Name: ____________________ Teacher: _______________ Pd. ___ Date: ________

STAAR Science Tutorial 01
TEKS 8.2 & 8.3: Scientific Inquiry & Models

TEKS 8.2A,B,E: The student is expected to plan, design and implement comparative and descriptive investigations by making observations, asking well-defined questions, formulating testable hypotheses, and using appropriate equipment and technology, to analyze data to formulate reasonable explanations, communicate valid conclusions supported by the data, and predict trends.

TEKS 8.2B,C: The student is expected to use models to represent aspects of the natural world such as an atom, a molecule, space or a geologic feature; and identify advantages and limitations of models such as size, scale, properties, and materials.

Science and Technology

- **Science** is the study of the natural world, and the body of knowledge that has been gained in that process. Scientists are people who study one of the branches of science to learn new knowledge of the natural world.
- The main divisions of science are physical science, life science and earth science.
- Physical science is the study of matter and energy. The two main branches of physical science are physics and chemistry. **Physics** focuses on energy forms and their behavior, while **chemistry** focuses on the interactions of matter.
- Life science (**biology**) studies living organisms, at scales ranging from a single cell to the interactions of all living organisms on Earth. Cellular or micro-biology studies the structures and processes within single cells. **Genetics** is the study of how organisms pass traits from one generation to the next. **Anatomy** studies the structures and processes in complex organisms such as humans. **Ecology** studies the interactions of whole populations or communities with their environment.
- The main divisions of earth science are **geology**, the study of the Earth's crust, mantle and core, **meteorology**, the study of the Earth's atmosphere, and **astronomy**, the study of space beyond the Earth.
- **Technology** is the practical application of scientific knowledge to make new products or tools. Examples of technology include buildings, telephones, televisions, automobiles and computers. Engineers are people who use scientific knowledge to design, build and maintain technology.

Scientific Inquiry Methods

- There is no one process or set of steps that scientists use to learn new scientific knowledge. Scientists do use a basic set of observation and reasoning skills, and follow a general process, in many scientific investigations. This process was once called "the scientific method," though in fact there was never one standard method.

The following paragraphs describe the most common steps that may be included in a scientific inquiry.

- **Question**: The scientific inquiry process always begins with a question or problem which can be answered by scientific inquiry. It can be comparison, such as: "Which laundry detergent, Tide or Cheer, will remove mustard stains from cotton the best?", or a description, such as the migration habits of caribou or the structure of DNA. Not all questions can be answered by scientific inquiry. Human opinions, such as who was the best-ever baseball player, or teenagers' favorite recording artist, can be collected and summarized in opinion surveys, but this is not science. Some questions cannot be answered by scientific inquiry. For example, religious beliefs are based on faith, not experimentally-testable laws of nature. No experiment can determine if there is (or is not) a God. Some questions cannot presently be answered because of limitations in current technology, but may be answerable in the future.
- **Observation**: Before a question can be answered, observations are needed to understand the scope of the question, guess at possible answers, and design an experiment that can answer the question. In science, an observation is the use of one or more of the senses to gather and record detailed information about some element of the natural world. Observations can either be qualitative, described in words, such as color or shape, or quantitative, measured and described in numbers with standard units. If possible, scientists prefer quantitative (numeric) observations, because they are universally understood and easily analyzed. The recorded observations are called data.
- **Research**: Once a scientist has a proposed question, and has made some initial observations about it, he or she will want to know what other scientists have published about the question. This research will help in predicting the most likely answer to the question, and in designing an experiment that will answer the question with the fewest sources of error. Research may reveal that an experiment is not needed to answer the question, because it has already been answered and verified by other scientists.
- **Inferences**: An inference is a logical interpretation based on observations and prior knowledge. We all use inferences many times each day to interpret the world around us. For example, when the lights go out in a room, possible inferences would include a power failure, a burned-out light bulb, a tripped circuit breaker, or simply someone turning the light switch off. By collecting more information and making more inferences, the answer choices are narrowed, hopefully to one. Scientists use inferences to make sense of their observations, to make initial guesses about what will happen in an experiment, and why it will happen.
- **Hypothesis**: A hypothesis is a prediction about the results of an experiment, possible explanation of a set of observations, or predicted answer to a scientific inquiry question. It is usually stated in a sentence that begins with "It is predicted that . . . .", or in an 'if-then' logical statement: "If more carbon dioxide is added to the Earth's atmosphere, then the average temperature of the atmosphere will rise." The hypothesis must be testable by observation or experiment. It must be falsifiable. If there is no way to prove a false hypothesis is actually false, it is not a proper hypothesis for scientific inquiry.

