CHAPTER 3 - EXPERIMENTATION IN SCIENCE

People sometimes pretend to be certain about things when they really are not. We can look to the ancient Greeks as an illustration. Their version of science depended almost entirely upon logic, with little or no testing. For instance, Aristotle said that the stars were all the same distance away, that the earth was the center of the solar system, that heavier objects always fall faster, that all object possess an innate tendency to com e to rest, and that there are no such things as atoms. Because he was so highly regarded, scientific progress stopped in many areas for over 2,000 years. We in modern times could likewise pretend to know things beyond doubt if we make up clever enough logical sounding stories, and perhaps people would believe us.

Visual #3-1

Science depends on more than logic, though. It also requires knowledge by senses and authority. In order to incorporate all three of these so that others can repeat the work and see if the results are the same, scientists through the centuries have devised standard methods of testing hypotheses through experiments. We decide to use these methods because we trust the authority of those who came up with them.

As a brief review of scientific methodology, we:

Visual #3-2

(1) Ask a question or pose a problem because of something we observe.
(2) Do research to find out what others have done. (Authority).

Not researching what others have done could result in a great deal of wasted time. For instance, if you needed to know details about the life cycle of the Malaysian tree frog you could move to the Malaysian jungle and observe the frogs for 20 years, or you could save years of jungle dwelling by looking up what others have discovered.

Though we would hope that scientists would be completely unbiased, some may not be. Sad to say, there have been occasions where results have been exaggerated or even falsified. Thus, it is always a good idea to use multiple sources. Whenever possible, these should be primary sources, i.e., the author's original article rather than someone's summary of it.

Visual #3-3

One of the most anti-scientific statements going around is "Follow the science." Even if you are referring to authorities considered reliable, you should still be skeptical. The most intelligent scientists can make mistakes. If Bohr, de Broglie, and Schrödinger had accepted earlier claims without question, they would never have developed quantum chemistry. If Einstein had stopped with what earlier physicists said, he would never have proposed his theory of relativity.

(3) Propose a reasonable (logical) hypothesis to explain our observations.

The hypothesis may or may not prove to be true, but at least it needs to be reasonable.

(4) Devise a way to test the hypothesis by performing controlled experiments.
(5) Perform the test repeatedly while observing the results. (Senses).
(6) Report our results (inductive logic) so others can confirm or falsify our conclusions.

Visual #3-4

Professional scientists rely heavily on *peer review*, in which the work of a chemist would be published in a chemistry journal, that of a physicist in a physics journal, and so on. The peers carefully examine the report to look for errors. If they think they have found one, they return it to the author, who can defend the original conclusion or make corrections. When the reviewers are satisfied, the work is published.

This process does not completely eliminate the possibility of error, but it makes it much less likely.

Once the results have been confirmed through peer review, they become part of the scientific literature and are later used by other researchers.

I. HOW TO DESIGN EXPERIMENTS.

Visual #3-5

Experiments are attempts to determine cause and effect relationships. If our hypothesis is that Thing 1 will cause Thing 2 to happen, we set up a way to change Thing 1 while we watch to see if Thing 2 does indeed change in a predictable way. For instance, if we think that the amount of fertilizer we give plants would affect their growth, we might come up with a hypothesis that could be expressed in an if-then form, e.g., If the amount of fertilizer changes, then the growth of the plant will also change.

A. Independent Variable.

The thing we change on purpose is called the *Independent Variable*. It is independent because it does not depend on anything but the will of the experimenter. (Time is often used as an independent variable because, even though we cannot control it, we can control when we start and stop making measurements.)

B. Dependent Variable.

We then watch to see if Thing 2 changes. Because we want to know if it *depends* on the Independent Variable, it is called the *Dependent Variable*.

C. Constants.

Visual #3-6

Having more than one independent variable would make our results uncertain. For instance, if we changed the fertilizer, the amount of water, and the amount of light, we could not be certain that the fertilizer was the cause of change. Thus, we attempt to keep every factor except the Independent Variable a *Constant*.

D. Experimental Group.

An experiment done on only one individual is not very persuasive. If at all possible, the experiment should be done on *Experimental Groups* instead. The size of the groups should be as large as circumstances allow.

If the groups are small (e.g., a small number of plants), the experiment should at least be done as many times as possible.

E. Control Group.

When we devise experiments, we always have to allow for the possibility that we may be overlooking something.

Visual #3-7

For instance, if we do our experiment on fertilizers and plant growth, there could be some factors that we have no way to know about. Suppose that when we changed the amount of fertilizer all our experimental plants died. Though we might assume that the change had killed them, there could have been other circumstances of which we were unaware. Thus, experiments usually involve a *control group* for which we deliberately do NOT change the independent variable (in this case, the amount of fertilizer). If we had a control group and the plants in that group also died, it would indicate that we probably overlooked something. (Perhaps there was a burst of gamma radiation from the sun or an infestation of microscopic parasites.)

