has built in error correction mechanisms that we'll expand on in a few minutes.
4. Think about this example: Isaac Newton proposed his classical mechanics (classical physics) hundreds of years ago. They appear to be pretty good models of how physics works. That is, they make fairly accurate predictions, particularly as far as they could be tested by Newton at the time. Now move forward to the early 20th century. Technology had advanced quite a bit. We could now observe things impossible to observe in Newton's time, and we could also measure things more accurately. When Einstein proposed his Theories of General and Special Relativity, he did not ignore Newton's theories. He just had data that Newton didn't have. Particularly, information about the way particles behave at very large scales, very small scales, and very fast speeds (all things that Newton couldn't observe). So Einstein observed that in these instances Newton's laws weren't as good at making predictions, so Einstein revised the model. In fact, if you take Einstein's equations and reduce out the very large, very small, and very fast, you end up with Newton's equations. And in

practice, it turns out that Newton's equations are very accurate, at least here on the surface of the Earth.

5. This example shows how science is an iterative process and continually builds on itself. Keep in mind that new data can help refine existing theories or it can completely refute them. However, remember that the strength of science is in its ability to make predictions. So the real test of a hypothesis is how accurate its predictions are. Notice I've been using the terms **hypothesis** and **theory**, once we go through the method we'll revisit these terms and explain what we mean by them.

**F. The Scientific Method**

1. Now that we've talked about science in general terms let's get into the scientific method itself, which we have already alluded to in the Newton/Einstein example.

2. In a nut shell, the scientific method is a process for generating, testing, and refining objective models that describe the world around us. It can be depicted in this flow chart: (see also diagram on the board in class)

    1. Observation(s)
    2. Generate a hypothesis based on the observed data
    3. Perform experiments to test the hypothesis
    4. Return to 2 and continue

3. This can be expanded, but I think the simple version is helpful for starting to think about how science works. Now let's expand (see also ozone example in text)

    1. Observation(s) about a topic/object/etc → X
    2. Define problem/question about X suggested by the observations
    3. Based on the information, formulate a model or hypothesis to describe how X works. Keep in mind that it must make predictions about the outcome of experiments designed to assess the validity of the model/hypothesis. Sometimes several alternative hypotheses are suggested.
    4. Perform experiments that check the predictions by the model/hypothesis
    5. Refine or reject the model based on the observed data. Return to step 2

4. **The scientific method is iterative**. That is, it is conducted over and over. Thus models will constantly be refined until they reflect as accurately as possible the way things work.

5. It is also **self-correcting**. Consider the possibility that a scientist fabricates data to support his or her pet hypothesis. He or she might lead others to believe based on the data that the hypothesis was correct (when in fact it's not). Later on when other scientists reconstruct or repeat the experiment, they will find that it can't be reproduced. Or they will find that any models based on that hypothesis can't make accurate predictions. Thus, eventually the error will be corrected. Sometimes this happens quickly, sometimes not for a long time. Examples: Korean Stem Cells (fraudulent), Recent Crystallography retraction in Nature (accidental)

**G. Variables and Controls**

1. When designing experiments, each factor that might influence a process is called a **variable**
2. In order to evaluate hypotheses about a variable, all other variables must be kept constant so that we don't get misled or confused by their influences.
3. When performing experiments to test hypotheses about a variable, we also set up a second **control experiment** in which we do not alter that variable.

**H. Hypotheses and Theories**

1. Now that we've talked about the scientific method, we can talk about some of the terminology and subtleties of it. What is a theory?

2. We've already talked about hypotheses and models, which are essentially

elaborate hypotheses or collections of hypotheses. **A hypothesis is simply a suggested explanation of a phenomenon or a reasonable proposal suggesting a correlation between multiple phenomena**.

a. Note that this definition is actually how theory is used in a non-scientific context.

3. **In scientific usage, a theory *does not* mean an unsubstantiated guess or hunch, as it can in everyday speech**. A theory is a logically self-consistent model or framework for describing the behavior of a related set of natural or social phenomena. It originates from and/or is supported by experimental evidence (see scientific method). In this sense, a theory is a systematic and formalized expression of all previous observations that is predictive, logical and testable. In principle, scientific theories are always tentative, and subject to corrections or inclusion in a yet wider theory.
4. In simple terms, it's a hypothesis until there is a large set of supporting data, then it is generally accepted and considered a theory.
5. **A scientific theory is as close as science can get to fact**.
6. Some scientific disciplines refer to scientific laws, which are mathematically defined expressions.

### I. Inference and Observation

1. We have sort of glossed over the role of observation in the scientific method, but it is an important point.
2. Science often uses **inference** (deriving a conclusion based on what one already knows) to come to conclusions, but sometimes it is difficult to tell the difference between an objective observation and simple inference (since we are hard-wired to make inferences). In science, objectivity is crucial, so it is important to at least be aware of biases, if not eliminate them completely.
3. Examples of observations vs inferences

### J. Ockam's Razor

1. First proposed by William of Ockam in the 14th Century. He was a Franciscan monk.
2. States that the explanation of any phenomenon should make as few assumptions as possible, eliminating, or "shaving off", those that make no difference in the observable predictions of the explanatory hypothesis or theory.
3. **Given two hypotheses with equal predictive power, favor the one with the fewest assumptions**.
4. We prefer simpler theories to more complex ones "because their empirical content is greater; and because they are better testable" (Popper 1992). In other words, a simple theory applies to more cases than a more complex one, and is thus more easily refuted.
5. "Theories should be as simple as possible, but no simpler." –Einstein

### K. Logic and Reasoning

1. Science is a process of investigation using observation, experimentation, and reasoning
2. However, not all investigations are scientific
    a. What’s in a particular type of food?
    b. We can approach this question in two ways:
        1. Read the label, research on the internet (like map example in text)
        2. Gather empirical evidence → as we’ll see in lab next time
3. **Deductive Reasoning**
    a. Decisions made by applying a ‘guide’, which is usually accepted general principles
    b. Another way to state this is that general principles explain specific observations
    c. We use this type of reasoning every day
4. **Inductive Reasoning**
    a. Where do general principles come from?
    b. Science tries to discover the general principles that govern the physical world
    c. How? Observation!
    d. Inductive reasoning uses examination of specific cases to discover/describe general principles

e. Scientists use their observations to create hypotheses or models which have predictive power. If they work, they become the general principles!

**L. Biology as a Science**

1. There are four basic theories that unify biology as a science (these are the general principles that started out as hypotheses, but their predictive power was established/confirmed to such a degree that they became theories (remember in science, this is as close as we can get to fact!)
2. These four theories are
   a. **Cell Theory –** Living organisms are organized into cells, which were first observed by Robert Hooke in 1665 using one of the first microscopes ever made
   b. **Gene Theory –** Units of DNA are the molecular basis of inheritance. It is transcribed into RNA, which is in turn translated into protein. These molecules determine to a large extent what an organism will be like
   c. **Theory of Heredity –** Describes the unity of life and the passage of traits from generation to generation. Based on the work of Gregor Mendel in the 1800s
   d. **Theory of Evolution –** Explains the diversity of life and how it came about. Originally proposed by Darwin and Wallace in 1859