- **Experimental Design**: Once a hypothesis has been created, an experiment must be designed to test that hypothesis. The experimental design consists of a list of materials, and a series of steps (procedures) that must be followed. Both the materials and procedures should be specific and exact, so that each time the experiment is performed, the results will be the same, no matter who performs the experiment. The material list should include quantities, sizes and brands. The procedures should be numbered in proper order, and give details of how each step should be performed. The design must avoid as many sources of error as possible, and lead to repeatable results. In other words, if the experiment is repeated ten times, each should get about the same result. If the results are not consistent, there are sources of error that must be corrected.
- **Controlling Variables**: A properly designed experiment can only test changes in one variable at a time. This variable is called the independent or manipulated variable. All other variables in the experiment must be "controlled" (that is, kept the same throughout the experiment) as much as possible. The variables that are measured by the scientist in the experiment are called the dependent or responding variables. There can be more than one dependent or responding variable in an experiment. For example, in an experiment testing which laundry detergent removes mustard and ketchup stains the best, the brand of laundry detergent would be the independent variable, and the amount of mustard and ketchup stain removal would be the two dependent variables. The controlled variables would be the cloth type, the stains on each sample, the water temperature, the length of wash cycle and every other step in the testing procedure. When a variable in the experiment cannot be completely controlled, such as the genetic variations of people in drug tests, the variation is minimized by averaging results from a large number of tests or test subjects.
- **Control Group**: In some comparative experiments, there is a need to compare the inclusion of some factor with the absence of that factor in the independent variable. For example, in testing an experimental vaccine for the flu, the scientist will give some subjects the tested vaccine (the test group), while others are not given the vaccine (the control group). In "double-blind" experimental studies, neither the scientist nor the subjects know whether they are getting the actual test vaccine—this is assigned randomly by computer. The control group gets a "placebo", a place-holder which looks like the test vaccine, but in-fact a harmless but useless substance. At the end of the experiment, the subjects (both test and control) report their response to the vaccine (whether they got the flu). A computer then reveals which subjects got the test vaccine or placebo. If fewer test group subjects get the flu than control group subjects, the vaccine has some effectiveness.
- **Data Collection**: Once the experiment is designed, it must be performed exactly as designed, and both quantitative and qualitative data collected. Standard units of measurement, and accurate and precise measuring devices must be used to minimize error. (*See STAAR Science Tutorial 2-Measurement*.) Most measurements are subject to some error, due to uncontrollable outside influences or human error in making measurements. To minimize the impact of that error, multiple trials of the experiment should be performed. The larger the number of experimental trials, the smaller the resulting error when the data is averaged. A data collection table is used to record the data.

- **Data Analysis:** Once all data is collected, it must be analyzed to reach a conclusion supported by the data. If the data is quantitative, it must be averaged, and the range (difference between low and high data points) compared to the average. If the range is large, the reliability of the data must be questioned. A small range suggests that the non-tested variables were well controlled. Graphs should be prepared to best illustrate the results. (*See STAAR Tutorial 3-Graphing.*) In most experiments, there is one graph of the data which will best show the outcome of the experiment. Qualitative data should be presented as footnotes to the numeric data, or on a separate table, depending on their importance.
- **Conclusions:** A conclusion is the result of the experiment, in the form of an answer to the original question. It should be stated as a freestanding <u>claim</u>, a detailed statement which includes both the tested independent variable and resulting dependent variable. For example, in the laundry detergent example given above, the claim might be: "Tide detergent cleans mustard stains from cotton better than Cheer." The claim should be followed by a statement of the supporting <u>evidence</u>, including averages of multiple trials, and the range of measured results. Finally, the conclusion should contain the <u>reasoning</u> linking the evidence to the claim, including any supporting scientific principles, and analysis of potential sources of error. In some cases, the conclusion may be that no conclusion can be reached, because the data averages are too close, data range is too high, or sources of error too great. In these cases, the scientist will usually try to redesign the experiment to get a more reliable result. Even when the conclusion seems well supported, the scientist will repeat the experiment several more times to verify the conclusion.
- **Publication**: When a scientist reaches a conclusion in a well-designed series of experiments, he or she will try to publish an article summarizing and communicating it in a "peer-reviewed" scientific journal. Before the journal decides to publish an article, the article will be reviewed by other scientists who are experts in that field of study. If they find no reason to question the conclusion, and believe that the experimental design is reliable, they will recommend publication. Other scientists will then read the article, and perhaps test the conclusion in their own experiments. If many other scientists test the conclusion and agree with it, over time it will be accepted into the body of scientific knowledge.