Since we don't know what we don't know, control groups help us to avoid false conclusions based on unforeseen circumstances.

The difference between a constant and a control is that the constant is a factor in the experiment, whereas a control group is a group of individual test subjects.

We can never claim that we have absolutely proved anything through experimentation, only that have a high confidence level. For example, one of the clay pots in which the Dead Sea Scrolls were found at Qumran, Israel was tested to see if it was made of the same type of clay found there. It was. This would tend to give us a very high confidence level. Though we accept it as being an artifact from Qumran, we cannot say with absolute certainty that this is the only clay deposit in the world with that particular chemical composition.

Likewise, an honest scientist does not claim to have proved his/her hypothesis, but instead reports that it was confirmed or falsified, often with a percent confidence level.

II. SCIENTIFIC HYPOTHESES, LAWS, THEORIES, AND MODELS.

A. HYPOTHESES.

Visual #3-8

Scientific experiments are usually intended to confirm or refute a tentative though reasonable explanation known as a hypothesis.

B. LAWS.

Suppose we come up with a hypothesis regarding things we expect to happen under certain circumstances. We test it over and over, and find that every experiment supports the hypothesis. Others repeat the experiment for years or decades and always reach the same conclusion. If no one has ever observed a single exception, the observation may eventually be regarded as a law of science.

Visual #3-9

A scientific law is simply a description of WHAT always seems to happen, without attempting to explain WHY it happens. If a single exception is ever observed the law will either need to be modified if the exception is minor, or thrown out if the exception is major. For instance, for thousands of years people thought that the qualitative statement "what goes up must come down" was a scientific law – until the development of rockets. The principle still works in most cases, so we modify it to say something like "what goes up must come down unless it is traveling with sufficient velocity to escape the earth's gravity." A scientific law does not make anything happen; it simply describes what happens.

C. SCIENTIFIC THEORIES.

A scientific law tells us WHAT happens. In contrast, a scientific theory is a thoroughly tested explanation for WHY it happens.

Unless we are dealing with topics such as time dilation or the behavior of submicroscopic particles in physics, we usually deal with classical (as opposed to relativistic or quantum) physics. In classical physics, the force of gravitational attraction between two objects is described by the equation $F_g = \frac{G\, m_1\, m_2}{d^2}$ where Fg is the force of gravity, G is a gravitational constant that depends on the measuring system used, m_1 and m_2 are the masses of the two objects, and d is the distance between their centers. (The gravitational constant G can be measured by means of instrument such as a Cavendish Balance.)

Visual #3-10

This equation for the Law of Gravity tells us WHAT happens. However, it does not tell us WHY gravity exists. For that, we need an explanatory theory.

In ordinary conversation, many people use the word *theory* to simply indicate a guess. However, in science, the word has a much more precise meaning. If a hypothesis is confirmed by repeated experimentation and has never failed a test, it eventually begins to be recognized as a THEORY. (A scientific theory may never have actually passed a test, but at least there have been attempts to test it.) We can envision a test that, if failed, would show that the theory is wrong. That is, it at least has the potential to be falsified.

For a given phenomenon, there are usually more theories than there are laws. For instance, there is only one Law of Gravity describing what happens, but there are several explanatory theories attempting to explain why it happens.

- One proposal is that particles known as gravitons move back and forth between objects.
- Another is that gravity moves in waves.
- Another is that space is not really three-dimensional (length, width, height) as we perceive it, but that there is a fourth direction toward which the presence of mass

somehow distorts it. (Time is considered yet another dimension.)

No one has figured out a way to detect gravitons or to be sure that the curvature of space is correct rather than some other explanation. The most promising theory seems to be gravity waves, which some physicists claim to have detected for a short period of time on at least two occasions. Nevertheless, each of the above ideas qualifies as a scientific theory because scientists have attempted to test them, and they have not failed the tests so far.

D. SCIENTIFIC MODELS.

Visual #3-11

When it comes to things we cannot directly observe or test, we can never be sure we have enough evidence to draw a correct conclusion. Our situation is somewhat like the old John Saxe poem entitled "The Six Blind Men of Hindostan," in which six blind men encountered an elephant. Depending on which part they touched, each had a different idea what an elephant was like. One thought it was like a spear, one like a rope, one like a wall, one like a tree, one like a snake, and one like a fan. Each was only partially right. Had they pooled their insight, they might have been better able to understand elephants.

