SCIENTIFIC INVESTIGATION CONCEPTS

These go with all chapters (we use them throughout the course).

- To paraphrase Albert Einstein: “Science is a refinement of everyday thinking.”

- Science is concerned with objective “proof.” The goal is to explain things about the world that can be investigated using observation, experimentation, mathematics, and logic. Scientists attempt to answer questions about how the universe and its occupants behave. If a question cannot be investigated in this way, it is not a scientific question. For example, you might say: “Some of the laws that govern nature cannot be detected by scientists.” If they cannot be detected, than they cannot be investigated. Since this statement can neither be proven correct or incorrect, it is not a scientific claim.

- Science proceeds by collecting “facts” from nature. Other terms for these facts are observations or *data*. A scientist tries to use logic to weld the facts together into a theory.

- A *theory* is not a guess; a theory is an explanation of something we observe in nature. A successful theory is based on facts and can be used to predict what will happen in a specific situation. Some explanations that are still called theories have been around so long and are supported by so much evidence that there is no question that they are accurate explanations of nature.

- The term *law* has little useful meaning in science. This is because it has been inconsistently and haphazardly applied in the past. Law seems to imply that the idea applies to very many situations. Some scientific theories that have been called laws simply don’t apply to a wide range of situations. Other theories, such as the “Theory of Relativity” are still called theories even though they have been found to apply to a wide range of situations.

- Some theoretical physicists work largely on paper, using mathematics to develop theories explaining nature (A fellow named Einstein comes to mind). Many great discoveries and important theories have been developed in this way. However, their explanations did not earn complete acceptance until they were confirmed by experiment or direct observation of nature.

- Theories are often superseded by later work. Isaac Newton formulated a "Law of Universal Gravitation." For many years this was believed to be a complete explanation of the behavior of gravity. That is, until our buddy Einstein came along and formulated his "Theory of General Relativity." This theory provided more accurate predictions of nature than Isaac Newton's theory. It is not so much that Newton was "wrong," but rather that his explanation was incomplete. Einstein's theory described more situations in greater accuracy than Newton's theory. Today, scientists are working on a theory of quantum gravity, which will hopefully explain more and be more accurate than Einstein's theory.

- Before beginning an investigation, a scientist might make a guess about how things behave. This guess is called a *hypothesis*. What we call *experiments* are often conducted to confirm or disprove a hypothesis. An experiment is a manipulation of nature in order to observe something specific, often the response to something the experimenter changes. An experiment might be considered a success even if the hypothesis is disproved.

- An experiment must be carefully *controlled*. In general, this involves the simple idea that we only change one thing at a time, until we understand the effect that thing has on the situation or phenomenon. In a pendulum experiment, if you changed both the length of the pendulum and the mass of the pendulum bob, you would not know if one or both of those changes were responsible for any changes in the period of the swing that you observed. Instead, we would keep everything *constant* but one characteristic of the pendulum. We would only change that one thing at a time.

- In some experiments, a *control group* must be included. For example, if you are interested in the effect of pollutants on Ozark Blind Cave Fish, you might put several fish in different tanks, and expose them to common pollutants. Suppose some of the fish died because you failed to consistently maintain their temperature and some because of the pollutants. Your conclusions about which pollutants are dangerous to cave fish would be invalid. If you include fish that received no pollutants, and observe them dying also, you would realize that the pollutants had not killed all the fish.

- In an experiment, the thing we change in order to see its effect is called the *independent variable*. If we collect data that can be graphed, the independent variable is placed on the *x*-axis.

- The thing that changes in response to the independent variable is called the *dependent variable.* It is placed on the *y*-axis of the graph.

- Some simple, logical ideas can help you construct "scientific proof" in the classroom. The first is the idea above, that until you know what is happening, you change only one thing at a time.

- Another is that measuring or observing something once is not enough. Every measurement contains some error. Try measuring the length of your desk three times. You are very likely to get three slightly different lengths. Some observations may be atypical. If an alien based a description of all human beings on yours truly, it would decide that all humans are short, slight, balding, and error-prone. Measure things as many times as necessary to absolutely convince people that your measurement is correct.

- Another important idea in experimentation is that we don't want to read too much into our experiments. For example, the relationship between pendulum length and period is different when the pendulum is swung at small angles than it is when swung at large angles. An experiment done at small angles will not produce an explanation that is correct for large angles, even though all other aspects of the pendulum would be the same.

- We use mathematics for greater precision in our descriptions. Saying “pretty wide” is much less precise than saying “1.24 m” wide. Like it or not, the world is mathematical, meaning that scientists have been able to construct mathematical *models* that predict the way the world behaves. Sometimes we know these models as equations.

- In physics, we believe that the universe is understandable. What’s more, we believe that we can describe aspects of it with very simple, and often very beautiful mathematics.

- Since the time of Galileo (often called “the father of science”), physics has proceeded by simplifying situations. When the simple situation is understood, physicists begin to look at the complications. The most famous example is Galileo’s assertion that, in the absence of air resistance, two falling objects of different masses would hit the ground at the same time. In physics class, after the situation without air resistance is understood, we then investigate the situation with air resistance.