<u>Scientific Models</u>

- A **scientific model** is a physical, conceptual or computer-generated representation of reality, used to test a hypothesis or demonstrate a theory. Models are used when the reality they represent is too big, small, complex or even unknown to be actually seen and tested. Models can take the place of a controlled experiment.
- For example, a globe is a model of Earth, which allows us to see the very large sphere of Earth as a whole—something we cannot do sitting on Earth. Maps are two-dimensional models of the three-dimensional surface of Earth, reduced in size to allow viewing of a larger area. A diagram of a cell enlarges a reality too small to see.
- Computer simulations allow scientists to test the outcome of events they cannot actually perform: What would happen if a 10 km diameter asteroid hit the Earth?

What will the orientation of planets in our solar system be in a thousand years? What will the path of a hurricane be over the next three days?

- All models are less-than-perfect, because they cannot include all of the detail and structure of the reality they test and represent. A food web is a model that represents the predator-prey relationships in a community, but it cannot possibly show all the relationships, just some of the main ones. A model of the solar system can either show the relative distance between planets, or the relative size of each planet, but not both at the same time. Weather models cannot show all the small variations in temperature and wind that actually exist, and thus are not very accurate in the predictions they make.
- Over time, scientists improve the accuracy of computer models by comparing the predictions they make with the actual outcome, and correcting the mathematical algorithms used in the model. As computers become more powerful, and more detailed data can be included in a model, the accuracy of the computer model should further improve.

Scientific Laws and Theories

- Scientists do not easily accept newly proposed hypotheses or models. When a hypothesis or model has been tested many times by different scientists, and has become generally accepted by the scientific community, it may eventually become a scientific law, principle or theory. Even then, all scientific knowledge is subject to revision or rejection, as new scientific discoveries are made. Scientists can never be 100% certain that any law or theory is absolutely true.
- A **scientific law** is a statement that describes how some specific part of nature behaves generally or under defined conditions. For example, the law of universal gravity states that all objects with mass exert an attractive force on all other objects with mass. Scientific laws describe <u>what</u> will happen under certain circumstances, not why it will happen. Laws are often stated as mathematical equations. For example, Newton's Second Law of Motion can be stated as F=ma: Force = mass times acceleration. Scientific laws are useful to scientists and engineers, because they can be used to predict future behavior. As new scientific discoveries are made, scientific laws may need to be limited, modified or even discarded, as exceptions to the law are found. For example, Einstein discovered that Newton's Laws of Motion do not accurately describe the motion of objects when they travel at near the speed of light.
- A **scientific principle** is similar to a scientific law, but usually narrower in scope. Examples are Archimedes' Principle (describing buoyancy) and the Copernican Principle (the Earth is not the center of the Universe).
- A **scientific theory** is a general description of <u>how</u> and <u>why</u> some part of the natural world behaves as it does. Theories typically make predictions that can be tested over a wide range of conditions. In science, a theory is generally accepted as true by scientists working in that field. (In common English use, the word "theory" has a meaning closer to a scientific hypothesis, as in the expression "it is just a theory".) An example of a scientific theory is the Plate Tectonic Theory, which describes how and why crustal plates on Earth move as they do, why earthquakes and volcanic eruptions occur, and how the Earth's surface features

were created. This theory was created when substantial evidence supporting the earlier continental drift and seafloor spreading hypotheses were accepted.

Practice Questions

1. What is the difference between science and technology? ____________________
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2. With what step does the scientific inquiry process always begin?
____________________________.

3. What is an inference? ____
____.

4. What is a hypothesis? ____
____.

5. A proper hypothesis in a scientific inquiry is both ____________________ and
_________________________.

6. An independent or manipulated variable is ________________________________
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7. A dependent or responding variable is ____________________________________
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8. The controlled variables in an experiment are ______________________________.

9. A control group in an experiment is ______________________________________
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10. What are the three parts of a conclusion? _________________________________
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11. What is a scientific model? ____
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12. What are the limitations of scientific models? ______________________________
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13. What is a scientific law? ____
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14. What is a scientific theory? ____
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