Like the blind men, we sometimes encounter things in nature we cannot directly observe because they are too fast or too slow, too big or too small, too far away, past, future, etc. When this happens, we can still put together whatever information is available. We may not have enough to come up with a theory, but we can still put together a model. A model need not be directly testable to be useful because it helps us to better "wrap our minds around the idea." For instance, the Planetary Model of the Atom represents the atom like a miniature solar system with the nucleus at the center and the electrons like tiny planets orbiting it. Nobody believes this model is exactly correct, but it helps us visualize what atoms are like.

Visual #3-12

"ONLY A THEORY?" It is a mistake to say that evolution is "only a theory." What we call the theory of evolution is not a theory at all, because there is no way to perform experiments to test either the idea that all life came from one common ancestor or that humans came from apelike ancestors. There is no test that would falsify either one.

Rather than a well-tested theory, there are several contradictory hypotheses or *models* of evolution such as Neo-Darwinism and Punctuated Equilibria. Likewise, the term "big bang theory" is incorrect because the idea of a "big bang" is not testable. It relies on many contradictory computer models (Hot Big Bang, Cold Big Bang, Inflation, String, Texture, Steady-State, et al.) rather than experimentation. Each of these is a hypothesis or model rather than a theory.

To summarize:

- A HYPOTHESIS is a tentative explanation for something observed in nature.
- A LAW has also been tested by many experiments (usually for many years). It describes WHAT happens, without trying to say WHY it happens.
- A THEORY is a hypothesis that has been thoroughly tested by many experiments. It is an attempt to explain WHY something happens. We should be able to envision some sort of test that, if failed, would falsify the theory.
- A MODEL is a description, object, drawing, set of equations, etc. that helps us get a mental picture of something we cannot directly observe.

III. MAJOR DIVISIONS OF SCIENCE.

Different branches of science cover a wide range of topics. This course will deal mostly with those that are considered *empirical* or *operational* - that is, they deal with phenomena that can be tested by direct observation and experimentation. By contrast, the branches of science that deal with hypothetical past events that cannot be tested are called *historical* sciences.

The distinction between science and technology is often blurred. Science is the quest for new knowledge, whereas technology is the application of previously acquired knowledge, especially through the use of measuring devices.

A. PHYSICS.

Visual #3-13

Physics is the study of forces, motion, energy, and the like. It is often divided into classical physics and modern physics.

1. **Classical physics** tends to deal with macroscopic, i.e., visible, phenomena. This would include astronomy, mechanics (the study of motion), thermodynamics (the flow of heat and other forms of energy), acoustics (the study of sound), optics (the study of light), and the study of electric and magnetic fields.
2. **Modern physics.** On the largest scale, modern physics deals with relativity (the study of velocities approaching the speed of light, the effect of gravity on time, the behavior of objects at high energy) and similar topics. On the scale of atoms and below, it deals with such quantum mechanical topics as the dual wave/particle nature of matter. It is also concerned with quantum field theory, which tries to explain the ultimate causes of electric, magnetic, and gravitational fields.

B. CHEMISTRY.

Chemistry is the study of the interaction of atoms and molecules. It is often divided into several major categories.

Visual #3-14

1. **Organic chemistry** deals with carbon-based compounds that usually have their source in living things.

   Carbon dioxide is usually not considered within organic chemistry because it does not contain any of the other elements needed by living things, such as hydrogen.
2. **Inorganic chemistry** focuses on compounds not based on carbon.
3. **Analytical chemistry** has to do with the atomic structure of compounds. Some of the focus is on quantitative analysis and some is on qualitative.
4. **Physical chemistry** blurs toward physics. It has to do with the effects of energy on matter and chemical reactions.
5. **Nuclear chemistry** has to do with the nucleus of the atom.
6. **Biochemistry** has to do with the chemical reactions and processes that go on within living things.

C. BIOLOGY.

Visual #3-15

Biology touches on all aspects of life. For instance, botany studies plants, zoology studies animals, marine biology studies sea life, cell biology studies the operation of the cell and its parts, bacteriology focuses on bacteria, and so on.

Since science requires experimentation, the branches of biology that allow for experimental testing fall within the realm of empirical science. Those branches deal with repeatable processes going on in the present. For example, studying how cells absorb and process nutrients is amenable to testing. Likewise, the idea that living things might gain extra genetic information and complexity under laboratory conditions can be tested and is thus part of empirical science. (Note: no experiments have succeeded in producing increasing complexity.)

An idea does not necessarily need to be true in order to be part of empirical science, just testable.

D. PHYSICAL GEOLOGY.

Visual #3-16

Some aspects of geology such as the study of oil and mineral deposits, earthquakes, plate tectonics, volcanoes, and the like have to do with present processes. These are testable.

Oceanography and meteorology (the study of weather) are similar to physical geology in their goals and methods.

E. HISTORICAL SCIENCES.

Following are a few of the areas called historical sciences They often use scientific techniques, but are primarily concerned with past processes and events that are beyond the range of experimentation.

1. **Evolutionary biology** has to do not with what is happening in living things now, but with hypothetical explanations of how they got that way. However, the idea that living things evolved in the past from one-celled organisms all the way to the highest levels cannot be tested and is often presented as part of "historical science."

   We can come up with models of how living things might have evolved in the distant past but since we cannot test them, we cannot legitimately call them scientific theories or laws.

2. **Historical Geology** is used to try to determine untestable quantities such as the age of the earth and of particular strata within the geologic record. There is no way to experimentally confirm the values obtained.

   Most geologic ages are obtained by stratigraphic means. The age assigned to a stratum is determined by the group or suite of fossils it contains, and the age of the suite is determined by the strata in which it occurs. If any of the material contains enough radioactive substances to allow radiometric dating, such a test may be performed. However, only a very small minority of radiometric ages match with the previously assigned age. Those that do not are discarded.

   Historical geology is based on the unprovable assumption that "The present is the key to the past." This statement gives a brief summary of the principle of *uniformitarianism*, which says that geologic processes always occur at slow, steady, uniform rates. Compare uniformitarianism's denial that there has ever been a worldwide Flood to the warning given in 2 Pet. 3:3-6:

   > "Knowing this first, that there shall come in the last days scoffers, walking after their own lusts, And saying, Where is the promise of his coming? for since the fathers fell asleep, all things continue as they were from the beginning of the creation.
   > For this they ***willingly are ignorant of***, that by the word of God the heavens were of old, and the earth standing out of the water and in the water: Whereby the world that then was, being overflowed with water, perished."

3. **Cosmology.**

   Visual #3-17

   The field of cosmology is different from astronomy. Much of it does not deal with processes operating in the universe today, but in proposed explanations of how those processes came to be. For instance, it seems that most cosmologists believe in a "big bang."

   Since there is no way to repeat and test the beginning of the universe, cosmology relies almost entirely upon mathematical models that cannot be confirmed by experimentation. Many of the models contradict each other. Though they are designed to be compatible with present day observations, there is no way to perform tests to determine whether any of them are correct about the distant past.

4. **Paleontology.**

   A fossil consists of the remains of a formerly living animal or plant, whether the entire organism, part of it, or traces such as footprints and burrows. Since many fossils do not have living counterparts, paleontologists use them to try to determine not just the structure of the organism but also its behavior, the environment in which it lived, and so on. They could possibly be right, but there is no way to test their conclusions.

5. **Archaeology** focuses on studying past societies. Though archaeologists use technology

for analysis of ancient artifacts, their conclusions are logical inferences and are almost never capable of being tested.

6. **Forensics** is the use of science and technology in an attempt to establish facts, usually in historical or legal matters. It involves many disciplines.
   - Crime scene investigators might use physics to determine the height of a shooter by calculating the trajectory of a bullet.
   - They might use chemistry to determine whether the mud on a person's shoes is likely to have come from a specific site.
   - They might use biology to determine how long a person has been dead by measuring the state of development of larvae in a corpse.

   Legal proof is not the same as scientific proof. An honest forensic scientist would never claim to have scientifically proven who committed a crime. Instead, he/she usually attempts to persuade a jury beyond a *reasonable doubt* as to the identity of the perpetrator.
7. **Textual criticism** is the study of ancient manuscripts in an attempt to determine their age and original contents. Since it includes the study of Bible manuscripts, it is of particular importance to Christians.

It would be far beyond the scope of this course to try to deal with every branch of science, whether empirical or historical. Instead, it will focus mostly on empirical science and will only touch on historical sciences as they relate to the Christian faith.

CHAPTER 3 REVIEW QUESTIONS

1. Why is peer review important in science? ____

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2. Why is it important to have only one independent variable in an experiment? _______________

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3. What is the purpose of having a control group in an experiment? __________________________

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4. What is the purpose of a scientific LAW? ____

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5. What is the purpose of a scientific THEORY? ____

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6. Why is it incorrect to say evolution is "only a theory"? __________________________________

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7. Since we cannot directly test phenomena that are too big, too small, too slow, too fast, past, future and so on, what do we do to try to understand them better? ___________________________

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8. What does "empirical" mean? ____

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9. What is the difference between empirical (also called "operational") and historical science?

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10. Give an example of an empirical part of biology. ______________________________________

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11. Give an example of something usually considered part of biology that should instead be called "historical biology." ____

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12. What is uniformitarianism? ____

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13. How does 2 Pet. 3:3-6 tell us that uniformitarianism is wrong? __________________________

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